

# Magma contemporaneous with mineralization at the Hishikari gold deposit, Japan

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A thesis submitted to the University of Ottawa  
In partial fulfillment of the requirements for the  
M.Sc. degree in Earth Sciences

Ottawa-Carleton Geoscience Center  
Faculty of Science  
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## Abstract

The Hishikari deposit is a high-grade low-sulphidation epithermal gold deposit in southwestern Kyushu, Japan. The mineralization age data by previous researchers suggest that the Hishikari Lower Andesite is contemporaneous with the mineralization. The relationship between mineralization and volcanism is unclear where this study aims to characterize the parental magmas of the Hishikari Lower Andesites. The Hishikari Lower Andesites collected ~11 km west of Hishikari mine consist of basalts ( $\text{MgO} \leq 5.7 \text{ wt\%}$ ) and basaltic andesite lavas ( $\text{MgO} \leq 3.4 \text{ wt\%}$ ) containing Mg-rich clinopyroxene ( $\text{Mg\#} \leq 82$ ) and normal zoned olivine (~Fo 82-66, Mn = 2090 – 4260 ppm, Ni = 150 – 690 ppm) with magnetite inclusions (0.66 wt% V). Samples collected from the Hishikari mine area are basaltic andesites, andesites and dacites. The andesites (1.8 – 3.7 wt% MgO) are characterized by containing clinopyroxene ( $\text{Mg\#} \leq 84$ ) and orthopyroxene ( $\text{Mg\#} \leq 70$ ). The basaltic andesites consist of Mg-rich basaltic andesite lavas ( $\text{MgO} \leq 7.3 \text{ wt\%}$ ) and pyroclastic rocks ( $\text{MgO} \leq 3.3 \text{ wt\%}$ ) containing Mg-rich clinopyroxene ( $\text{Mg\#} \leq 84$ ) and olivine phenocrysts (Fo77, Ni ~ 500 ppm, Mn  $\leq 3600$  ppm) with Cr-bearing (~1.6wt% Cr, 0.46wt% V) magnetite inclusions. The presence of Mg-rich basaltic andesites suggests partial melting in the mantle for volcanism during the mineralization. Primitive mantle-normalized trace element patterns are similar in all rocks and show a subduction geochemical signature with depletions in Nb and Ti. The rocks collected ~11km west of Hishikari mine show similar  $^{87}\text{Sr}/^{86}\text{Sr}$  values (0.704510 to 0.704754) and  $\epsilon\text{Nd}$  values (-1.4 to +0.4) to the basaltic andesites in the Hishikari mine area ( $^{87}\text{Sr}/^{86}\text{Sr} = 0.704373 - 0.704500$ ;  $\epsilon\text{Nd} = -0.04$  to +0.5) suggesting a similar mantle source. In the Hishikari mine area, the andesites show higher  $^{87}\text{Sr}/^{86}\text{Sr}$  values (0.704701 to 0.706168) and lower  $\epsilon\text{Nd}$  values (-5.3 to +0.3) than the basaltic andesites. The andesites fall along a mixing hyperbola between the basaltic andesites and the Shimanto sedimentary basement rocks suggesting that the parental magmas interacted with sediments from the Shimanto basement. In samples collected west of Hishikari,  $\text{Fe}^{2+}/\text{Mg}$  ratios of the olivine equilibrium melt show that olivine crystallized in a more evolved composition than the bulk rock, suggesting early crystallization of Cpx likely due to elevated water contents in the parental magmas. Cpx exhibits weak Eu anomalies in the mafic samples ( $\text{Eu}/\text{Eu}^* = 0.64$  to 1.1) and no correlation with Sr, suggesting that the parental magmas were mildly oxidized to contain high  $\text{Eu}^{3+}/\text{Eu}$ . A clear positive relationship between Ni and Fo components in olivine, the lack of sulphides observed in samples



and low bulk rock S content ( $<0.01\text{wt}\%$ ) suggests low S contents in the parental magmas. Our samples are similar in lithology, mineralogy and bulk rock compositions to two samples from the Yamagano Kinzan andesite as well as Pliocene-Pleistocene volcanic rocks in large volcanic fields of Hisatsu and Hokusatsu in Kyushu. These geochemical similarities are possible evidence for a similar mantle source beneath south-central Kyushu

## Acknowledgements

My deepest gratitude goes to my thesis supervisor, Professor Keiko Hattori. Her unwavering support, guidance, and constructive feedback have been invaluable. Keiko has not only helped me navigate the complexities of my study but also challenged me to think critically and approach problems with a more analytical mindset and holistic perspective. Her mentorship has been instrumental in my growth as a geoscientist. I am truly fortunate to have had the opportunity to learn from such a knowledgeable mentor.

I would like to thank Samuel Morfin for his help with the LA-ICP-MS for clinopyroxene, and olivine analysis. I am grateful to Alain Mauviel for processing samples and Glenn Poirer (Canadian Museum of Nature – University of Ottawa) for his help with SEM and EPMA analysis as well as Maryam Shahabi Far (Carleton University) for her help with the use of SEM. I am thankful for Victor Garcia (University of Ottawa) and Shuangquan Zhang (Carleton University) for their help with Sr-Nd isotope analysis.

I am grateful to Hishikari mine geologists, especially Dr. Yuki Beppu, for their help during field sampling and Irving Resources for providing samples from the Yamagano area. Thank you to associate professor K. Yonezu and his students at Kyushu University for their assistance with sampling. I am thankful for Professor Y. Watanabe at Akita University for providing location information and one important sample. I would also like to thank Dr. Keiko Hattori and Dr. Jeffrey Hedenquist for their hospitality and making my experience in Japan one of a kind.

Finally, I could not have finished the project without the constant moral support from my family and friends.

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## List of Abbreviations

Hishikari basaltic andesite = HK-BA  
 Hishikari andesite = HK-A  
 Hishikari felsics = HK-FEL  
 Basalt and basaltic andesite west of Hishikari = HKWest-BBA  
 Yamagano basaltic andesite = YAM-BBA  
 Olivine = Ol  
 Clinopyroxene = Cpx  
 Orthopyroxene = Opx  
 Pyroxene = Pyx  
 Magnetite = Mag  
 Ilm = Ilmenite  
 Plagioclase = Pl  
 Amp = Amphibole  
 Pyrite = Py  
 Ap = Apatite  
 Qz = Quartz  
 THI = Tholeiitic Index  
 NBO/T = non-bridging oxygen / tetrahedrally coordinated cations

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# Chapter 1: Introduction

## 1.1 Preamble

Epithermal deposits occur in shallow environments (<1km) in subaerial settings and host precious metals such as Au and Ag, as well as base metals (Cu, Pb and Zn). They can be broadly classified into high-, intermediate- and low-sulphidation types based on the sulphidation state of the sulphide assemblage (Hedenquist et al., 2000). These deposits often share a suite of geological characteristics including thick underlying sedimentary rocks subject to extensive uplift and extension followed by large volumes of magmatism. These geological settings are evident in high-grade epithermal deposits worldwide, such as the Hauraki Goldfield in New Zealand (Mauk et al., 2011) and Gunung Pongkor in Indonesia (Basuki et al., 1994). These deposits are often spatially and temporally associated with igneous rocks similar in age to the mineralization (Taylor, 2007), suggesting a genetic relationship. Volcanism may play an important role in the genesis of epithermal deposits, providing heat that helps drive hydrothermal activity (Hedenquist and Lowenstern, 1994). Low sulphidation fluids, despite being mostly meteoric water in origin, have evidenced a close genetic relationship to magmatism (Hedenquist and Sillitoe, 2003). The interaction between ascending magmas and its surrounding crustal rocks can lead to the incorporation of sulphur, carbon, and other volatiles that enhance the ability of hydrothermal fluids to transport metals like gold. This interaction lowers the system's oxidation state, stabilizing gold in solution, while structural traps like faults and fractures provide sites for metal precipitation as fluids cool or lose pressure (Richards, 2011). How volcanism contributes to the genesis of epithermal deposits is still unclear. Thus, studying magmas associated with epithermal mineralization contributes to a better understanding of the genesis of these deposits. The Hishikari deposit showcases these geological characteristics, situated in an extensional tectonic setting with a thick underlying metasedimentary basement. Here, extensive andesitic magmas were emplaced directly atop the basement, with mineralization occurring contemporaneously with the volcanism.

### **1.1.1 The Hishikari Deposit**

The Hishikari deposit is one of the highest-grade gold mines in the world (>265t Au produced and 155t of reserves as of the end of March 2023, Sumitomo Metal Mining) and is a low sulphidation epithermal gold deposit (Hedenquist and Sillitoe, 2003). The deposit is located in the south end of the Hisatsu volcanic district in southern Kyushu, Japan (orange, Fig.1 and is one of the many low sulphidation epithermal gold deposits occurring in the region. Mineralization at Hishikari (1.25 – 0.61Ma) is contemporaneous with young volcanic rocks in the area including the Hishikari Lower Andesites (1.62 – 0.98 Ma) which hosts the Yamada deposit, consisting of low-grade gold veins. The high-grade veins (Honko and Sanjin zones) are hosted primarily within the underlying Shimanto metasedimentary basement (Seto et al., 2020). Several stable isotope studies (Matsuhisa and Aoki, 1994; Imai et al., 1998; Hayashi et al., 2000; Faure et al., 2002; Imai and Uto, 2002) and Pb-Sr isotope studies (Hosono and Nakano, 2004) have linked mineralization to magmatism at Hishikari through the origin of auriferous fluids. However, the Hishikari Lower Andesites are not well studied where the origin and genesis of the volcanic rocks are still unclear. Moreover, the spatial extent and classification of the Hishikari Lower Andesites is also unclear where andesites directly overlying the Shimanto basement have been named the “Hishikari Lower Andesites”. These andesites are discontinuously exposed in the area and have been given different names by previous workers (New Energy and Industrial Technology Development Organization (NEDO) (1991) and Hosono et al. (2003)). Thus, we collected representative samples of the Hishikari Lower Andesites to clarify the relationship between these discontinuous andesites as well as characterize the parental magmas contemporaneous with mineralization to gain a better understanding of volcanism during mineralization at Hishikari.

### **1.1.2 The Yamagano Deposit**

Yamagano deposit is a low sulphidation epithermal gold deposit. It produced 28.4t Au between the 16<sup>th</sup> to 20<sup>th</sup> century (Murakami and Freebrey, 2001). The deposit is situated 11km southwest of the Hishikari gold mine and is part of the Hokusatsu volcanic terrane (Fig. 1). Mineralization (1.87 - 1.95 Ma) is hosted by the Yamagano Kinzan Andesite (1.88 - 2.30 Ma) (Fig. 2) (Watanabe, 2005; Murakami and Freebrey, 2001). The Yamagano Kinzan Andesite is underlain by the Shimanto metasedimentary basement, similar to the Hishikari Lower Andesites. The



relationship between the Yamagano Kinzan Andesites and the Hishikari Lower Andesites are unknown, and this thesis compares the two.

## **1.2 Previous Work Related to this Study**

The stratigraphy of rocks around the Hishikari mine was reported by Izawa et al. (1990) and (NEDO) (1991) who documented a Cretaceous metasedimentary basement (Shimanto basement) overlain by Quaternary volcanic rocks (Fig. 3).  $^{40}\text{Ar}/^{39}\text{Ar}$  ages of vein minerals as well as K-Ar ages and fission track dating of volcanic rocks have been determined by several authors (Izawa et al. (1990); NEDO (1991); Sekine et al. (2002); Sanematsu (2005); Tohma et al. (2010)). The geology, including alteration of the Hishikari deposit has been compiled by Seto et al. (2020).

The Hishikari mine has been the focus of numerous studies, mostly on mineralization and hydrothermal activity. Several authors including Watanabe (2005), Izawa and Watanabe (2001), and Izawa and Urashima (2001) described the geological setting and volcanism contemporaneous with epithermal deposits in Kyushu. Additionally, Nagao et al. (1999) provided a geochemical study of the Hisatsu volcanic rocks (7.6 to 0.4 Ma, Fig. 2), who identified three kinds of parental magmas: High-K Mg-rich andesite, Low-K Mg-rich andesite, and tholeiite magmas. Similarly, this study reports medium to high-K Mg-rich andesites and tholeiite magmas.

Hosono et al. (2003) studied the origin of volcanic rocks in the Hishikari area using Sr-Nd-Pb isotope compositions. The authors also divided the Hishikari volcanic rocks in two groups based on Sr-Pb-Nd isotope variations which show a mixing array between two reservoirs: a depleted MORB-like mantle and an enriched component in the lower crust. Hosono et al. (2008) later used Sr-Nd-Pb isotope compositions to study the genesis of volcanic rocks in the region, including the Hisatsu and Hokusatsu rocks. Hosono et al. (2003) and Hosono et al. (2008) suggested that the volcanic rocks in the Hisatsu and Hokusatsu regions including those in the Hishikari area are derived from a partial melt from an upwelling mantle. They concluded that the Shimanto sedimentary rocks played no role in the formation of the Hishikari rocks. This study has determined that the parental magmas of the Hishikari Lower Andesites assimilated the Shimanto sedimentary rocks.

### **1.3 Objectives**

- i. To characterize the Hishikari Lower Andesites by analyzing its geochemistry and petrology
- ii. To evaluate the composition, nature and sources of the parental magmas

### **1.4 Contributions of the Author**

This thesis constitutes the original research conducted by Catherine Suclan under the supervision of Professor Keiko Hattori at the University of Ottawa. The following outlines the contributions of the author:

- C. Suclan wrote all chapters and produced all figures and tables
- C. Suclan collected samples in June 2022 with Dr. Keiko Hattori and Dr. Jeffery Hedenquist.
- C. Suclan conducted petrographic studies on thin sections and hand samples
- C. Suclan pulverized and measured loss of ignition of samples at the University of Ottawa in preparation for major and trace element analysis
- C. Suclan separated olivine and clinopyroxene grains, followed by mounting the grains into epoxy puck and polishing the surface of the puck
- C. Suclan conducted scanning electron microscope (SEM) work and electron microprobe analysis (EPMA) on olivine, clinopyroxene, Fe-Ti oxides and plagioclase at the University of Ottawa and Carleton University with the assistance of Glenn Poirier and Maryam Shabibi-Far
- C. Suclan conducted Laser-Ablation Inductively Coupled Plasma Mass Spectrometry (ICP-MS) analysis on olivine and clinopyroxene grains mounted in the epoxy puck and data reduction at the University of Ottawa with the assistance of Samuel Morfin.
- C. Suclan conducted Sr-Nd separation of samples at the University of Ottawa with the assistance of Victor Garcia
- C. Suclan conducted Sr-Nd isotope analysis at Carleton University with the assistance of Shuangquan Zhang

Several aspects of the data in this thesis have been presented at conferences and reported as conference abstracts, which can be found in Appendix 2:

1. Suclan, C., Hattori, K., Watanabe, Y., 2022. Olivine andesite pyroclastic rocks contemporaneous with mineralization at the Hishikari deposit. Annual meeting of Resource Geology, Tokyo. June 28-July 1.
2. Suclan, C., Hattori, K., 2023. Characterization of the parental magmas associated with the Hishikari epithermal gold deposit, Japan. SEG-PDAC Minerals Colloquium, Toronto. March 2023.
3. Suclan, C., Hattori, K., 2024. Volcanism during the gold mineralization at the Hishikari and Yamagano deposits, Japan. SEG-PDAC Minerals Colloquium, Toronto. March 2024.
4. Suclan, C., Hattori, K., 2025. Volcanism during the mineralization at the Hishikari gold deposit, Japan. Geological Association of Canada – Mineral Association of Canada (GAC-MAC) Annual Meeting, Ottawa, May 2025.

## **1.5 Statement of Scientific Contributions**

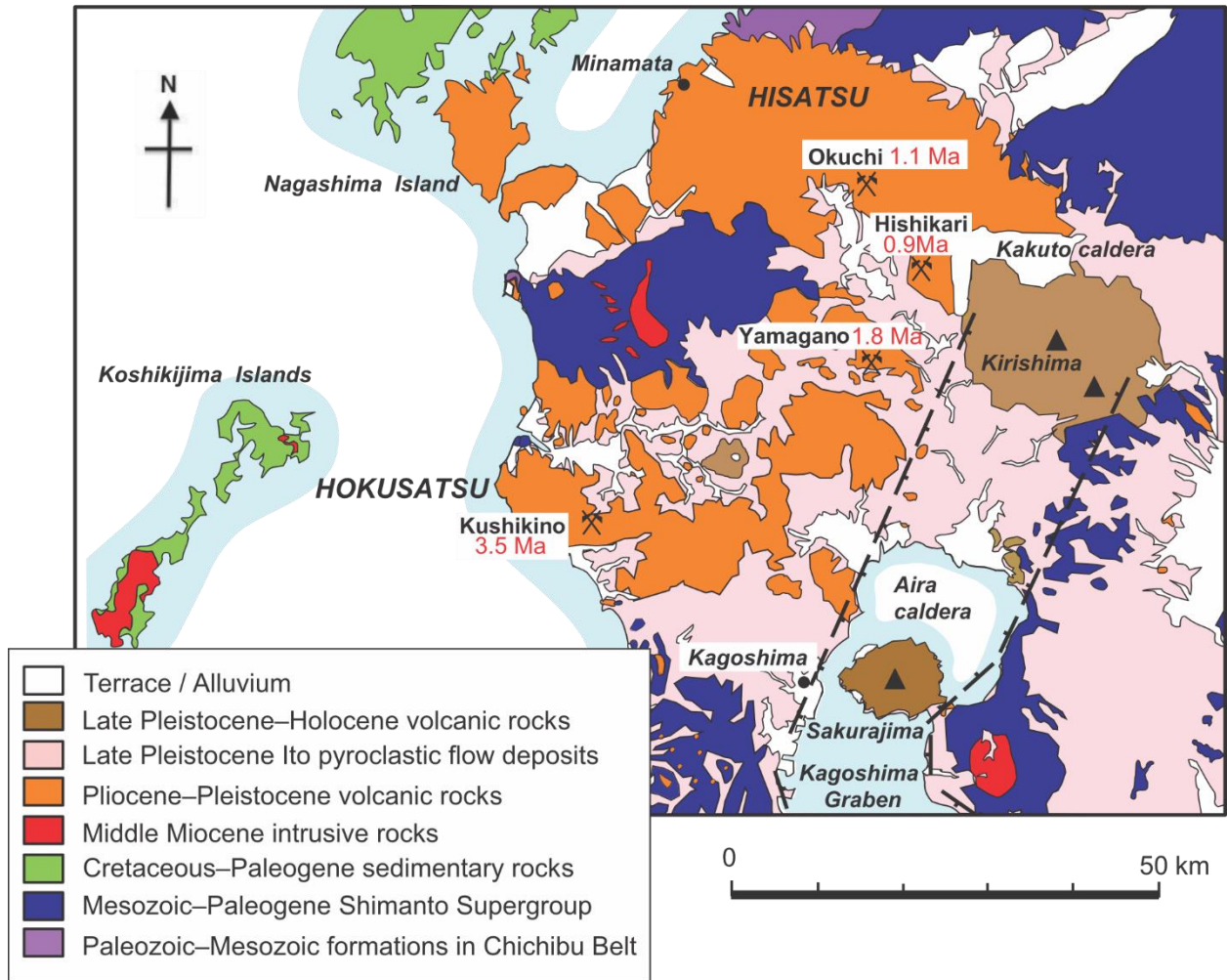
- i. I provide petrographic descriptions and compositions of bulk rock, olivine, pyroxenes, and Fe-Ti oxides. This study presents the first documentation of trace element compositions of clinopyroxene and olivine. I evaluate the nature of the magmas including the water and sulphur abundance. Bulk rock Sr-Nd isotope compositions are also used to investigate magma origins.
- ii. The mineralogy and bulk rock compositions of andesite at various locations overlying the basement are compared to evaluate the relationship among these discontinuously distributed andesites. This contributes to the understanding of the nature and continuity of the Hishikari Lower Andesites in different locations.
- iii. I compare the Hishikari Lower Andesites to Yamagano Kinzan andesite and other Pliocene-Pleistocene volcanic rocks in two large volcanic districts, providing insights to the origin and geographic breadth of the Hishikari Lower Andesites.

## Chapter 2: Regional Geology

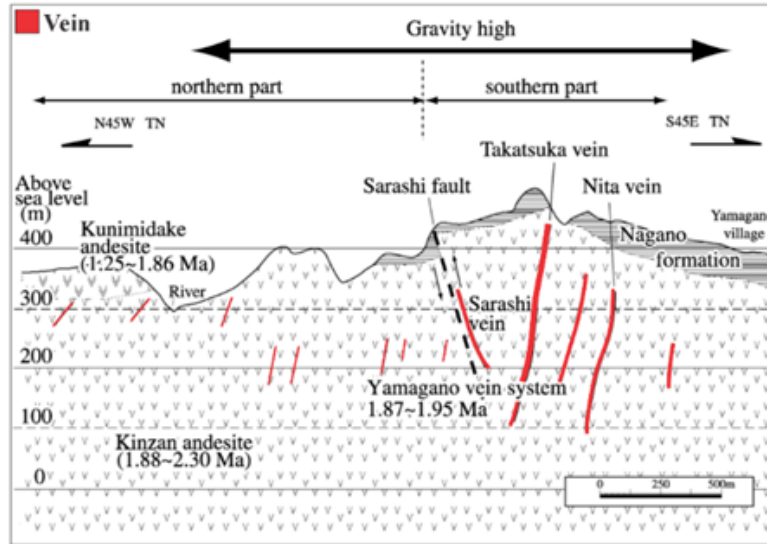
### 2.1 Regional Geology

Southern Kyushu is covered by young volcanic rocks (<5 Ma) that are predominately calc-alkaline in composition (Watanabe, 2005). There are two large young volcanic terranes in the area: Hisatsu terrane in the north and Hokusatsu terrane in the south (orange, Fig. 1). The Hishikari deposit is located in the south end of the Hisatsu terrane. The Hisatsu and Hokusatsu volcanic terranes contain widespread voluminous andesite (Mahony, 2011) of Pliocene-Pleistocene age that are covered by 70 ka year old ash deposits (pink, Fig. 1). The basement rock in the area includes metasedimentary rocks of the Shimanto Supergroup (dark blue, Fig. 1) and the Chichibu belt (purple, Fig. 1).

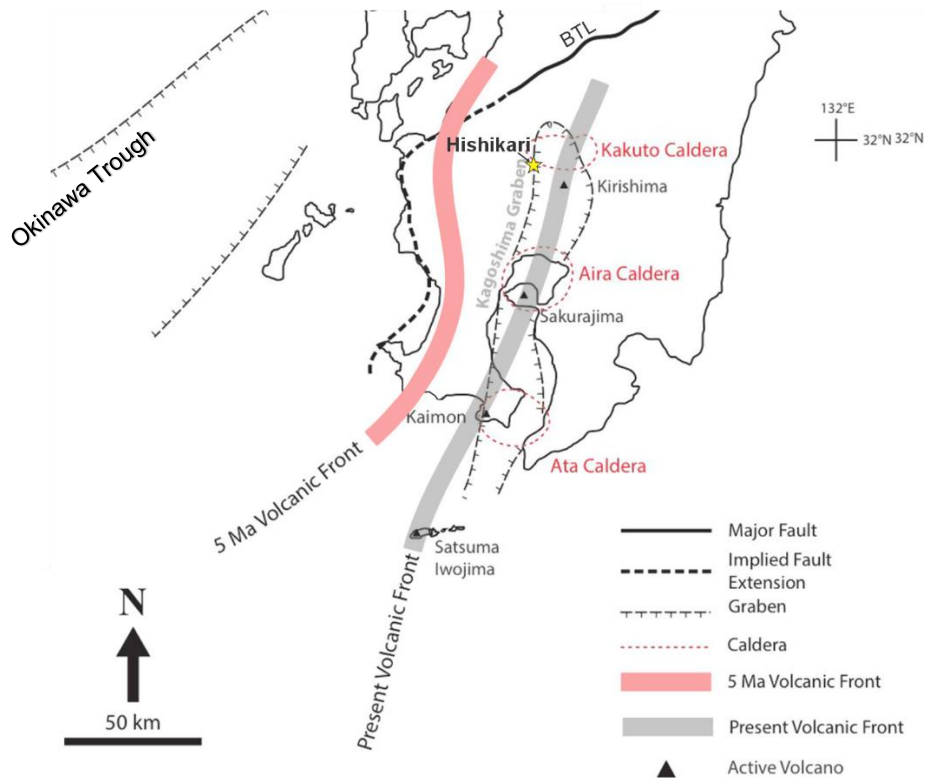
The Hisatsu and Hokusatsu volcanic districts contain several other low sulphidation epithermal Au deposits. Major deposits include the Kushikino, Yamagano, and Okuchi deposits ranging in ages of mineralization from ~3.6 Ma to 0.9 Ma which decrease in age towards the current volcanic front to the east (Fig. 3) (Seto et al., 2020). The current volcanic front includes Quaternary volcanoes in a north-northeast trend; along the Kagoshima Graben (Fig. 1 and 3) The volcanic front formed in response to the subduction of the Philippine Sea Plate and has progressively shifted eastward over time. It consists of volcanoes that have formed calderas (Kakuto, Aira and Ata) after eruptions of huge volumes of rhyolitic pyroclastic flows. Active volcanoes within the graben include the Kirishima volcanoes, Sakurajima volcano and the Kaimondake volcanoes (Fig. 3). The Hishikari mine is located west of the Kagoshima graben, 15-20 km from the Kirishima volcanoes (Fig. 3).



**Figure 1.** Regional geology of the Hishikari deposit demonstrating the Hokusatsu and Hisatsu volcanic districts (orange) and the current volcanic front from Seto et al. (2020). The Kagoshima Graben is outlined by dashed lines.



**Figure 2.** NW-SE geological cross section through the main Yamagano vein system after Murakami and Feebrey (2001). Veins are shown in red.

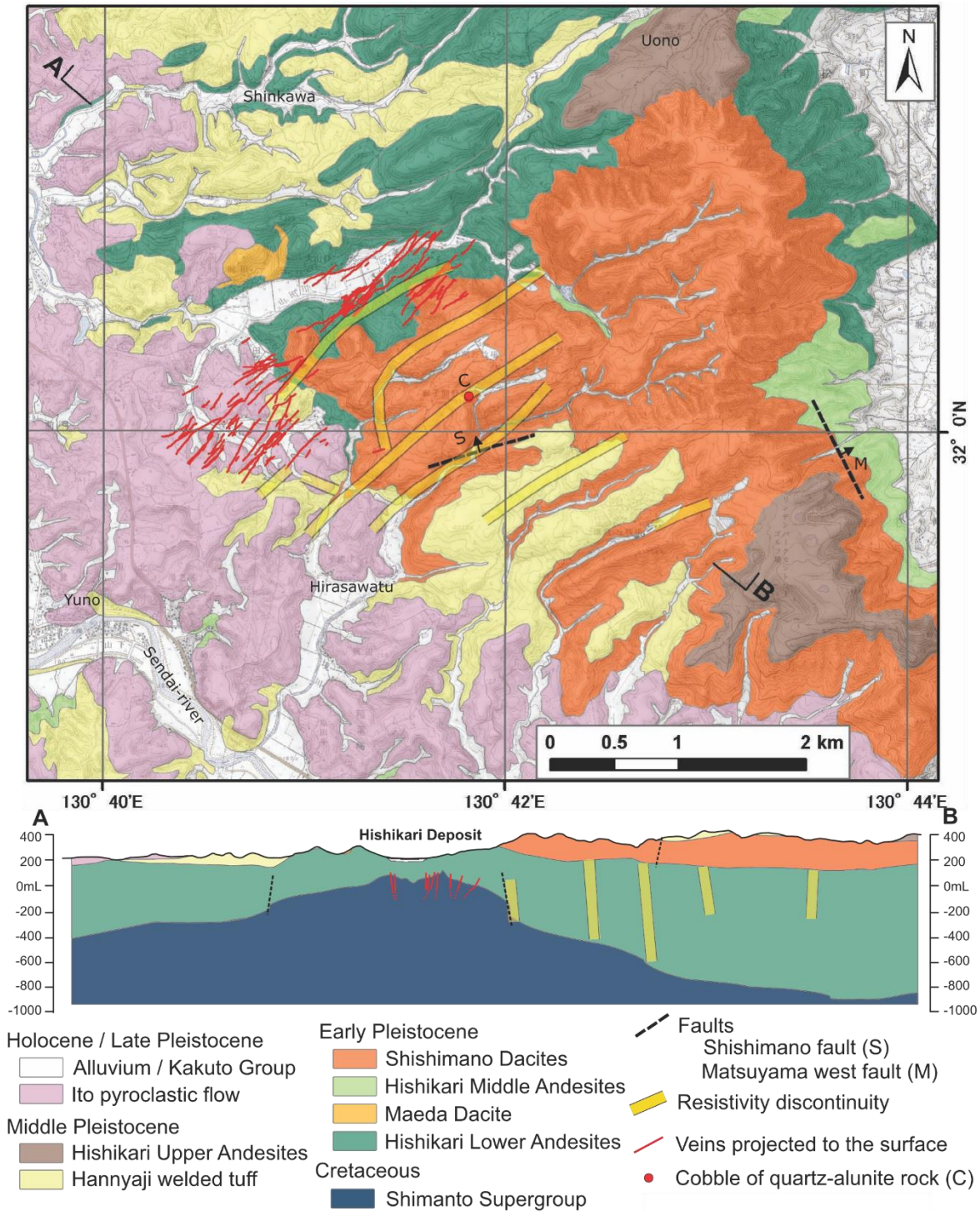


**Figure 3.** Location of the Hishikari deposit and tectonic makeup of Southern Kyushu from Tindell et al. (2018). The volcanic front in Southern Kyushu formed in response to the subduction of the Philippine Sea plate and has been moving eastwardly over time. The present volcanic front (grey line) contains active volcanoes and calderas along the Kagoshima graben. The Hishikari mine (yellow star) is located on the western margin of the Kagoshima graben, 15–20 km from the active Kirishima volcano. BTL = Butsuzo Tectonic Line

## 2.2 Geology of Hishikari Mine

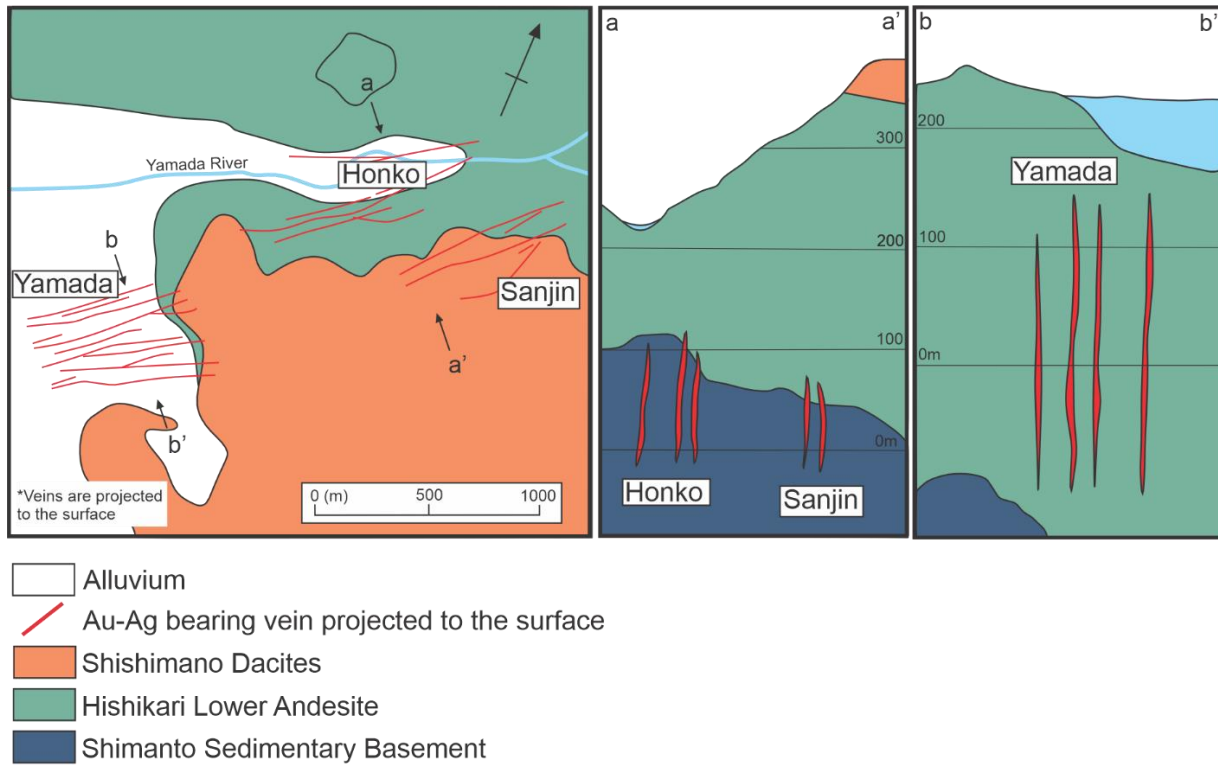
The geology of the Hishikari mine area and ages of igneous rocks are compiled by Seto et al (2020). The Cretaceous Shimanto metasedimentary basement is overlain by Quaternary volcanic rocks. This includes the Hishikari Lower Andesites (1.62 - 0.84 Ma), Maeda Dacites (1.16 Ma), Hishikari Middle Andesites (~0.78 Ma), Shishimano Dacites (1.1 - 0.66 Ma), Hannyaji Welded Tuff (0.73 - 0.58 Ma), Hannyaji Rhyodacites (0.7 - 0.6 Ma), Hishikari Upper Andesites (0.58 - 0.51 Ma), lacustrine sediments (0.56 - 0.57 Ma and 0.33 - 0.34 Ma) to the east and the Ito pyroclastic flow (29 ka) to the west (Fig. 4). The deposit has two separate mineralized zones: High Au grade Honko-Sanjin Zones (1.11 - 0.75 Ma) in Shimanto metasedimentary basement and Yamada Zone (1.25 - 0.61 Ma) in Hishikari Lower Andesites (Fig. 5). Most of the high-grade veins are hosted by the Shimanto basement where the Hishikari Lower Andesites host the upper parts of the veins (Morishita and Nakano, 2008). The Shimanto basement is an accretionary complex mainly consisting of interbedded mudstone and sandstone (Wallis et al., 2020). The Shimanto basement occurs less than 400m below sea level in the Hishikari area and rises to 130m above sea level in the central part of the mine (Watanabe, 2005). In the Hishikari area, the basement mainly consists of alternating beds of sandstone and shale with minor amounts of chert and tuffaceous shale (Seto et al., 2020). The sedimentary rocks of the Shimanto basement underwent low grade regional metamorphism of the prehnite-pumpellyite facies (Teraoka et al, 1990). The Hishikari Lower Andesites directly overlie unconformably to the Shimanto basement and is up to 700 m thick around the mine (Seto et al., 2020). The Hishikari Lower Andesites (dark green, Fig. 3) are discontinuously exposed in the area and are overlain by the Shishimano dacites (orange, Fig. 3), which occur in the south.





**Figure 4.** Geologic Map of Hishikari Mine (Seto et al., 2020). Hishikari Lower Andesites (dark green) overlie the Shimanto basement (dark blue). Hishikari Lower Andesites are up to 700m thick and are discontinuously exposed in the Hishikari mine area. Veins are projected to the surface on the map.





**Figure 5.** Locations and cross sections of the Honko, Sanjin and Yamada deposits from Hosono and Nakano (2004). Honko and Sanjin are high-grade veins. Veins are projected to the surface (left). The cross sections a-a' and b-b' (right) show the extent of the veins in the Shimanto basement and the Hishikari Lower Andesites. Numbers are elevation above sea level in meters.

## Chapter 3: Analytical Methods

### 3.1 Bulk-rock Analysis

Loss on ignition (LOI) was obtained by heating samples in a Jelenko ACCU-THERM model 150 burnout oven at  $>1000^{\circ}\text{C}$  for at least an hour. The abundances of major elements were measured using a Rigaku Supermini 200 wave-length dispersive X-ray fluorescence spectrometer (XRF) at the University of Ottawa calibrated with a range of natural rock and cement certified reference materials. The samples were prepared using the borate fusion method. A mixture of sample and lithium borate flux (1:8), followed by 1% Lithium bromine was processed into glass beads using a Claisse M4 gas fusion fluxer. The abundances of trace elements, including REE, were determined by Actlabs (Analytical code Ultratrace6) in Ancaster, Ontario, Canada. Each 0.25g sample was digested using four acids (HF,  $\text{HClO}_4$ ,  $\text{HNO}_3$  and HCl). The samples were analyzed using inductively coupled plasma mass spectrometer (ICP-MS). Accuracy was calculated by comparing measured values to certified values of OREAS101b, OREAS98, OREAS13b, OREAS904, OREAS45d, OREAS96, OREAS77b, OREAS72b, OREAS681, OREAS521, OREAS70b, OREAS620, OREAS753 by Actlabs. We inserted JB-1 basalt from the Geological Survey of Japan as a sample to check the accuracy of the analysis. Accuracy was evaluated by comparing the measured values of JB-1 to known JB-1 values from the literature. The value of Nb for JB-1 determined by Actlabs was 4.9ppm which is lower than the Nb value for JB-1 certified by the Geological Survey of Japan (33.3ppm (Imai et al., 1995)). In addition, the values of Nb determined by Actlabs for samples were significantly low ( $<2.2\text{ppm}$ , avg  $0.7\text{ppm}$ ). Therefore, it was determined that the Nb values reported by Actlabs were not correct and that the actual values of Nb were likely higher. Thus, Nb was determined by LA-ICP-MS from glass beads prepared for XRF. The Nb values determined by LA-ICP-MS are reported in Table 2.

| Nb value reported by Actlabs | Nb value certified by the Geological Survey of Japan |
|------------------------------|------------------------------------------------------|
| 4.9ppm                       | 33.3ppm (Imai et al., 1995)                          |

Table 1. Nb (ppm) of JB-1 determined by Actlabs vs Nb (ppm) values of JB-1 from the literature.

| Method          | Nb (ppm) determined by Actlabs | Nb (ppm) determined by LA-ICP-MS |
|-----------------|--------------------------------|----------------------------------|
|                 | TD-MS                          | LA-ICP-MS                        |
| Detection Limit | 0.1                            | 0.007                            |
| 220620-1        | 0.6                            | 4.59                             |
| 220620-2        | 0.2                            | 3.08                             |
| 220620-3        | 0.2                            | bdl                              |
| 220620-4        | 2.2                            | 5.85                             |
| 220623-5        | 0.3                            | 6.10                             |
| 220621-1        | 0.5                            | 4.59                             |
| 220621-2A       | 1                              | 4.04                             |
| 220621-2F       | < 0.1                          | 2.56                             |
| 220621-5        | 0.6                            | 5.01                             |
| 220621-6        | 1.3                            | 4.08                             |
| 220621-7        | 0.4                            | 3.00                             |
| 220621-8        | 0.5                            | 6.06                             |
| 220621-9A       | 0.6                            | 5.10                             |
| 220621-9B       | 0.4                            | 6.71                             |
| 220622-4        | 0.1                            | bdl                              |
| 220622-5        | 1.7                            | 4.73                             |
| 220623-1        | < 0.1                          | 3.67                             |
| 220623-2        | 0.1                            | 5.58                             |
| 220623-4        | 0.2                            | 3.89                             |
| 220623-3        | 0.3                            | 5.11                             |
| 220621-4        | 0.2                            | 5.46                             |
| 220622-2A       | 0.2                            | 4.08                             |
| 220622-2B       | 0.2                            | bdl                              |
| 220622-6        | 0.4                            | 6.10                             |
| 220622-7        | 0.4                            | 4.05                             |
| YAM001          | 0.3                            | 6.82                             |
| YAM002          | 0.4                            | 6.09                             |

Table 2. Nb (ppm) concentrations determined by Actlabs vs Nb (ppm) concentrations determined by LA-ICP-MS. See text for explanation. bdl = below detection limit.

### **3.2 Mineral Analysis**

Polished thin sections (30µm thick) were examined with a petrographic microscope. Mineral texture and mineralogy were studied with a JEOL 6610 LV scanning electron microscope (SEM) equipped with an Oxford X-max SDD energy dispersive spectrometer (EDS) at the University of Ottawa, as well as a JEOL JSM-IT500 SEM equipped with an Oxford ULTIM MAX SDD-EDS. Quantitative analysis of major and minor element abundance of olivine, clinopyroxene, orthopyroxene and Fe-Ti oxides were conducted using a JEOL-JXA 8230 Super Probe electron microanalyzer (EPMA) at the University of Ottawa. The analytical conditions are at an accelerating voltage of 20KeV, beam current of 20nA and electron beam focused to 5 µm. Counting times were 20s on peak and 20s off peak to get background counts for all elements except for Ni. The counting times for Ni were 40s on peak and 40s off peak. The calibration standards were sanidine (Si, Al, K), diopside (Ca, Mg), albite (Na), hematite (Fe), tephroite (Mn), rutile (Ti), chromite (Cr), vanadium (V), and San Carlos olivine (Ni).

### **3.3 Olivine and Clinopyroxene Minor and Trace Element Analysis**

Trace elements in clinopyroxene and olivine are measured in both epoxy pucks and thick (50-60µm) thin sections. Cpx and Ol grains within the epoxy pucks were hand-picked under a binocular microscope and then mounted in an epoxy resin. The grains were examined using a transmitted light microscope to identify inclusions and fractures avoided during the analysis. The grains were analyzed by SEM-EDS to obtain major element abundances. Trace element analysis was done using a Photon Machine Analyte Excite 193nm excimer laser attached to an Agilent 7700x LA-ICP-MS at the University of Ottawa. Each analysis consisted of 15s of background measurement followed by ablation with the laser focused on a 52-µm size. The following isotopes were measured: 7Li, 23Na, 27Al, 29Si, 42Ca, 45Sc, 47Ti, 51V, 53Cr, 55Mn, 59Co, 60Ni, 66Ni, 88Sr, 89Y, 93Nb, 139La, 140Ce, 141Pr, 146Nd, 147Sm, 153Eu, 157Gd, 159Tb, 163Dy, 165Ho, 166Er, 169Tm, 172Yb, 175Lu, 208Pb, which all had a dwell time of 10ms. GSE-1G was used as the calibration reference material. Accuracy was measured by comparing the calculated concentrations with standards BCR-2G and GSD. Reference materials were ablated for every 6 – 11 unknown olivine grains and for every 13 unknown clinopyroxene grains. The counts of 27Al, 47Ti, and 51V were monitored during the analysis to check the presence of any inclusions, and the

data was filtered to remove outliers. Run parameters and analysis profile examples can be found in Appendix 2.1.

### 3.4 Sr-Nd Isotope Analysis

100 - 200mg of each selected sample was digested in a mixture of HF and HNO<sub>3</sub> in screw-top Teflon vial for 3 days at 120°C. Sr and LREE collection was done in glass columns (inside diameter of 7 mm) and were filled with 12cm of AG50w - XB 200 - 400 mesh resin. Cleaning was done with 6N HCl. Conditioning, washing and collection was done with 2.5N HCl. Nd collection was done using pre-packed Eichron LN columns containing 2ml of LN spec-resin (100 - 150 mesh) in 0.05M HNO<sub>3</sub>. Conditioning, washing and collection were done with 0.25N HCl. Prior to Nd collection, 0.5ml of 0.25N HCl was added to each LREE fraction and left for 30 minutes. Sr purification was done using polypropylene columns (inside diameter of 7mm) filled with 3mm of Eichron's 50 - 100 micrometer Sr-spec resin. Conditioning and washing were done with 6M HNO<sub>3</sub> and purified Sr was collected with 0.05M HNO<sub>3</sub> and MilliQ. Since more than 100mg of sample was digested, each containing >300ppm Sr, only 25% of the Sr fraction was used for mass spectrometer analysis. A detailed description can be found in appendix 2.2.

Sr and Nd isotopes were measured using a Thermo Finnigan Neptune multi-collector inductively coupled plasma mass-spectrometer (MC-ICP-MS) at Carleton University. Samples were diluted in 2% HNO<sub>3</sub> which was aspirated through a nebulizer at a flow rate of 50-100 microliters/minute. Argon gas was used as the carrier gas. Standards NIST SRM987 and JNdi-1 were used to check accuracy during the analysis. Rb was also monitored during the analysis. All measured Sr isotope data are normalized to  $^{87}\text{Sr}/^{86}\text{Sr} = 0.11940$ , to correct for mass fractionation in the mass spectrometer. NIST SRM 987 yielded  $^{87}\text{Sr}/^{86}\text{Sr}$  value of 0.710224, which is 0.000021 less than the accepted NIST SRM 987 value of 0.710245. Thus, the data was normalized to  $^{87}\text{Sr}/^{86}\text{Sr} = 0.710245$  by adding 0.000021 to the measured values. All measured ratios are normalized to a  $^{143}\text{Nd}/^{144}\text{Nd} = 0.71290$  to correct for the mass fractionation of the mass spectrometer. The average value measured for the Jndi-1 standard matched the agreed upon value of Garcon et al., (2018) and thus the  $^{143}\text{Nd}/^{144}\text{Nd}$  values are reported as measured. Raw data can be found in appendix 2.2.

## Chapter 4: Sampling

### 4.1 Samples

Andesite directly overlying the Shimanto sedimentary basement in the Hishikari mine area is named Hishikari Lower Andesite, and its distribution is shown by Seto et al. (2020). However, andesite in different locations were given different names due to their discontinuous distribution. For example, andesite in the village of Uono is called Uono Andesite. In order to determine if these andesites are all geologically one unit, representative andesitic samples that were exposed in different towns and villages in the area were collected (Fig. 6, Table. 3). 22 samples were collected around the Hishikari mine area (within 3 km of the mine), 5 samples were collected ~11 km west of Hishikari mine and two unaltered samples of Yamagano Kinzan andesite (referred to as Yamagano basaltic andesite in the thesis) were provided by Irving Resources Inc. Sample locations are listed in Table 3 and 4 and shown in Fig. 6. Mineralogy for each sample is shown in Table 5.

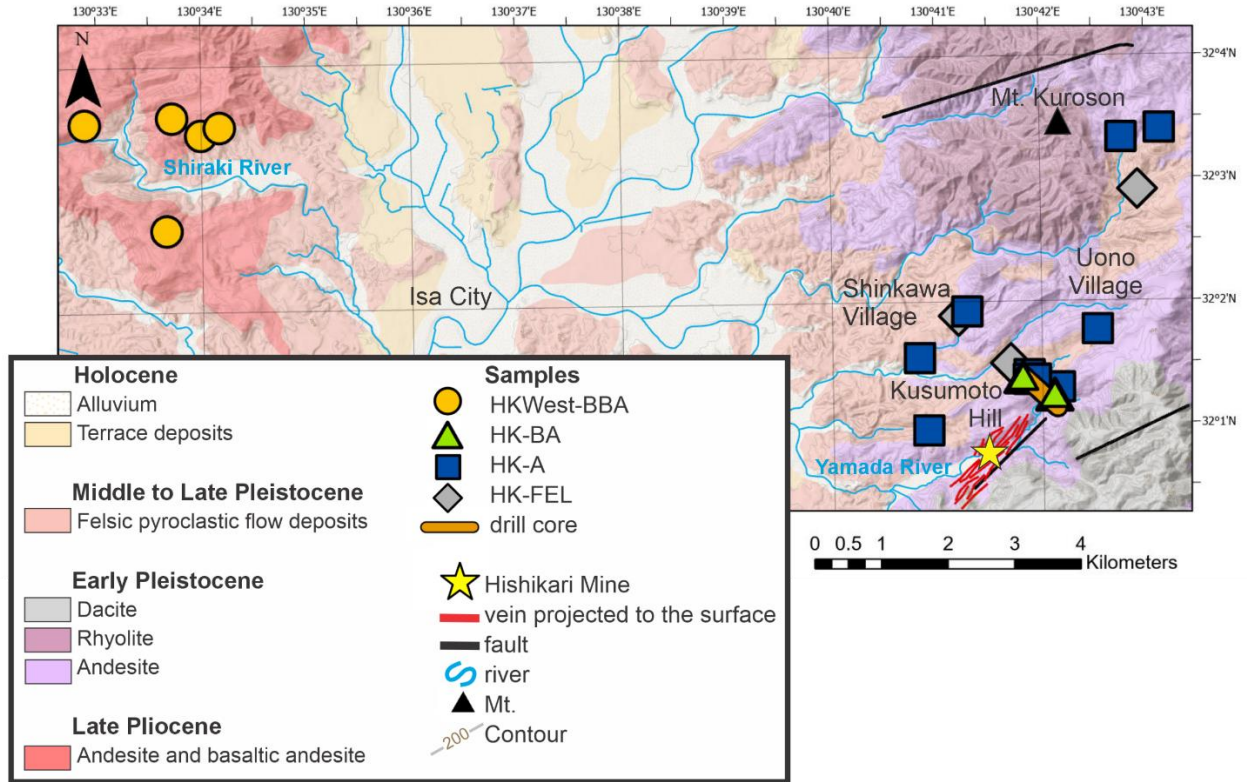
Samples collected around the Hishikari mine area consisted of basaltic andesites, andesites and felsic samples which are dacites. The locations of collected Hishikari andesite (HK-A) lava samples are shown as blue squares in Fig. 6. The sampling sites of Hishikari basaltic andesite (HK-BA) are shown as green triangles in Fig. 6. HK-BA samples consist of a lava and a pyroclastic. The pyroclastic fragments were collected in the same location and were indistinguishable in the field. Since these fragments had the similar composition and mineralogy, they were grouped as one sample (220621-5). Samples collected from a drill core (orange line, Fig.6) are andesite lava (DDH17MAHY-8B (106m length from the surface of the core with inclination of -25 degree, aka sample 220623-2, Appendix 3.3, Fig. A3.3-17)) and basaltic andesite lava (DDH17MAHY-8A (695m length of the core with the total length of 700 m and -25 to -40 inclination, aka sample 220623-1, Appendix 3.3, Fig. A3.3-17)). These samples will be referred to sample 220623-2 and 220623-1 respectively for the rest of the thesis. Sites for the Hishikari felsics (HK-FEL) which overlie andesite and basaltic andesite and are shown as grey diamonds in Fig. 6. All samples are relatively unaltered except for sample 220623-3 (andesite), which contains chlorite and possibly smectite. One sample (119-05) was provided by Dr. Y. Watanabe of Akita University which has a similar location as sample 220621-5. Our sample (220621-5) and his sample (119-05) are both Ol-bearing pyroclastic basaltic andesites. In addition, the sites of samples collected ~11 km west of Hishikari mine (HKWest-BBA) are shown as orange circles in Fig. 6 and consist of basalts and

basaltic andesite lavas. Samples of Yamagano basaltic andesite (YAM-BA) are not shown in Fig. 6 but were collected ~11km southwest of Hishikari mine. Hand sample descriptions and locations are in Appendix 3.1 and the petrographic descriptions are in Appendix 3.2. A field work report can be found in appendix 3.3.

**Table 3.** Sample locations

| Area                          | Location                                                                                    | Lithology (sample numbers)                                                                                                              |
|-------------------------------|---------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------|
| Within 3 km of Hishikari Mine | Kusumotogawa Natural Park, near Kusumoto Hill (n=6)                                         | Andesite (220621-6, 220621-7, 220621-8, 220621-9A, 220621-9B), Dacite (220621-4)                                                        |
|                               | Shinkawa Village (n=4)                                                                      | Andesite (220621-1, 220622-5), Dacite (220622-6, 220622-7)                                                                              |
|                               | Uono Village (n=2)                                                                          | Andesite (220621-2A, 220621-2F)                                                                                                         |
|                               | East of Mt. Kuroson (n=4)                                                                   | Andesite (220622-1, 220622-4), Dacite (220622-2A, 220622-2B)                                                                            |
|                               | Yamada Ore Zone (underground sample) ~100 ML, West 138 crosscut (n=1)                       | Andesite (220623-3)                                                                                                                     |
|                               | Drill core (700.7 m total length, inclination 25 degree) (n=2)<br>Drilled by JOGMEC in 2006 | Andesite (DDH17MAHY-8B, 106m depth of the core (aka 220623-2)), Basaltic Andesite (DDH17MAHY-8A, 695m depth of the core (aka 220623-1)) |
|                               | Hishikari Mine property (n=3)                                                               | Pyroclastic Basaltic Andesite (220621-5*, 119-05), Yamadagawa Andesite (220623-4),                                                      |
| ~11 km west of Hishikari mine | Along Shiraki River (n=5)                                                                   | Basalt (220620-1, 220620-3), Basaltic Andesite (220620-2, 220620-4, 220623-5)                                                           |
| Yamagano Deposit              | Yamagano Kinzan andesite (n=2)                                                              | Basaltic Andesite (YAM001, YAM002)                                                                                                      |

n = number of samples collected at location. \*This sample includes several fragments of pyroclastic rocks in the area that are indistinguishable to each other.



**Figure 6.** Sample locations and geological map of study area modified from the Geological Survey of Japan (Saito et al., 2010). Samples collected in the Hishikari mine area include Hishikari basaltic andesites (HK-BA, green triangles), Hishikari andesites (HK-A, blue squares) and Hishikari felsics (HK-FEL, grey diamonds). Samples collected west of Hishikari mine include basalt and basaltic andesite (HKWest-BBA, orange circles). Samples of Yamagano basaltic andesite (YAM-BA) are not shown on the map but are located ~11km southwest of Hishikari mine. Au – Ag bearing veins (red lines) and drill core (orange line) are projected to the surface. Contours are in increments of 20 m. Note that some samples have been collected at similar locations and appear to be overlapping on the map.



**Table 4.** Sample locations (System: WGS 84)

| Sample ID                   | Location                                                                                                                                       |                 |
|-----------------------------|------------------------------------------------------------------------------------------------------------------------------------------------|-----------------|
|                             | Latitude                                                                                                                                       | Longitude       |
| 220620-1                    | 32°3'32.2"                                                                                                                                     | 130°32'53.1"    |
| 220620-2                    | 32°3'35.1"                                                                                                                                     | 130°33'43.2"    |
| 220620-3                    | 32°3'26.5"                                                                                                                                     | 130°33'59.7"    |
| 220620-4                    | 32°3'30.2"                                                                                                                                     | 130°34'10.4"    |
| 220621-1                    | 32°1'32.8"                                                                                                                                     | 130°40'49.8"    |
| 220621-2A                   | 32°1'46.1"                                                                                                                                     | 130°42'31.9"    |
| 220621-2F                   | 32°1'46.1"                                                                                                                                     | 130°42'31.9"    |
| 220621-4                    | 32°1'29.8"                                                                                                                                     | 130°41'41.8"    |
| 220621-5                    | 32°1'15.3"                                                                                                                                     | 130°42'6.7"     |
| 220621-6                    | 32°1'18"                                                                                                                                       | 130°42'9.7"     |
| 220621-7                    | 32°1'24.2"                                                                                                                                     | 130°41'52.4"    |
| 220621-8                    | 32°1'21.9"                                                                                                                                     | 130°41'51.9"    |
| 220621-9A                   | 32°1'21.9"                                                                                                                                     | 130°41'56"      |
| 220621-9B                   | 32°1'21.9"                                                                                                                                     | 130°41'56"      |
| 220622-1                    | 32°3'24.2"                                                                                                                                     | 130°43'8.6"     |
| 220622-2A                   | 32°2'54.3"                                                                                                                                     | 130°42'55.6"    |
| 220622-2B                   | 32°2'54.3"                                                                                                                                     | 130°42'55.6"    |
| 220622-4                    | 32°3'19.9"                                                                                                                                     | 130°42'46.6"    |
| 220622-5                    | 32°1'55.3"                                                                                                                                     | 130°41'17.3"    |
| 220622-6                    | 32°1'53.1"                                                                                                                                     | 130°41'12.3"    |
| 220622-7                    | N/A Shinkawa village                                                                                                                           |                 |
| 220623-1 (aka DDH17MAHY-8A) | Drill core from the surface (700.7 m total length, inclination 25 to 40 degree, 695m length). Drill core log is in Appendix 3.3, Fig. A3.3-17. |                 |
| 220623-2 (aka DDH17MAHY-8B) | Drill core from the surface (700.7 m total length, inclination 25 d, 106m length) Drill core log is in Appendix 3.3, Fig. A3.3-17.             |                 |
| 220623-3                    | Yamada Ore Zone ~100ML below the surface, West 138 crosscut                                                                                    |                 |
| 220623-4                    | 32°0'57.4"                                                                                                                                     | 130°40'54.5"    |
| 220623-5                    | 32°2'40"                                                                                                                                       | 130°33'39.6"    |
| YAM001                      | 31°54' 37.9567"                                                                                                                                | 130°38' 29.641" |
| YAM002                      | 31°55' 24.7296"                                                                                                                                | 130°36' 58.349" |

## Chapter 5: Results

### 5.1 Bulk-rock Composition and Mineralogy

#### 5.1.1 Grouping of Samples

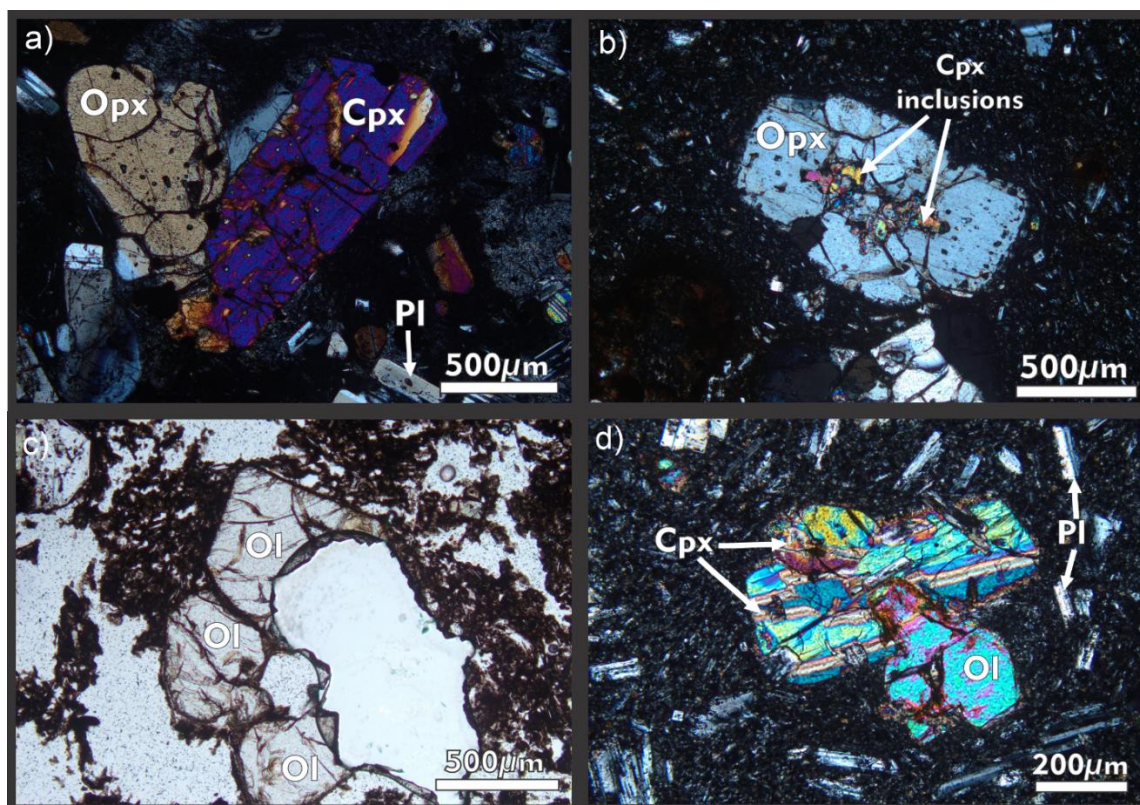
The representative Hishikari Lower Andesite samples collected are grouped into 3 based on mineralogy, bulk rock composition and location: (1) Hishikari andesite (HK-A) and (2) Hishikari basaltic andesite (HK-BA) collected in the Hishikari mine area, as well as (3) basalt and basaltic andesite collected west of Hishikari mine (HKWest-BBA). The younger dacitic samples collected in the Hishikari mine area are grouped as Hishikari felsics (HK-FEL) and are represented by grey diamond symbols. Yamagano basaltic andesite samples are referred to as YAM-BA and are represented by red crosses. Hishikari andesite (HK-A) will be represented by blue square symbols. Hishikari basaltic andesite (HK-BA) is represented by green triangles for the pyroclastic unit and hollow triangles for the lava. Basalt and basaltic andesite west of Hishikari mine are represented by orange circles. Samples of HK-A are characterized by phenocrysts of clinopyroxene (~15 - 20 vol.%), orthopyroxene (~10 - 15 vol.%), plagioclase (25 – 50 vol.%), magnetite (<10 vol.%), and trace ilmenite (Fig. 7a). Rare amphibole phenocrysts are present in 2 samples (220622-4 and 220622-5) which commonly has opacite rims. HK-BA consists of basaltic andesite lava (Fig. 7b). and pyroclastics (Fig. 7c). The basaltic andesite lava contains clinopyroxene (~20 vol.%), orthopyroxene (~10 vol.%), plagioclase (30 vol.%) and trace magnetite and apatite (<5 vol.%) in a glassy groundmass containing many microlites of plagioclase. Opx commonly contains Cpx inclusions (Fig. 7b), suggesting that Cpx formed before or during Opx crystallization. The pyroclastics are similar in mineralogy, also containing clinopyroxene (10 vol.%), orthopyroxene (10 vol.%), plagioclase (20 vol.%) and magnetite (5 - 10 vol.%) but contain olivine phenocrysts (5-10 vol.%, 0.5 - 2mm in diameter). YAM-BA consists of two basaltic andesite samples (YAM001 and YAM002) that contain phenocrysts of plagioclase (25 – 30 vol.%), clinopyroxene (15 vol.%), orthopyroxene (10 vol.%) and magnetite (~5-10 vol.%) where sample YAM002 contains trace ilmenite. Clinopyroxene, orthopyroxene, plagioclase and oxides commonly form aggregates in most samples. HKWest-BBA consist of basalts and basaltic andesites (Fig. 8). Both contain olivine (5 - 10 vol.%), clinopyroxene (5 – 15 vol.%), orthopyroxene (5 – 20 vol.%), minor Ti-magnetite (<5 vol.%) and variable amounts of plagioclase

where the basaltic andesites contain more plagioclase (~50 - 70 vol.%) than the basalts (~30 - 45 vol.%). The mineralogy for each sample is listed in Table 5.

**Table 5.** Mineralogy of each sample

| Group      | Sample              | Lithology                        | Mineralogy                                  | Remarks                                                                                                                                                                                                                   |
|------------|---------------------|----------------------------------|---------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| HKWest-BBA | 220620-1            | basalt                           | Pl, Cpx, Opx, Ol, trace Mag                 | Opx grains exhibit reverse zoning and homogenous textures. Opx grains also commonly contains Ol inclusions. Cpx grains exhibit oscillatory and reverse zoning. Ol grains exhibit normal zoning and contain Opx inclusions |
|            | 220620-2            | basaltic andesite                | Pl, Cpx, Opx, trace Mag                     |                                                                                                                                                                                                                           |
|            | 220620-3            | basalt                           | Pl, Cpx, Opx, Ol, trace Mag                 | Ol grains exhibit normal zoning and contain Mag inclusions. Opx grains exhibit patchy zoning and homogenous textures. Cpx grains exhibit oscillatory zoning and homogenous textures.                                      |
|            | 220620-4            | basaltic andesite                | Pl, Cpx, Opx, Ol, trace Mag                 | Ol grains exhibit normal zoning and contain Mag inclusions. Several Ol grains contain an Opx rim (<20 µm). Opx grains exhibit normal zoning. Cpx grains exhibit oscillatory zoning.                                       |
|            | 220623-5            | basaltic andesite                | Pl, Cpx, trace Opx, trace Ol, and trace Mag |                                                                                                                                                                                                                           |
| HK-BA      | 220621-5 and 119-05 | basaltic andesite<br>pyroclastic | Pl, Cpx, Opx, Ol, trace Mag                 | Ol is homogenous and contains Mag inclusions. Vesicular and Pl is heavily sieved. Cpx grains exhibit oscillatory, reverse and patchy zoning as well as homogenous textures. Opx grains are homogenous.                    |
|            | 220623-1            | basaltic andesite<br>lava        | Pl, Cpx, Opx, trace Mag and trace Ap        | Opx grains commonly contain Cpx inclusions that are patchy zoned. Opx grains also exhibit oscillatory and normal zoning. Cpx grains exhibit oscillatory zoning.                                                           |
| HK-A       | 220621-1            | andesite                         | Pl, Cpx, Opx, trace Mag                     |                                                                                                                                                                                                                           |
|            | 220621-2A           | andesite                         | Pl, Cpx, Opx, Mag                           |                                                                                                                                                                                                                           |
|            | 220621-2F           | andesite                         | Pl, Cpx, Opx, Mag                           |                                                                                                                                                                                                                           |
|            | 220621-6            | andesite                         | Pl, Cpx, Opx, Mag                           | Cpx grains exhibit oscillatory and reverse zoning. Opx grains exhibit reverse zoning and homogenous textures.                                                                                                             |
|            | 220621-7            | andesite                         | Pl, Cpx, Opx, Mag, trace Ilm                |                                                                                                                                                                                                                           |
|            | 220621-8            | andesite                         | Pl, Cpx, Opx, Mag, trace Ilm                |                                                                                                                                                                                                                           |
|            | 220621-9A           | andesite                         | Pl, Cpx, Opx, Mag,                          |                                                                                                                                                                                                                           |
|            | 220621-9B           | andesite                         | Pl, Cpx, Opx, trace Mag                     |                                                                                                                                                                                                                           |
|            | 220622-4            | andesite                         | Pl, Cpx, Opx, Amp, Mag                      | Several Amp contains opacite rim (50 µm)                                                                                                                                                                                  |

|        |           |                   |                                                |                                                     |
|--------|-----------|-------------------|------------------------------------------------|-----------------------------------------------------|
|        | 220622-5  | andesite          | Pl, Cpx, Opx, Amp, Mag, trace Ilm and trace Ap | Several Amp contains opacite rim (20 - 100 $\mu$ m) |
|        | 220623-2  | andesite          | Pl, Cpx, Opx, trace Mag and trace Ap           |                                                     |
|        | 220623-3  | andesite          | Pl, Cpx, Opx, Mag, trace Py                    | Altered to form possible smectite or chlorite       |
|        | 220623-4  | andesite          | Pl, Cpx, Opx, Mag                              |                                                     |
| HK-FEL | 220621-4  | dacite            | Qz, Pl, Cpx, Opx, Amp, trace Mag               |                                                     |
|        | 220622-2A | dacite            | Qz, Pl, Cpx, Opx, Amp, Mag                     |                                                     |
|        | 220622-2B | dacite            | Qz, Pl, Cpx, Opx, Amp, Mag                     |                                                     |
|        | 220622-6  | dacite            | Pl, Cpx, Opx, Amp, Qz, Mag                     |                                                     |
|        | 220622-7  | dacite            | Qz, Pl, Cpx, Opx, Amp, Mag                     |                                                     |
| YAM-BA | YAM001    | basaltic andesite | Pl, Cpx, Opx, Mag                              |                                                     |
|        | YAM002    | basaltic andesite | Pl, Cpx, Opx, Mag, trace Ilm                   |                                                     |



**Figure 7.** Photomicrographs of samples from a) HK-A. (sample 220621-1, andesite lava), b) HK-BA (sample 220623-1 basaltic andesite lava), c) HK-BA (sample 220621-5 basaltic andesite pyroclastic), d) HKWest-BBA (sample 220620-1, basalt lava)

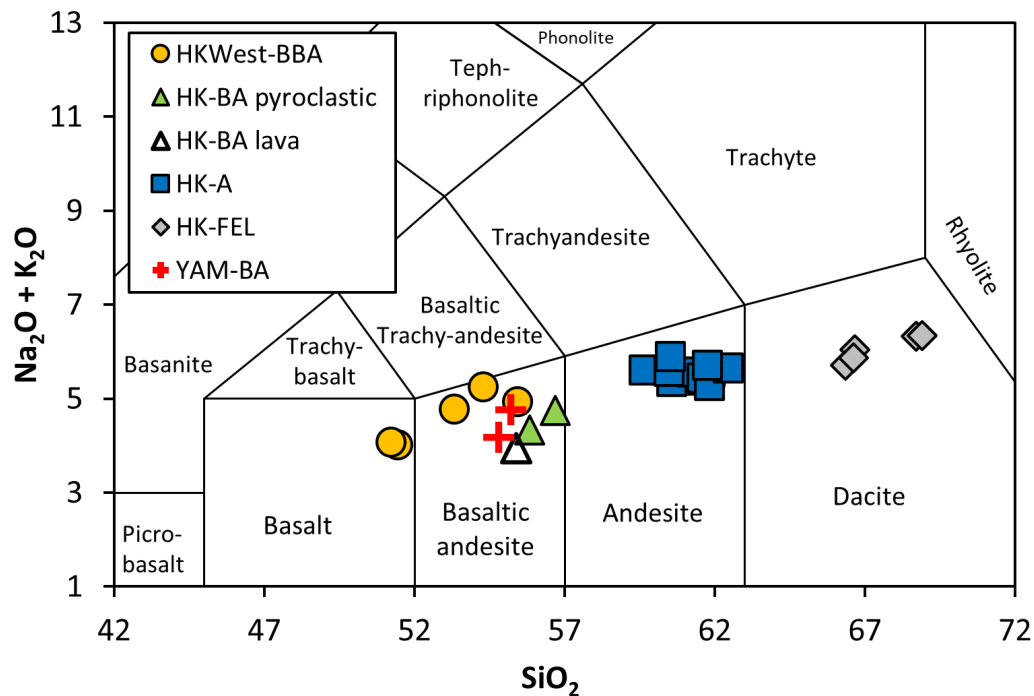
### 5.1.2 Bulk Rock Major Element Composition

Major element compositions are listed in Table 6. All samples fall along a similar liquid line of descent where FeO, MgO, CaO, Al<sub>2</sub>O<sub>3</sub>, MnO, TiO<sub>2</sub>, and P<sub>2</sub>O<sub>5</sub> decrease and K<sub>2</sub>O and NaO<sub>2</sub> increase with increasing SiO<sub>2</sub> (Fig. 9). Hishikari andesite (HK-A) contains MgO ranging from 1.8 – 3.7 wt%, (Mg# 40 - 55, where Mg# is  $[\text{Mg}]/([\text{Mg}] + [\text{Fe}^{2+}])$  and Fe<sup>2+</sup> is assumed to be 90% of total Fe). Hishikari basaltic andesite (HK-BA) contains ~3.3wt% MgO (Mg# ~50) in the pyroclastic unit and ~ 7.3wt% MgO (Mg# 66) in the lava. In the basalt and basaltic andesite west of Hishikari mine (HKWest-BBA), MgO ranges from 2.7 to 3.4 wt% for the basaltic andesites (Mg# 41 – 47) and from 5 to 5.7 wt% for basalts (Mg# 53 – 56). Yamagano basaltic andesite (YAM-BA) contains ~4.6wt% MgO (Mg# 54). All samples are quartz normative (0.80 – 17.14wt% quartz) where sample 220620-1 (basalt from HKWest-BBA) contains the lowest amount of normative quartz.

Samples collected in the Hishikari mine areas (HK-BA, HK-A and HK-FEL ) plot in the medium to high-K field (1.11 – 2.34 wt% K<sub>2</sub>O), HKWest-BBA plot in the medium-K field (0.94 – 1.29 wt% K<sub>2</sub>O) and YAM-BA plot in the medium-K field (0.77 – 1 wt% K<sub>2</sub>O) following the classification of Gill (1981) (Fig. 10).

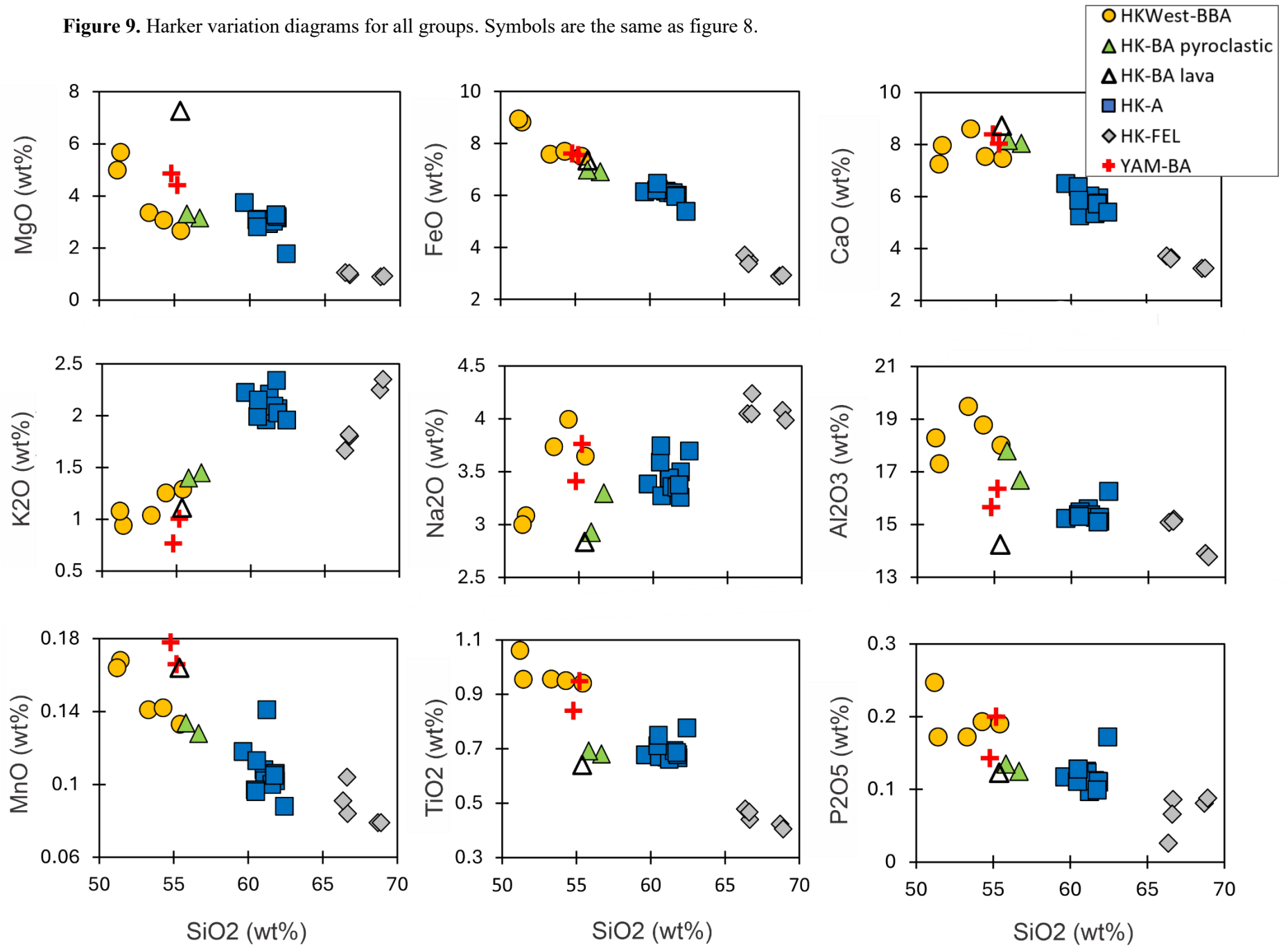
All samples plot near the boundary between calc-alkaline and tholeiitic fields where the samples collected in the Hishikari mine area (HK-BA, HK-A and HK-FEL) and the Yamagano samples (YAM-BA) generally plot in the calc-alkaline field and the samples collected west of Hishikari mine (HKWest-BBA) plot in the tholeiitic field on the SiO<sub>2</sub> vs FeO\*/MgO diagram following the classification of Miyashiro (1974) (Fig. 11). However, all samples plot within the calc-alkaline field on the AFM diagram (Fig. 12) following the classification of Irvine and Baragar (1971) and the cation diagram (Fig. 13) of Jensen (1976). The degrees of tholeiitic character were evaluated using the Tholeiitic Index (THI). The Tholeiitic Index (THI) is defined by  $\text{Fe}_{4.0}/\text{Fe}_{8.0}$ , where Fe<sub>4.0</sub> is the average FeO (total) concentration of samples at  $4 \pm 1$  wt% MgO and Fe<sub>8.0</sub> is the average FeO (total) concentration at  $8 \pm 1$  wt% MgO (Zimmer et al., 2010). The THI represents the enrichment or depletion of FeO (total) at parental compositions at 8 wt.% MgO to more fractionated compositions at 4 wt.% MgO. Since only one sample contains MgO greater than 7wt%, Fe<sub>8.0</sub> was estimated by extrapolating FeO (total) values using the linear equations derived from MgO-SiO<sub>2</sub> and FeO (total)-SiO<sub>2</sub> correlations. This is assuming FeO (total) varies linearly with SiO<sub>2</sub> within the chosen MgO ranges. The relationships and linear equations used for the

calculations are shown in Fig. A4.1-1 and A4.1-2 in Appendix 4.1. The THI value for the HKWest-BBA (0.81) is higher than rock in the Hishikari mine area (HK-BA, HK-A and HK-FEL) (0.66) where it appears to suggest a stronger tholeiitic character for HKWest-BBA.

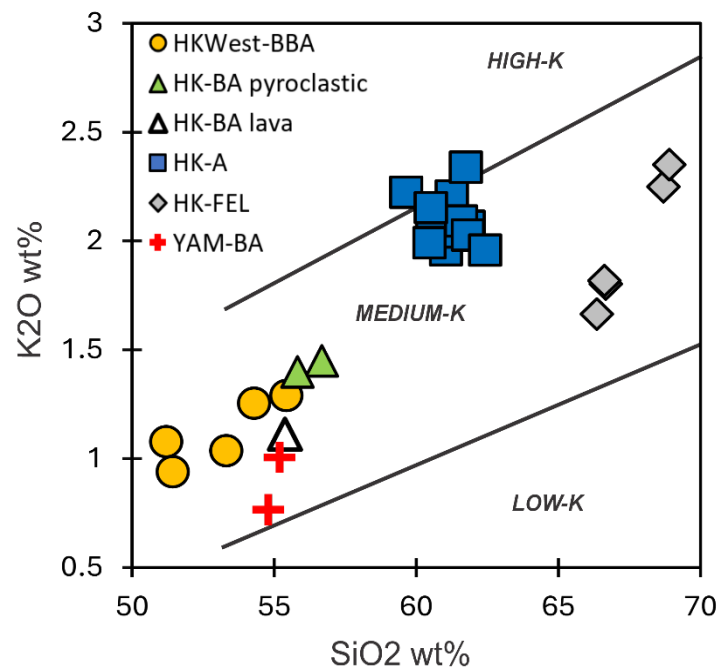


**Figure 8.** Total Alkali Silica (TAS) diagram after Le Bas et al. (1986). Hishikari basaltic andesites (HK-BA) are represented by green triangles for the pyroclastic unit and hollow black triangles for the lava. Hishikari andesites (HK-A) are represented by blue squares. Younger felsic samples collected in the Hishikari mine area (HK-FEL) are represented by grey diamonds. Basalt and basaltic andesite west of Hishikari mine (HKWest-BBA) are represented by orange circles. Yamagano basaltic andesite (YAM-BA) are represented by red crosses.

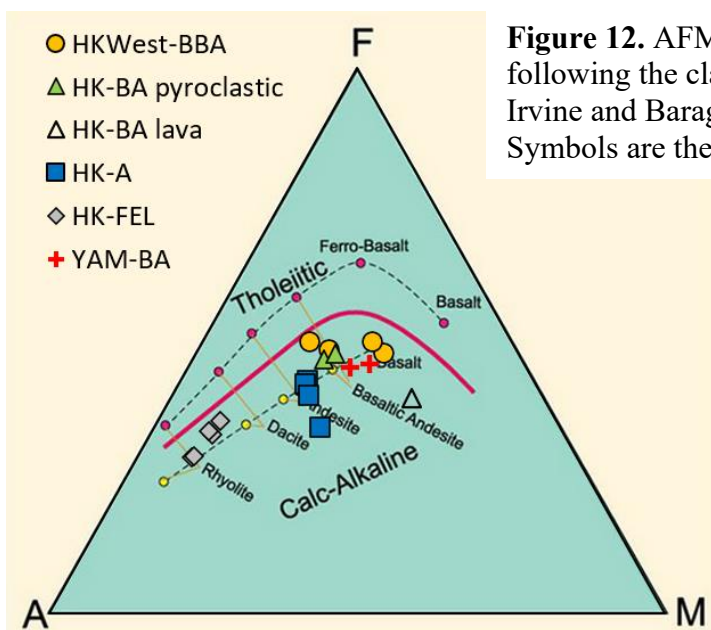
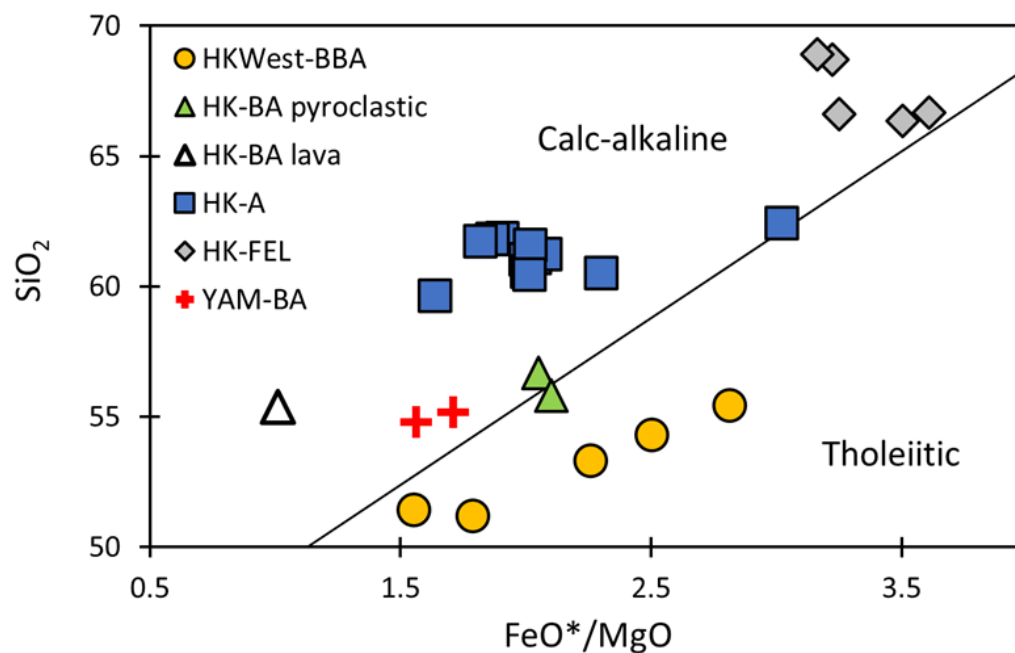
**Figure 9.** Harker variation diagrams for all groups. Symbols are the same as figure 8.



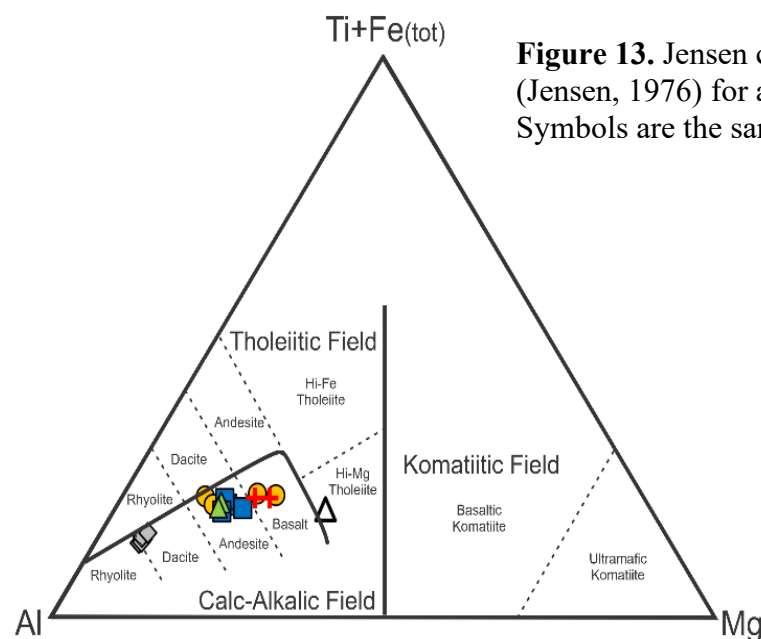
**Figure 10.** K<sub>2</sub>O vs SiO<sub>2</sub> diagram following the classification of Gill (1981). Symbols are the same as figure 8



**Figure 11.** Tholeiitic vs. Calc-Alkaline diagram following the classification of Miyashiro (1974). Symbols are the same as figure 8



**Figure 12.** AFM diagram following the classification of Irvine and Baragar (1971). Symbols are the same as figure 8



**Figure 13.** Jensen cation plot (Jensen, 1976) for all samples. Symbols are the same as figure 8



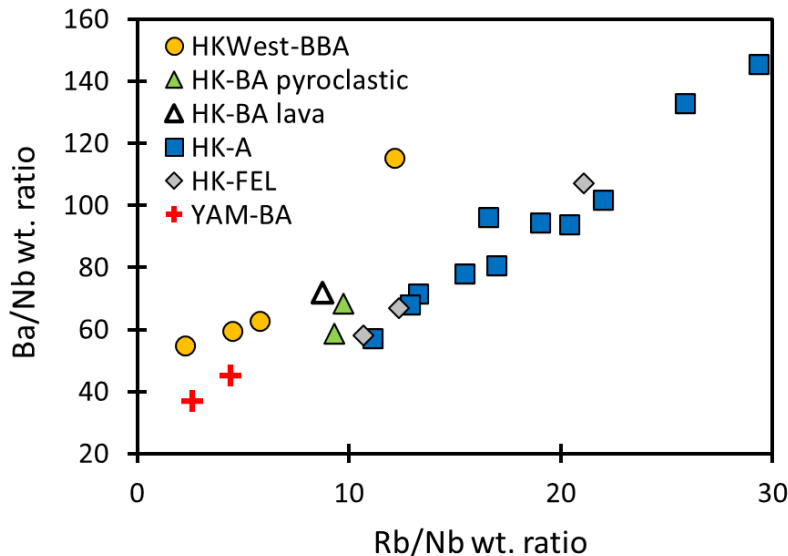
**Table 6.** Bulk rock major and trace element composition

| Group                     | HKWest-BBA | HKWest-BBA    | HKWest-BBA | HKWest-BBA    | HKWest-BBA    | HK-BA pyroclastic | HK-BA pyroclastic | HK-BA lava    | HK-A         | HK-A         | HK-A         | HK-A         | HK-A         | HK-A         | HK-A         | HK-A         | HK-A         | HK-A         | HK-A         | HK-A         | HK-A         | HK-FEL   | HK-FEL    | HK-FEL    | HK-FEL   | HK-FEL   | YAM-BA        | YAM-BA        |
|---------------------------|------------|---------------|------------|---------------|---------------|-------------------|-------------------|---------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|----------|-----------|-----------|----------|----------|---------------|---------------|
| Sample                    | 220620-1   | 220620-2      | 220620-3   | 220620-4      | 220623-5      | 220621-5          | 119-05            | 220623-1      | 220621-1     | 220621-2A    | 220621-2F    | 220621-6     | 220621-7     | 220621-8     | 220621-9A    | 220621-9B    | 220622-4     | 220622-5     | 220623-2     | 220623-3     | 220623-4     | 220621-4 | 220622-2A | 220622-2B | 220622-6 | 220622-7 | YAM001        | YAM002        |
| Lithology                 | basalt     | basaltic and. | basalt     | basaltic and. | basaltic and. | basaltic and.     | basaltic and.     | basaltic and. | two-Pyx and. | two-Pyx and. | two-Pyx and. | two-Pyx and. | two-Pyx and. | two-Pyx and. | two-Pyx and. | two-Pyx and. | two-Pyx and. | two-Pyx and. | two-Pyx and. | two-Pyx and. | two-Pyx and. | dacite   | dacite    | dacite    | dacite   | dacite   | basaltic and. | basaltic and. |
| Major elements            |            |               |            |               |               |                   |                   |               |              |              |              |              |              |              |              |              |              |              |              |              |              |          |           |           |          |          |               |               |
| SiO2 (wt%)                | 51.43      | 55.43         | 51.21      | 53.31         | 54.29         | 56.68             | 55.82             | 55.38         | 61.84        | 61.05        | 61.10        | 59.65        | 60.57        | 61.25        | 61.58        | 61.83        | 60.47        | 60.52        | 62.43        | 57.76        | 61.75        | 66.62    | 68.70     | 68.91     | 66.66    | 66.35    | 54.79         | 55.19         |
| TiO2                      | 0.96       | 0.94          | 1.06       | 0.96          | 0.95          | 0.68              | 0.69              | 0.64          | 0.67         | 0.68         | 0.67         | 0.68         | 0.67         | 0.66         | 0.69         | 0.68         | 0.71         | 0.75         | 0.78         | 0.62         | 0.69         | 0.47     | 0.42      | 0.41      | 0.44     | 0.48     | 0.84          | 0.95          |
| Al2O3                     | 17.31      | 18.01         | 18.29      | 19.49         | 18.78         | 16.69             | 17.81             | 14.25         | 15.13        | 15.41        | 15.60        | 15.23        | 15.48        | 15.37        | 15.28        | 15.27        | 15.38        | 15.31        | 16.26        | 15.07        | 15.10        | 15.13    | 13.90     | 13.78     | 15.21    | 15.08    | 15.66         | 16.36         |
| FeO tot                   | 8.82       | 7.50          | 8.94       | 7.58          | 7.69          | 6.91              | 6.98              | 7.34          | 6.00         | 6.16         | 6.16         | 6.14         | 6.23         | 6.11         | 6.10         | 6.00         | 6.21         | 6.46         | 5.39         | 6.04         | 5.96         | 3.37     | 2.90      | 2.93      | 3.51     | 3.71     | 7.61          | 16.36         |
| MnO                       | 0.17       | 0.13          | 0.16       | 0.14          | 0.14          | 0.13              | 0.13              | 0.16          | 0.10         | 0.11         | 0.10         | 0.12         | 0.11         | 0.14         | 0.10         | 0.11         | 0.10         | 0.10         | 0.09         | 0.22         | 0.11         | 0.10     | 0.08      | 0.08      | 0.08     | 0.09     | 0.18          | 16.36         |
| MgO                       | 5.68       | 2.66          | 4.99       | 3.36          | 3.07          | 3.16              | 3.32              | 7.27          | 3.15         | 3.08         | 3.03         | 3.75         | 3.10         | 2.94         | 3.02         | 3.21         | 3.08         | 2.81         | 1.78         | 3.29         | 3.27         | 1.04     | 0.90      | 0.93      | 0.97     | 1.06     | 4.87          | 16.36         |
| CaO                       | 7.96       | 7.47          | 7.25       | 8.60          | 7.54          | 8.05              | 8.16              | 8.73          | 5.95         | 5.98         | 5.68         | 6.50         | 5.25         | 6.02         | 5.34         | 5.75         | 6.38         | 5.86         | 5.40         | 3.48         | 5.72         | 3.60     | 3.24      | 3.24      | 3.65     | 3.72     | 8.40          | 16.36         |
| Na2O                      | 3.09       | 3.65          | 3.00       | 3.74          | 4.00          | 3.30              | 2.93              | 2.84          | 3.50         | 3.44         | 3.44         | 3.38         | 3.27         | 3.36         | 3.35         | 3.26         | 3.59         | 3.74         | 3.70         | 1.68         | 3.38         | 4.05     | 4.08      | 3.99      | 4.24     | 4.05     | 3.41          | 16.36         |
| K2O                       | 0.94       | 1.29          | 1.08       | 1.04          | 1.25          | 1.45              | 1.40              | 1.11          | 2.07         | 1.96         | 2.04         | 2.22         | 2.10         | 2.21         | 2.09         | 2.03         | 1.99         | 2.15         | 1.96         | 6.76         | 2.34         | 1.82     | 2.25      | 2.35      | 1.80     | 1.66     | 0.77          | 16.36         |
| P2O5                      | 0.17       | 0.19          | 0.25       | 0.17          | 0.19          | 0.13              | 0.14              | 0.12          | 0.11         | 0.13         | 0.12         | 0.12         | 0.12         | 0.10         | 0.11         | 0.11         | 0.11         | 0.13         | 0.17         | 0.12         | 0.10         | 0.07     | 0.08      | 0.09      | 0.09     | 0.03     | 0.14          | 16.36         |
| LOI*                      | 2.37       | 1.78          | 2.61       | 0.65          | 1.12          | 1.95              | 1.80              | 1.17          | 0.72         | 1.22         | 1.28         | 1.42         | 2.28         | 1.07         | 1.55         | 0.99         | 1.17         | 1.33         | 1.34         | 4.13         | 0.84         | 3.29     | 3.02      | 2.84      | 2.87     | 3.27     | 2.36          | 16.36         |
| Total                     | 98.88      | 99.05         | 98.84      | 99.03         | 99.03         | 99.11             | 99.17             | 99.03         | 99.23        | 99.22        | 99.21        | 99.20        | 99.19        | 99.22        | 99.22        | 99.22        | 99.19        | 99.15        | 99.29        | 99.15        | 99.24        | 99.55    | 99.57     | 99.54     | 99.52    | 99.50    | 99.03         | 203.41        |
| trace elements (ppm)      |            |               |            |               |               |                   |                   |               |              |              |              |              |              |              |              |              |              |              |              |              |              |          |           |           |          |          |               |               |
| Li                        | 10         | 14            | 11         | 13            | 15            | 12                | nd                | 9             | 19           | 19           | 17           | 19           | 18           | 17           | 21           | 19           | 15           | 16           | 22           | 57           | 18           | 21       | 19        | 19        | 19       | 20       | 10            | 7             |
| V                         | 227        | 109           | 98         | 209           | 141           | 170               | 228               | 95            | 90           | 110          | 60           | 150          | 67           | 93           | 162          | 65           | 59           | 141          | 66           | 135          | 67           | 41       | 20        | 30        | 20       | 21       | 192           | 167           |
| Cr                        | 65         | 8             | 34         | 15            | 10            | 25                | 33                | 149           | 33           | 44           | 23           | 35           | 27           | 18           | 34           | 30           | 26           | 30           | 9            | 29           | 31           | 7        | 7         | 5         | 6        | 6        | 97            | 41            |
| Ni                        | 26         | 6             | 25         | 12            | 12            | 13                | 20                | 62            | 10           | 9            | 9            | 16           | 10           | 9            | 9            | 10           | 11           | 9            | 3            | 12           | 14           | 2        | 3         | 2         | 1        | 2        | 28            | 13            |
| Cs                        | 1.39       | 1.84          | 1.37       | 1.17          | 0.83          | 3.17              | nd                | 1.36          | 4.29         | 4.47         | 4.74         | 4.77         | 2.76         | 3.31         | 3.75         | 2.95         | 2.84         | 3.39         | 4.04         | 19.1         | 2.72         | 4.5      | 7.81      | 5.64      | 4.69     | 8.35     | 1.78          | 4.16          |
| Co                        | 28         | 17            | 27         | 21            | 22            | 21                | 21                | 29            | 15           | 15           | 15           | 19           | 17           | 17           | 16           | 16           | 17           | 16           | 5            | 15           | 18           | 5        | 4         | 4         | 4        | 5        | 23            | 19            |
| Zn                        | 83         | 82            | 126        | 80            | 80            | 65                | 67                | 68            | 67           | 67           | 68           | 62           | 76           | 64           | 69           | 70           | 69           | 70           | 82           | 66           | 64           | 63       | 55        | 57        | 57       | 58       | 82            | 93            |
| Ga                        | 20.4       | 19.4          | 20.5       | 22            | 21.2          | 18.7              | 17.7              | 17.7          | 17.5         | 17.4         | 18           | 17.4         | 17.4         | 17.2         | 18.4         | 17.9         | 17.2         | 18.9         | 19.6         | 19.7         | 17.5         | 16.7     | 15.9      | 15.3      | 16.3     | 18.9     | 17.5          | 19            |
| Rb                        | 20.6       | 37.5          | 16.1       | 13.2          | 35.2          | 46.6              | 39                | 32.1          | 77.8         | 82.3         | 75.2         | 77.7         | 77.5         | 77.9         | 78.8         | 74.6         | 71.6         | 78.4         | 73.9         | 340          | 85.5         | 67.4     | 86        | 77.6      | 65.2     | 74.1     | 17.8          | 26.9          |
| Y                         | 22.1       | 32.7          | 23.6       | 17.8          | 22.3          | 17.1              | 18                | 14.2          | 25.4         | 25.8         | 27.9         | 21.3         | 23.4         | 31.2         | 28.4         | 26.3         | 25.5         | 27.9         | 24.6         | 23.5         | 20.5         | 19.4     | 18.7      | 26.8      | 21.9     | 14.6     | 20.7          | 22.3          |
| Sr                        | 547        | 511           | 629        | 609           | 602           | 496               | 451               | 544           | 353          | 358          | 395          | 323          | 336          | 318          | 333          | 356          | 335          | 331          | 411          | 284          | 314          | 264      | 243       | 233       | 281      | 278      | 411           | 447           |
| Zr                        | 84         | 81            | 74         | 84            | 82            | 80                | 110               | 40            | 105          | 115          | 76           | 119          | 79           | 81           | 128          | 91           | 69           | 111          | 124          | 116          | 95           | 72       | 58        | 64        | 45       | 46       | 78            | 86            |
| Nb                        | 4.59       | 3.08          | nd         | 5.85          | 6.10          | 5.01              | 4.00              | 3.67          | 4.59         | 4.08         | 2.56         | 4.08         | 3.00         | 6.06         | 5.10         | 6.71         | nd           | 4.73         | 5.58         | 5.11         | 3.89         | 5.46     | 4.08      | nd        | 6.10     | 4.05     | 6.82          | 6.09          |
| Ba                        | 273        | 356           | 394        | 321           | 383           | 294               | 274               | 264           | 370          | 379          | 373          | 385          | 399          | 412          | 398          | 383          | 340          | 455          | 399          | 426          | 396          | 365      | 437       | 402       | 355      | 361      | 252           | 276           |
| Cu                        | 45         | 18            | 45         | 63            | 28            | 71                | nd                | 81            | 21           | 21           | 33           | 65           | 21           | 21           | 13           | 19           | 30           | 27           | 2            | 26           | 50           | 3        | 3         | 2         | 3        | 2        | 26            | 20            |
| Pb                        | <3         | 6             | 14         | 5             | 4             | 3                 | nd                | 8             | 8            | 9            | 8            | 9            | 11           | 8            | 9            | 11           | 6            | 9            | 10           | 9            | 11           | 12       | 15        | 13        | 11       | 12       | 6             | <3            |
| Sc                        | 29         | 23            | 29         | 21            | 20            | 25                | nd                | 30            | 21           | 22           | 21           | 23           | 22           | 20           | 22           | 21           | 23           | 22           | 14           | 19           | 21           | 10       | 9         | 9         | 10       | 10       | 27            | 26            |
| Th                        | 3          | 4.3           | 6.9        | 2.1           | 3.4           | 5.1               | 4.31              | 3.5           | 7.7          | 7.7          | 7.6          | 8.5          | 8            | 7.9          | 7.7          | 8            | 7.6          | 7.9          | 6.7          | 9.5          | 8.8          | 6.9      | 7.3       | 7         | 6        | 5.8      | 2.5           | 3.2           |
| U                         | 0.6        | 0.9           | 1.2        | 0.6           | 0.8           | 1.2               | nd                | 0.9           | 1.7          | 1.7          | 1.8          | 1.9          | 1.7          | 1.7          | 1.7          | 1.7          | 1.7          | 1.7          | 1.5          | 2.2          | 1.9          | 1.6      | 1.6       | 1.5       | 1.4      | 1.2      | 0.6           | 0.7           |
| rare earth elements (ppm) |            |               |            |               |               |                   |                   |               |              |              |              |              |              |              |              |              |              |              |              |              |              |          |           |           |          |          |               |               |
| La                        | 16.5       | 28.4          | 22.4       | 11.5          | 16.6          | 13.8              | 18                | 12.1          | 23.1         | 24.5         | 25.5         | 18.2         | 19.8         | 21.3         | 22           | 22.3         | 18.4         | 24.1         | 22.8         | 21.5         | 18.1         | 27       | 19.6      | 38        | 31.7     | 14.5     | 11.3          | 14.3          |
| Ce                        | 31.9       | 42.1          | 45.8       | 26.4          | 33.4          | 28.6              | 35                | 25.6          | 38.7         | 41.4         | 36.3         | 36.2         | 36.2         | 38.3         | 38.1         | 38.5         | 35           | 47           | 43.9         | 42.9         | 38.6         | 55.4     | 39.1      | 52.2      | 33.7     | 26.2     | 23.6          | 30.2          |
| Pr                        | 4.7        | 8.7           | 6.4        | 3.5           | 4.7           | 3.6               | nd                | 3.4           | 6.2          | 6.5          | 6.3          | 4.8          | 5.2          | 5.4          | 5.6          | 5.6          | 5            | 6.4          | 5.5          | 5.4          | 4.8          | 6.8      | 4.7       | 8.7       | 7.2      | 3.2      | 3.2           | 4             |
| Nd                        | 20.2       | 35.9          | 26.1       | 14.8          | 19.9          | 14.5              | 19                | 14.1          | 24.7         | 25.7         | 25.6         | 20.1         | 21.5         | 20.7         | 22.6         | 21.4         | 18.9         | 25.3         | 21.9         | 20.5         | 18.9         | 25       | 17.1      | 30.5      | 25.8     | 12.1     | 13.2          | 16.8          |
| Sm                        | 4.4        | 9.2           | 6.7        | 4.3           | 4.5           | 3.6               | nd                | 3.7           | 5.5          | 6            | 6.1          | 4.6          | 5.1          | 5            | 5.6          | 5.2          | 4.3          | 5.8          | 5.2          | 4.5          | 4.6          | 4.7      | 3.6       | 6.6       | 5.3      | 2.9      | 3.4           | 4.1           |
| Eu                        | 1.39       | 2.34          | 1.58       | 1.11          | 1.39          | 0.97              | nd                | 0.95          | 1.26         | 1.33         | 1.39         | 0.99         | 1.15         | 1.09         | 1.29         | 1.09         | 1.09         | 1.18         | 1.26         | 1.04         | 0.97         | 1.13     | 0.84      | 1.27      | 1.19     | 0.83     | 1.02          | 1.14          |
| Gd                        | 4.8        | 8.1           | 5.5        | 4.1           | 4.7           | 3.4               | nd                | 3.3           | 5.4          | 5.5          | 5.8          | 4.2          | 4.9          | 5            | 5.5          | 4.6          | 4.5          | 5.3          | 4.8          | 4.4          | 4.2          | 4.5      | 3.5       | 5.7       | 4.6      | 2.6      | 3.6           | 4             |
| Tb                        | 0.7        | 1.3           | 0.8        | 0.6           | 0.7           | 0.6               | nd                | 0.5           | 0.9          | 0.9          | 0.9          | 0.7          | 0.8          | 0.8          | 0.8          | 0.7          | 0.7          | 0.9          | 0.8          | 0.7          | 0.7          | 0.7      | 0.6       | 0.9       | 0.7      | 0.4      | 0.6           | 0.7           |
| Dy                        | 4.4        | 7             | 4          |               |               |                   |                   |               |              |              |              |              |              |              |              |              |              |              |              |              |              |          |           |           |          |          |               |               |

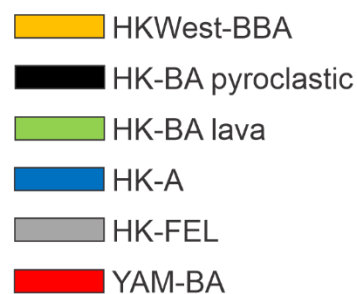
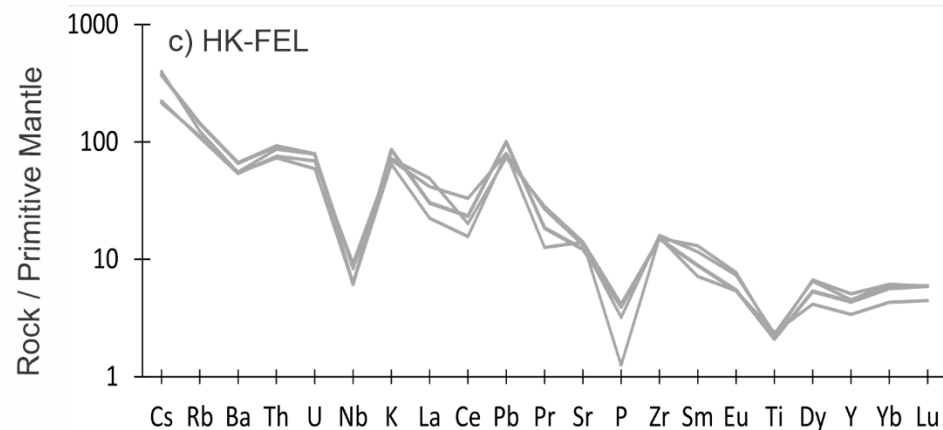
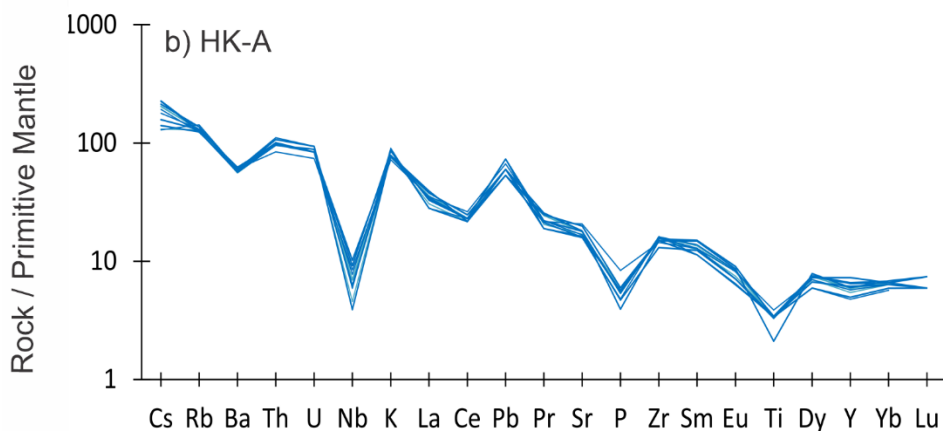
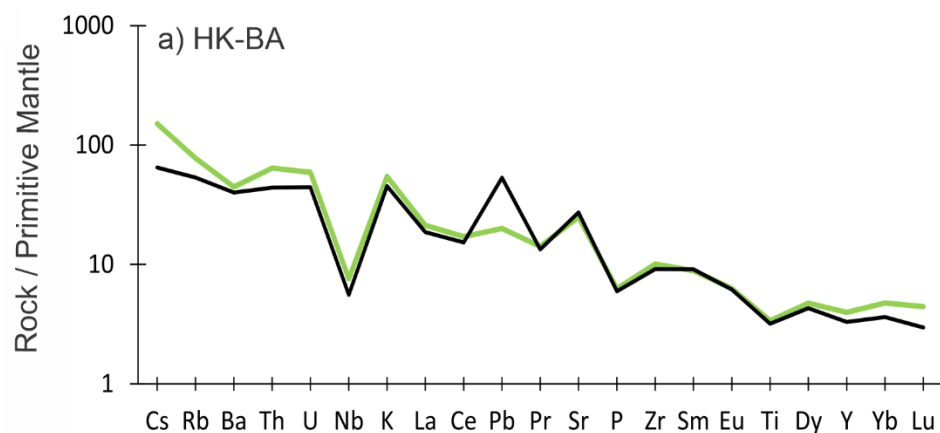
### 5.1.3 Trace Element Composition

Primitive mantle normalized trace element patterns are similar among all mafic rocks of the study area (Fig.11). They show a typical subduction geochemical signature with enrichment in large ion lithophile elements (LILE) (up to 100 times the primitive mantle values) and low contents of high field strength elements (HFSE) such as Nb, and Ti. The rocks also show a flat HREE pattern (up to 10 times the PM values). Additionally, the bulk rock S content is low (<0.01 wt% S) in all rocks.

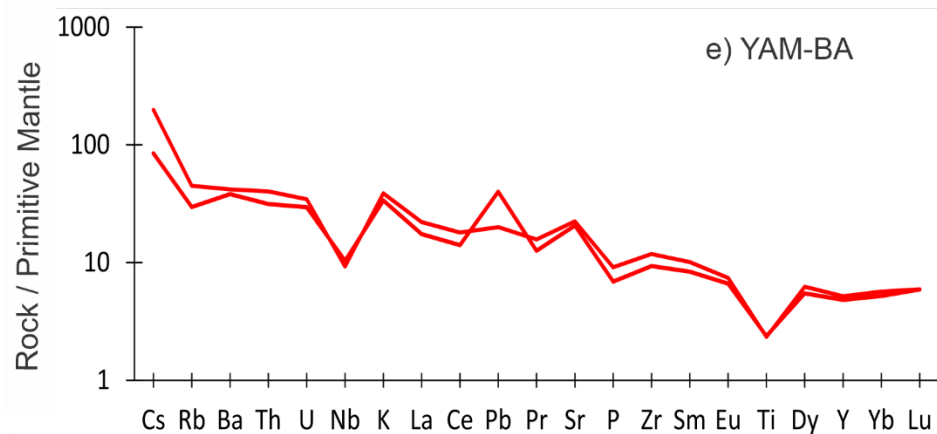
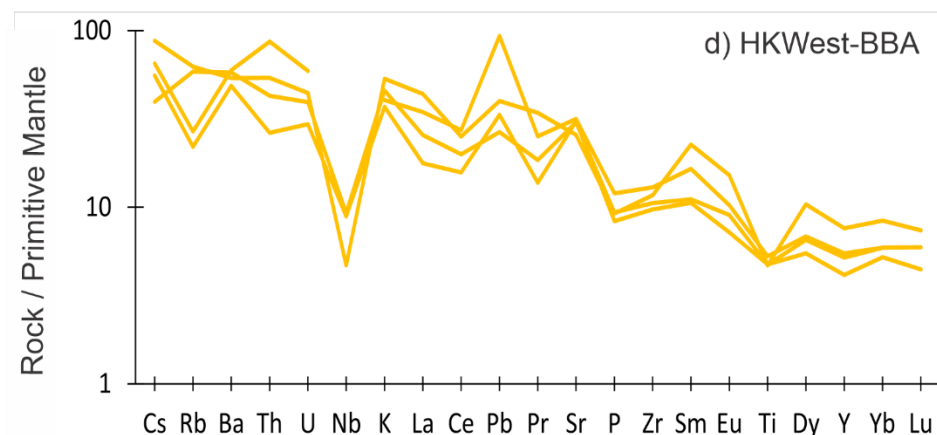
The samples collected in the Hishikari mine area (HK-BA, HK-A and HK-FEL) have generally higher weight ratios of LILE/HFSE (sum of K, Cs, Rb, Sr, Ba / sum of Ti, Zr, Nb, Hf) weight ratios (3 to 15) as well as higher individual LILE/HFSE, such as Ba/Nb and Rb/Nb weight ratios (Ba/Nb = 58 - 146 and Rb/Nb = 10 - 30, Fig. 14) than the samples collected west of the mine (HKWest-BBA: LILE/HSFE wt. ratios = 1.7 to 2.4, Ba/Nb = 55 - 115 and Rb/Nb = 2.3 – 12, Fig. 14) and in the Yamagano mine area (YAM-BA: LILE/HSFE wt. ratios = 8.5, Ba/Nb = 37 - 45 and Rb/Nb = 2.6 - 4.4, Fig. 14). In Addition, all rocks show high Ba/Nb and Rb/Nb wt. ratios compared to MORB (Ba/Nb wt. ratio = 2.7 and Rb/Nb wt. ratio = 0.24 (Sun and McDonough, 1989), suggesting that the mantle source was enriched in fluid-mobile elements before partial melting.



**Figure 14.** Ba/Nb vs Rb/Nb wt. ratios of all samples. Symbols are the same as figure 8.



**Figure 15.** Whole rock trace elements normalized to primitive mantle for a) Hishikari Basaltic andesites (HK-BA), b) Hishikari andesites (HK-A), c) Hishikari felsics (HK-FEL), d) Basalt and basaltic andesites west of Hishikari (HKWest-BBA) and e) Yamagano basaltic andesite (YAM-BA). Ta was below the detection limit of 0.1ppm determined by ActLabs. Nb was determined by LA-ICPMS from glass beads prepared for XRF. Primitive mantle values are from McDonough and Sun (1995).

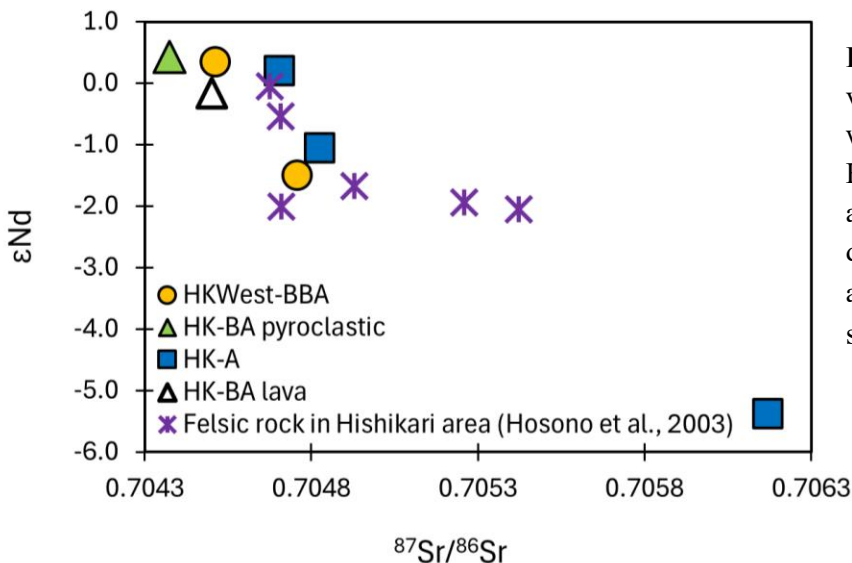


### 5.1.4 Whole Rock Sr-Nd Isotope Compositions

Whole rock Sr-Nd isotopic compositions are listed in Table 7 and shown in Fig. 16. The basalt and basaltic andesite west of Hishikari (HKWest-BBA) have  $^{87}\text{Sr}/^{86}\text{Sr}$  values ranging from 0.704512 – 0.704756 and  $\epsilon\text{Nd}$  values ranging from -1.5 to +0.3. The Hishikari basaltic andesite (HK-BA) ( $^{87}\text{Sr}/^{86}\text{Sr}$  = 0.704372 – 0.704502;  $\epsilon\text{Nd}$  = -0.2 to +0.4) has similar values to HKWest-BBA, suggesting a similar mantle source. The Hishikari andesite (HK-A) include higher  $^{87}\text{Sr}/^{86}\text{Sr}$  values (0.704703 – 0.706170) and lower  $\epsilon\text{Nd}$  values (-5.4 to +0.2) than HK-BA. Considering the young ages, age correction was not applied. Felsic rocks within the Hishikari mine area are plotted on Fig. 16 where they also have higher  $^{87}\text{Sr}/^{86}\text{Sr}$  and lower  $\epsilon\text{Nd}$  values than HK-BA.

**Table 7.** Sr-Nd isotopic composition of representative samples from HKWest-BBA, HK-BA, HK-A and YAM-BA.  $^{87}\text{Sr}/^{86}\text{Sr}$  measured ratios are normalized to NIST SRM 987  $^{87}\text{Sr}/^{86}\text{Sr}$  = 0.710245. The average value for the JNdi-1 analysis matched the agreed-upon value of  $^{143}\text{Nd}/^{144}\text{Nd}$  = 512100 of Garcon et al., 2018 and thus  $^{143}\text{Nd}/^{144}\text{Nd}$  ratios are reported as measured. A full analysis can be found in Appendix 3.2.

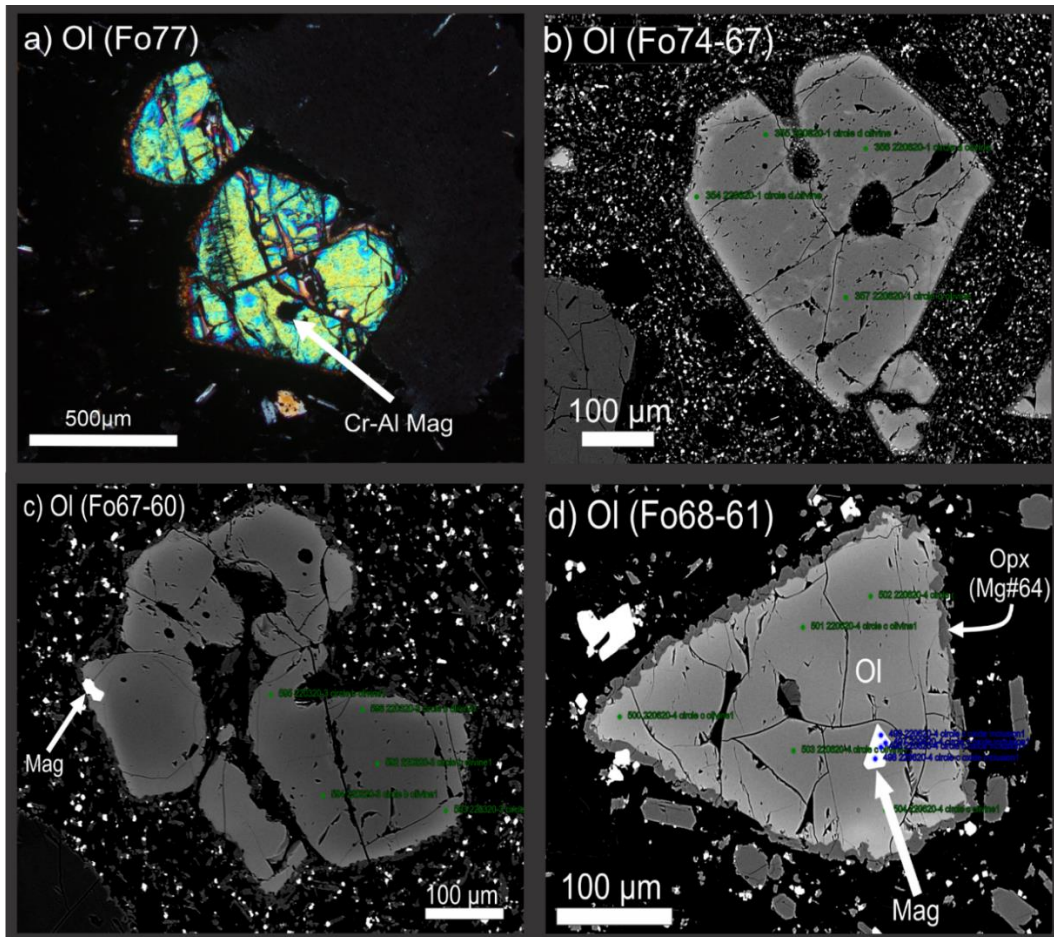
| Sample   | Group             | $^{87}\text{Sr}/^{86}\text{Sr}$ | Error (2 $\sigma$ ) | $^{143}\text{Nd}/^{144}\text{Nd}$ | Error (2 $\sigma$ ) | $\epsilon\text{Nd}$ |
|----------|-------------------|---------------------------------|---------------------|-----------------------------------|---------------------|---------------------|
| 220620-1 | HKWest-BBA        | 0.704512                        | 0.000012            | 0.512656                          | 0.000008            | 0.3                 |
| 220620-3 | HKWest-BBA        | 0.704756                        | 0.000013            | 0.512561                          | 0.000004            | -1.5                |
| 220621-5 | HK-BA pyroclastic | 0.704375                        | 0.000016            | 0.512660                          | 0.000006            | 0.4                 |
| 220623-1 | HK-BA lava        | 0.704502                        | 0.000012            | 0.512630                          | 0.000005            | -0.2                |
| 220621-7 | HK-A              | 0.704825                        | 0.000011            | 0.512584                          | 0.000004            | -1.0                |
| 220622-4 | HK-A              | 0.704703                        | 0.000017            | 0.512649                          | 0.000005            | 0.2                 |
| 220622-5 | HK-A              | 0.706170                        | 0.000019            | 0.512363                          | 0.000006            | -5.4                |
| YAM002   | YAM-BA            | 0.704334                        | 0.000014            |                                   |                     |                     |



**Figure 16.**  $\epsilon\text{Nd}$  vs  $^{87}\text{Sr}/^{86}\text{Sr}$  bulk rock values of representative samples as well as felsic rocks within the Hishikari mine area (purple asterisks). Error bars are not visible due to small error. The data and error are in Table 7. Symbols are the same as figure 8.

## 5.2 Olivine Composition

Olivine major and trace element compositions are listed in Table 8. Olivine (~0.5 - 2 mm) in HK-BA is unzoned and show similar composition among different grains in individual samples. They are Mg-rich (~Fo77), several containing Cr-Al bearing (~1.6wt% Cr and ~4wt% Al) magnetite inclusions (Fig. 17a). Olivine contains high Mn (~1500 - 2800 ppm) and low Ni (~330 - 760 ppm). Ni decreases with decreasing Fo (Fig. 18). Olivine from HKWest-BBA occur in basalts and basaltic andesites and are <1 mm in diameter. The compositions vary among different grains. They exhibit normal zoning (Fig. 17b, c and d) and are less Mg-rich (~Fo 64 - 73) than olivine in HK-BA. Some olivine grains contain Al bearing (<2.6wt% Al) magnetite inclusions (Fig. 17c and d). Olivine also contains high Mn (2085 - 4255ppm) and low Ni (150 - 690 ppm). The Ni content decreases systematically with Fo (Fig. 18).



**Figure 17.** a) Photomicrograph of homogenous olivine in pyroclastic basaltic andesite of the HK-BA (Sample 220621-5), b) euhedral olivine exhibiting normal zoning in basalt of HKWest-BBA (Sample 220620-1), c) olivine exhibiting normal zoning with magnetite inclusions in basalt of HKWest-BBA (sample 220620-3), and d) normal zoned olivine with magnetite inclusions and an Opx (Mg#64) rim in basaltic andesite of the HKWest-BBA.

**Table 8.** Representative olivine major and trace element compositions

| Grouping             |                            | HKWest-BBA        |                  | HKWest-BBA |       | HKWest-BBA           |       | HK-BA<br>pyroclastic | HK-BA<br>pyroclastic |
|----------------------|----------------------------|-------------------|------------------|------------|-------|----------------------|-------|----------------------|----------------------|
| Sample               |                            | 220620-1          |                  | 220620-3   |       | 220620-4             |       | 220621-5             | 119-05               |
| Lithology            |                            | basalt            |                  | basalt     |       | basaltic<br>andesite |       | basaltic<br>andesite | basaltic<br>andesite |
| #grains <sup>a</sup> |                            | <u>4</u>          |                  | <u>3</u>   |       | <u>6</u>             |       | <u>1</u>             | <u>4</u>             |
|                      | Method                     | Core <sup>d</sup> | Rim <sup>e</sup> | Core       | Rim   | Core                 | Rim   |                      |                      |
| SiO2wt. %            | EPMA                       | 38.38             | 37.51            | 37.39      | 36.57 | 37.25                | 36.38 | 38.64                | 38.54                |
| FeO                  | EPMA                       | 22.90             | 26.61            | 28.75      | 32.87 | 28.59                | 32.09 | 22.44                | 21.85                |
| MnO                  | LA-ICPMS/EPMA <sup>c</sup> | 0.40              | 0.48             | 0.48       | 0.59  | 0.53                 | 0.61  | 0.31                 | 0.31                 |
| MgO                  | EPMA                       | 38.74             | 35.19            | 34.01      | 30.24 | 33.75                | 30.59 | 39.37                | 39.29                |
| NiO                  | EPMA                       | 0.04              | 0.04             | 0.02       | 0.02  | 0.02                 | 0.02  | 0.05                 | 0.05                 |
| CaO                  | LA-ICPMS/EPMA              | 0.15              | 0.18             | 0.18       | 0.22  | 0.18                 | 0.20  | 0.09                 | 0.10                 |
|                      |                            | based on 4 O      |                  |            |       |                      |       |                      |                      |
| Si                   |                            | 0.996             | 0.999            | 0.997      | 1.000 | 0.998                | 0.998 | 0.997                | 0.999                |
| Fe <sup>2+</sup>     |                            | 0.497             | 0.592            | 0.641      | 0.751 | 0.641                | 0.736 | 0.484                | 0.474                |
| Mn                   |                            | 0.009             | 0.011            | 0.011      | 0.014 | 0.012                | 0.014 | 0.007                | 0.007                |
| Mg                   |                            | 1.499             | 1.397            | 1.352      | 1.232 | 1.348                | 1.251 | 1.514                | 1.519                |
| Ni                   |                            | 0.001             | 0.001            | 0.001      | 0.001 | 0.000                | 0.000 | 0.001                | 0.001                |
| Ca                   |                            | 0.004             | 0.005            | 0.005      | 0.006 | 0.005                | 0.006 | 0.003                | 0.003                |
| total                |                            | 3.007             | 3.005            | 3.006      | 3.004 | 3.005                | 3.006 | 3.005                | 3.003                |
| Fo%                  |                            | 75                | 70               | 69         | 62    | 68                   | 63    | 76                   | 76                   |
| #grains <sup>b</sup> |                            | <u>14</u>         |                  | <u>6</u>   |       | <u>8</u>             |       | <u>27</u>            | <u>4</u>             |
| Li ppm               | LA-ICPMS                   | 4.34              |                  | 6.60       |       | 8.89                 |       | 3.66                 | 4.45                 |
| Na                   | LA-ICPMS                   | 22.9              |                  | 23.0       |       | 21.2                 |       | 11.3                 | 11.4                 |
| Al                   | LA-ICPMS                   | 96.9              |                  | 87.8       |       | 84.1                 |       | 65.8                 | 63.7                 |
| Sc                   | LA-ICPMS                   | 10.6              |                  | 10.1       |       | 13.0                 |       | 7.95                 | 7.03                 |
| Ti                   | LA-ICPMS                   | 34.00             |                  | 53.2       |       | 65.8                 |       | 36.1                 | 35.0                 |
| V                    | LA-ICPMS                   | 11.0              |                  | 11.1       |       | 11.9                 |       | 4.91                 | 4.80                 |
| Cr                   | LA-ICPMS                   | 37.8              |                  | 42.7       |       | 2.9                  |       | 14.4                 | 11.6                 |
| Ni*                  | LA-ICPMS                   | 473               |                  | 285        |       | 177                  |       | 398                  | 418                  |
| Co                   | LA-ICPMS                   | 181               |                  | 175        |       | 172                  |       | 210                  | 214                  |
| Zn*                  | LA-ICPMS                   | 179               |                  | 206        |       | 274                  |       | 135                  | 153                  |

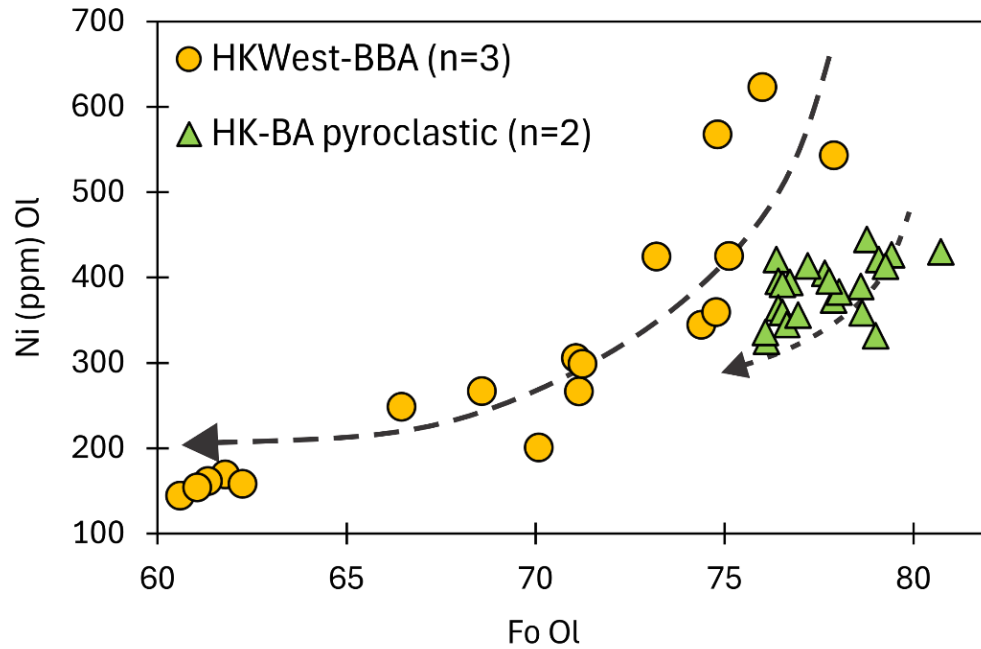
#grains<sup>a</sup> = Number of grains used to obtain average Ol major element composition determined by EPMA. The composition of each grain was determined using  $\geq 3$  analyses, so that the averages of high-Mg and low-Mg areas of the grain was obtained. Olivine major element data and detection limits can be found in Appendix 4.3.

#grains<sup>b</sup> = Number of grains used to obtain average Ol trace element composition determined by LA-ICPMS. The composition of each grain was determined using 1-4 analyses. Olivine trace element data can be found in Appendix 4.4.  
LA-ICPMS/EPMA<sup>c</sup> = composition determined by LA-ICPMS for homogenous grains and EPMA for zoned grains

Core<sup>d</sup> = average composition of core

Rim<sup>e</sup> = average composition of rim

\*Slightly less grains than shown are used for the average composition of Zn and N



**Figure 18.** Ni vs Fo of olivine in HKWest-BBA (orange circles) and HK-BA pyroclastic (green triangles). Black arrows represent empirical fractional crystallization of a mafic melt. n = number of samples from which several olivine grains were analyzed. Each point represents an analysis of a single olivine grain based on Ni contents from LA-ICP-MA and Fo from EPMA.

### 5.3 Clinopyroxene Composition

Clinopyroxene major and trace element compositions are listed in Table 9. Primitive mantle normalized Cpx trace element compositions and hypothetical Cpx equilibrium melt compositions are shown in Figs. 19 and 20, respectively. Clinopyroxene grains in HK-BA exhibit a variety of textures including reverse zoning with Mg-rich rims (Mg#78) and Mg-poor cores (Mg#73), patchy zoning with Mg-rich (Mg#78) and Mg-poor (Mg#75) areas, oscillatory zoning with Mg-rich (Mg# 78 - 84) and Mg-poor (Mg# 73 - 78) bands as well as homogenous Cpx (Mg#74). Cpx also occurs as inclusions that exhibit patchy zoning (Mg#80-75) in several Opx grains. Clinopyroxene in HK-A exhibit oscillatory zoning with Mg-rich (Mg#84 – 77) and Mg-poor (Mg#72) bands as well as reverse zoning with Mg-poor rims (Mg# 72) and Mg-rich (Mg# 74 - 84) areas. Clinopyroxene in HK-WestBBA exhibit oscillatory zoning with Mg-rich (Mg#82 - 67) and Mg-poor (Mg#73 - 66) bands, reverse zoning (Mg#82- 66) and homogenous Cpx (Mg#74). Clinopyroxene in YAM-BA exhibit normal zoning with Mg-rich cores (Mg#81) and Mg-poor rims (Mg#74), oscillatory zoning with Mg-rich (Mg#76) and Mg-poor (Mg#74) bands as well as homogenous Cpx (Mg#74). The different textures existing within one sample and patchy zoning suggests that some grains might be xenocrysts, incorporated from earlier rocks. It is also possible that there were injections of mafic magma resulting in reverse zoning. However, there is a lack of evidence of magma mixing such as Ca-rich rims on plagioclase. Pyroxene composition and texture descriptions can be found in Appendix 4.5.

In the Hishikari basaltic andesites (HK-BA), Ni content is higher in the lava (113 – 211ppm in Cpx; 62ppm in bulk rock) than the pyroclastic unit (62 – 121ppm in Cpx; 13ppm in bulk rock). In the lava, Ni content in Cpx decreases systematically with decreasing Mg# in Cpx (Fig. 21). In the pyroclastic unit, Ni content in Cpx does not systematically change with decreasing Mg# in Cpx (Fig. 21). This possibly suggests that Ni was preferentially partitioning into olivine during or before Cpx crystallization (assuming Ol was crystallizing during or before Cpx) in the lava. It is also possible that in-situ crystallization of the lava fractionated Ni into the matrix crystal and not the phenocrysts. In addition, the parental magma of the pyroclastic unit may have solidified before further fractional crystallization since pyroclastics quickly cool.

Cpx in the Hishikari basaltic andesites (HK-BA) exhibit weak Eu anomalies ( $\text{Eu}/\text{Eu}^* = 0.74 - 1.1$  for the pyroclastic unit and  $0.64 - 0.88$  for the lava). The Hishikari andesites (HK-A) exhibit stronger Cpx Eu anomalies ( $\text{Eu}/\text{Eu}^* \sim 0.4$ ). The samples collected West of Hishikari



(HKWest-BBA) also exhibit weak Cpx Eu anomalies ( $\text{Eu}/\text{Eu}^* = 0.75 - 1.1$ ). Eu anomalies in Cpx of the Yamagano basaltic andesites (YAM-BA) range from 0.45 – 0.87. Eu anomalies are shown in Fig. 22.

The composition of a hypothetical melt in equilibrium with Cpx is shown in Fig. 20. The distribution coefficients (D) listed in the Geochemical Earth Reference Model (GERM) were examined to find the most appropriate values for our rocks. The Distribution coefficients (D) were selected from experiments that had the most similar NBO/T, temperature and pressure conditions to our samples.  $\text{NBO}/\text{T} = (\text{\# of non-bridging oxygens}) / (\text{tetrahedrally coordinated cations})$ . NBO/T describes the degree of polymerization of a silicate melt. Our samples yielded NBO/T values ranging from 0.13 – 0.37 (average NBO/T = 0.22). Two-Pyx thermobarometry yielded equilibrium temperatures up to 1100°C and 6.2kbar (Fig. 23, Table 14). Thus, the hypothetical Cpx equilibrium melt composition was calculated using the distribution coefficients between Cpx and melt for elements Nb, La, Ce, Nd, Sr, Sm, Eu, Ti, Er, Y, Yb, Lu, V and Sc from Blundy et al. (1998) which were obtained through their experiments on a basaltic melt (NBO/T = 0.26) at 1260°C and 15kbar. Since the experiments were carried out at higher temperatures, the D values are closer to 1. The real D values should be smaller and the calculated concentrations of elements in the hypothetical melt should be smaller for these elements than the correct values. Unfortunately, Pb and Dy were not analyzed in Blundy et al. (1998), thus Pb and Dy distribution coefficients are from Hauri et al. (1994) which were also obtained through experiments on basaltic melts (NBO/T = 0.56) at 1430°C and 25 kbar. D values between Cpx and melt generally approach to one with increasing temperature and pressure. Thus, the calculated Pb and Dy melt compositions are the minimum estimates.

**Table 9.** Representative Clinopyroxene major and trace element compositions

| Group                          | HK-A                 |         | HK-BA lava                 |         |       | HK-BA pyroclastic              |         |        | HKWest-BBA             |         | HKWest-BBA                 |         |        | HKWest-BBA         |         | YAM-BA                     |         |       |
|--------------------------------|----------------------|---------|----------------------------|---------|-------|--------------------------------|---------|--------|------------------------|---------|----------------------------|---------|--------|--------------------|---------|----------------------------|---------|-------|
| Sample                         | 220621-6             |         | 220623-1                   |         |       | 220621-5                       |         |        | 220620-1               |         | 220620-3                   |         |        | 220620-4           |         | YAM002                     |         |       |
| Lithology                      | andesite             |         | basaltic andesite          |         |       | basaltic andesite              |         |        | basalt                 |         | basalt                     |         |        | basaltic andesite  |         | basaltic andesite          |         |       |
| #grains <sup>a</sup>           | <u>3</u>             |         | <u>2</u> <u>1</u>          |         |       | <u>3</u> <u>1</u>              |         |        | <u>3</u>               |         | <u>1</u> <u>1</u>          |         |        | <u>3</u>           |         | <u>2</u> <u>4</u>          |         |       |
|                                | zoned <sup>b,c</sup> |         | zoned <sup>c</sup> unzoned |         |       | zoned <sup>b,c,d</sup> unzoned |         |        | zoned <sup>b,c,d</sup> |         | zoned <sup>c</sup> unzoned |         |        | zoned <sup>c</sup> |         | zoned <sup>b</sup> unzoned |         |       |
|                                | Low Mg               | High Mg | Low Mg                     | High Mg |       | Low Mg                         | High Mg |        | Low Mg                 | High Mg | Low Mg                     | High Mg |        | Low Mg             | High Mg | Low Mg                     | High Mg |       |
| SiO <sub>2</sub> wt%           | 52.02                | 51.74   | 52.29                      | 52.42   | 52.57 | 52.58                          | 51.81   | 52.85  | 51.94                  | 51.57   | 51.66                      | 51.74   | 51.94  | 51.82              | 51.85   | 51.87                      | 53.15   | 51.52 |
| TiO <sub>2</sub>               | 0.53                 | 0.49    | 0.40                       | 0.37    | 0.39  | 0.36                           | 0.40    | 0.32   | 0.46                   | 0.63    | 0.58                       | 0.50    | 0.62   | 0.72               | 0.67    | 0.58                       | 0.37    | 0.68  |
| Al <sub>2</sub> O <sub>3</sub> | 1.96                 | 2.63    | 2.73                       | 2.95    | 2.63  | 1.77                           | 3.48    | 1.36   | 2.86                   | 2.82    | 2.98                       | 4.23    | 2.86   | 1.52               | 1.49    | 2.53                       | 2.04    | 2.81  |
| FeO <sup>T</sup>               | 10.11                | 8.52    | 9.20                       | 7.55    | 8.47  | 9.23                           | 6.95    | 9.27   | 7.75                   | 9.46    | 10.17                      | 7.52    | 9.91   | 13.99              | 13.66   | 9.43                       | 7.64    | 9.51  |
| MnO                            | 0.36                 | 0.27    | 0.24                       | 0.19    | 0.22  | 0.35                           | 0.18    | 0.39   | 0.23                   | 0.27    | 0.29                       | 0.20    | 0.26   | 0.46               | 0.46    | 0.30                       | 0.24    | 0.31  |
| MgO                            | 15.07                | 15.59   | 16.77                      | 16.83   | 16.56 | 14.63                          | 15.62   | 14.49  | 16.60                  | 15.83   | 15.29                      | 15.91   | 15.46  | 14.86              | 15.15   | 15.21                      | 16.34   | 15.37 |
| CaO                            | 19.46                | 20.05   | 17.64                      | 19.04   | 18.67 | 20.79                          | 21.08   | 21.06  | 19.10                  | 18.16   | 18.61                      | 19.82   | 18.77  | 16.19              | 16.10   | 19.42                      | 20.31   | 19.16 |
| Na <sub>2</sub> O              | 0.29                 | 0.28    | 0.30                       | 0.28    | 0.30  | 0.29                           | 0.25    | 0.29   | 0.27                   | 0.30    | 0.34                       | 0.34    | 0.32   | 0.27               | 0.26    | 0.33                       | 0.27    | 0.32  |
| Total                          | 99.80                | 99.58   | 99.57                      | 99.63   | 99.82 | 100.00                         | 99.77   | 100.03 | 99.20                  | 99.05   | 99.94                      | 100.26  | 100.13 | 99.84              | 99.65   | 99.68                      | 100.35  | 99.68 |
| Mineral formula based on 60    |                      |         |                            |         |       |                                |         |        |                        |         |                            |         |        |                    |         |                            |         |       |
| Si                             | 1.938                | 1.917   | 1.931                      | 1.926   | 1.931 | 1.954                          | 1.907   | 1.966  | 1.920                  | 1.924   | 1.916                      | 1.894   | 1.921  | 1.950              | 1.952   | 1.928                      | 1.948   | 1.914 |
| Ti                             | 0.015                | 0.014   | 0.011                      | 0.010   | 0.011 | 0.010                          | 0.011   | 0.009  | 0.013                  | 0.018   | 0.016                      | 0.014   | 0.017  | 0.020              | 0.019   | 0.016                      | 0.010   | 0.019 |
| Al                             | 0.086                | 0.115   | 0.119                      | 0.128   | 0.119 | 0.077                          | 0.151   | 0.060  | 0.124                  | 0.124   | 0.130                      | 0.183   | 0.125  | 0.067              | 0.066   | 0.111                      | 0.088   | 0.123 |
| Cr <sup>3+</sup>               | 0.000                | 0.003   | 0.004                      | 0.006   | 0.003 | 0.000                          | 0.005   | 0.000  | 0.005                  | 0.003   | 0.002                      | 0.003   | 0.002  | 0.000              | 0.000   | 0.001                      | 0.002   | 0.000 |
| Fe <sup>3+</sup>               | 0.030                | 0.042   | 0.016                      | 0.014   | 0.012 | 0.014                          | 0.027   | 0.012  | 0.025                  | 0.013   | 0.029                      | 0.024   | 0.020  | 0.012              | 0.012   | 0.024                      | 0.013   | 0.034 |
| Fe <sup>2+</sup>               | 0.285                | 0.222   | 0.268                      | 0.218   | 0.249 | 0.272                          | 0.186   | 0.276  | 0.215                  | 0.282   | 0.287                      | 0.206   | 0.287  | 0.428              | 0.418   | 0.269                      | 0.221   | 0.262 |
| Mn                             | 0.011                | 0.008   | 0.008                      | 0.006   | 0.007 | 0.011                          | 0.005   | 0.012  | 0.007                  | 0.009   | 0.009                      | 0.006   | 0.008  | 0.015              | 0.015   | 0.010                      | 0.007   | 0.010 |
| Mg                             | 0.837                | 0.861   | 0.923                      | 0.922   | 0.909 | 0.810                          | 0.857   | 0.804  | 0.915                  | 0.880   | 0.845                      | 0.868   | 0.853  | 0.834              | 0.850   | 0.843                      | 0.893   | 0.852 |
| Ca                             | 0.777                | 0.796   | 0.698                      | 0.750   | 0.737 | 0.828                          | 0.831   | 0.839  | 0.756                  | 0.726   | 0.740                      | 0.777   | 0.744  | 0.653              | 0.649   | 0.773                      | 0.797   | 0.763 |
| Na                             | 0.021                | 0.020   | 0.022                      | 0.020   | 0.021 | 0.021                          | 0.018   | 0.021  | 0.019                  | 0.022   | 0.025                      | 0.024   | 0.023  | 0.020              | 0.019   | 0.024                      | 0.019   | 0.023 |
| K                              | 0.001                | 0.001   | 0.001                      | 0.001   | 0.001 | 0.001                          | 0.001   | 0.001  | 0.000                  | 0.001   | 0.001                      | 0.001   | 0.001  | 0.001              | 0.001   | 0.001                      | 0.001   | 0.001 |
| total                          | 4.000                | 4.000   | 4.000                      | 4.000   | 4.000 | 4.000                          | 4.000   | 4.000  | 4.000                  | 4.000   | 4.000                      | 4.000   | 4.000  | 4.000              | 4.000   | 4.000                      | 4.000   | 4.000 |
| Mg# <sup>e</sup>               | 73                   | 77      | 76                         | 80      | 78    | 74                             | 80      | 74     | 79                     | 75      | 73                         | 79      | 74     | 65                 | 66      | 74                         | 79      | 74    |
| #grains <sup>f</sup>           | <u>10</u>            |         | <u>6</u>                   |         |       | <u>11</u>                      |         |        | <u>8</u>               |         | <u>9</u>                   |         |        | <u>8</u>           |         | <u>9</u>                   |         |       |
| Sc ppm                         | 170                  |         | 114                        |         |       | 119                            |         |        | 113                    |         | 93.3                       |         |        | 79.5               |         | 151                        |         |       |
| Ti                             | 2151                 |         | 2060                       |         |       | 2693                           |         |        | 2808                   |         | 1700                       |         |        | 1664               |         | 2963                       |         |       |
| V                              | 232                  |         | 372                        |         |       | 398                            |         |        | 460                    |         | 267                        |         |        | 289                |         | 292                        |         |       |
| Cr                             | 16.5                 |         | 1017                       |         |       | 673                            |         |        | 950                    |         | 1139                       |         |        | 1304               |         | 28.1                       |         |       |
| Ni                             | 32.8                 |         | 166                        |         |       | 83.3                           |         |        | 67.1                   |         | 73.7                       |         |        | 97.7               |         | 23.0                       |         |       |
| Sr                             | 20.6                 |         | 34.3                       |         |       | 26.9                           |         |        | 30.5                   |         | 30.8                       |         |        | 25.7               |         | 28.3                       |         |       |
| Y                              | 67.2                 |         | 17.8                       |         |       | 16.5                           |         |        | 14                     |         | 7.81                       |         |        | 8.08               |         | 39.8                       |         |       |
| Nb                             | 0.03                 |         | 0.02                       |         |       | 0.02                           |         |        | 0.02                   |         | 0.01                       |         |        | 0.01               |         | 0.05                       |         |       |
| La                             | 4.65                 |         | 1.27                       |         |       | 0.79                           |         |        | 1.18                   |         | 0.59                       |         |        | 0.43               |         | 2.39                       |         |       |
| Ce                             | 22.1                 |         | 5.22                       |         |       | 3.85                           |         |        | 5.83                   |         | 3.07                       |         |        | 2.19               |         | 10.3                       |         |       |
| Pr                             | 4.37                 |         | 1.16                       |         |       | 0.90                           |         |        | 1.20                   |         | 0.67                       |         |        | 0.48               |         | 2.17                       |         |       |
| Nd                             | 27.4                 |         | 6.75                       |         |       | 5.85                           |         |        | 7.12                   |         | 4.04                       |         |        | 2.98               |         | 13.9                       |         |       |
| Sm                             | 9.90                 |         | 2.81                       |         |       | 2.40                           |         |        | 2.67                   |         | 1.52                       |         |        | 1.20               |         | 5.33                       |         |       |
| Eu                             | 1.43                 |         | 0.73                       |         |       | 0.75                           |         |        | 0.79                   |         | 0.50                       |         |        | 0.45               |         | 1.25                       |         |       |
| Gd                             | 11.8                 |         | 3.27                       |         |       | 3.21                           |         |        | 3.16                   |         | 1.67                       |         |        | 1.64               |         | 6.57                       |         |       |
| Tb                             | 1.81                 |         | 0.49                       |         |       | 0.49                           |         |        | 0.47                   |         | 0.25                       |         |        | 0.25               |         | 1.05                       |         |       |
| Dy                             | 12.7                 |         | 3.31                       |         |       | 3.25                           |         |        | 3.11                   |         | 1.62                       |         |        | 1.67               |         | 7.16                       |         |       |
| Er                             | 7.88                 |         | 2.14                       |         |       | 2.11                           |         |        | 1.83                   |         | 1.03                       |         |        | 1.11               |         | 4.68                       |         |       |
| Yb                             | 6.46                 |         | 1.70                       |         |       | 1.73                           |         |        | 1.56                   |         | 0.80                       |         |        | 0.93               |         | 3.82                       |         |       |
| Lu                             | 0.98                 |         | 0.24                       |         |       | 0.25                           |         |        | 0.21                   |         | 0.10                       |         |        | 0.12               |         | 0.55                       |         |       |
| Pb                             | 0.26                 |         | 0.08                       |         |       | 0.06                           |         |        | 0.07                   |         | 0.06                       |         |        | 0.05               |         | 0.13                       |         |       |

#grains<sup>a</sup> = number of grains used to obtain average Cpx major element composition determined by EPMA. If only 1 grain was analyzed, the table shows the average composition of analyses done on that grain. The composition of each Cpx grain was determined using  $\geq 3$  analysis, so that the averages of high-Mg and low-Mg areas of the grain was obtained. Cpx major element data and detection limits can be found in Appendix 4.3.

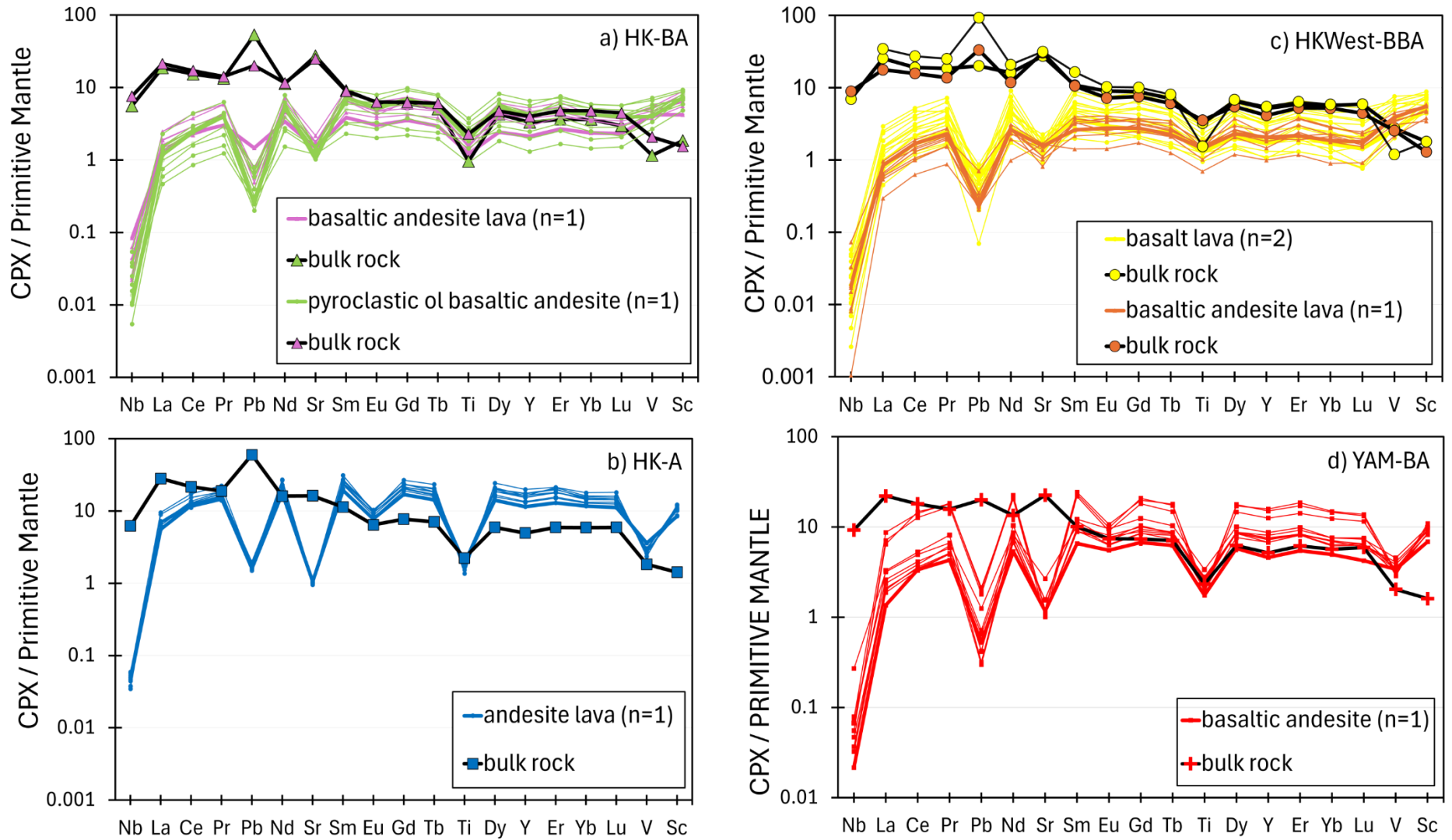
#grains<sup>f</sup> = number of grains used to obtain average Cpx trace element composition determined by LA-ICPMS. The composition of each Cpx grain was determined using  $>1$  analyses. Cpx trace element data and detection limits can be found in Appendix 4.4.

b = reverse zoned with high Mg rims and low Mg cores

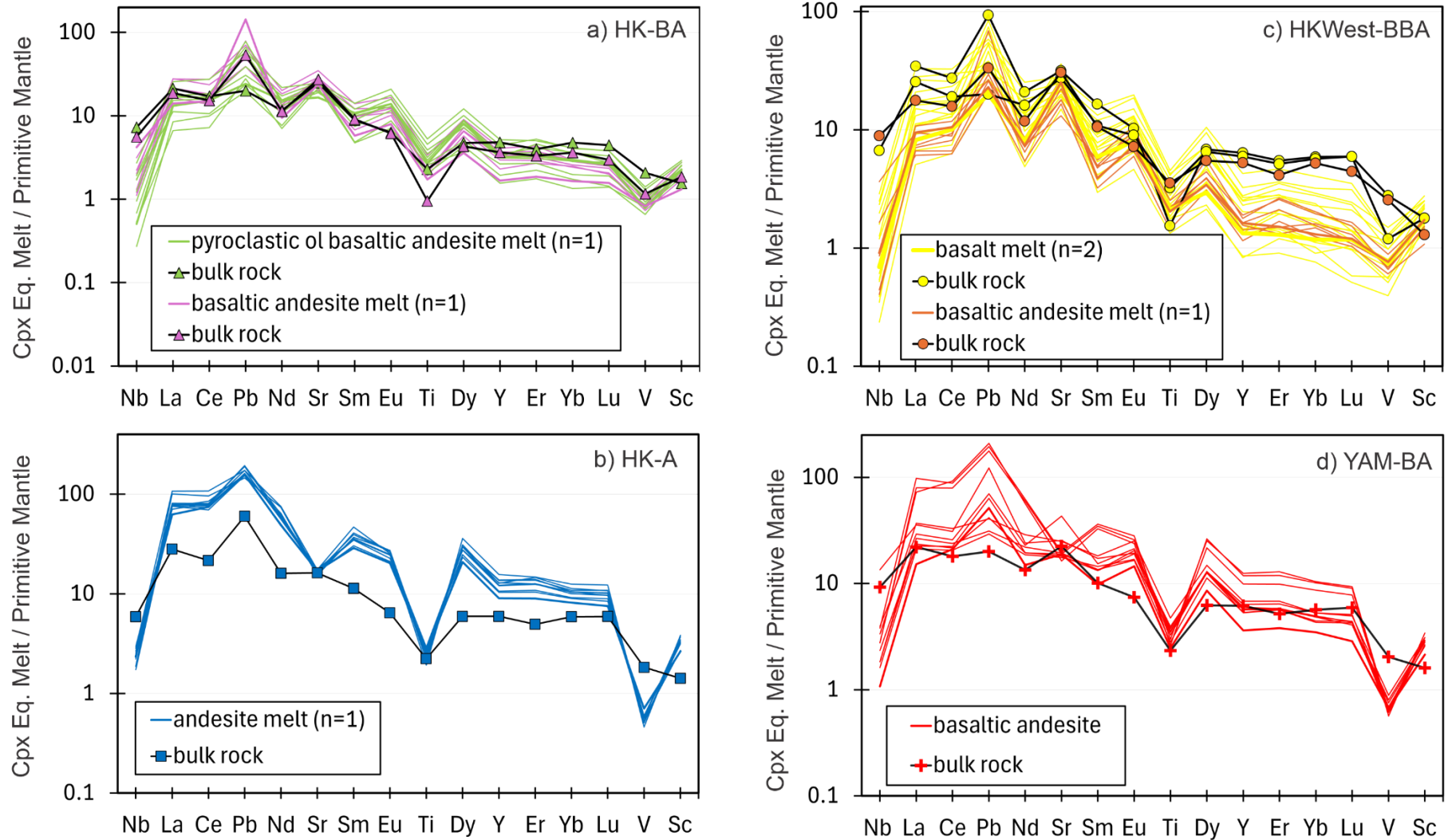
c = oscillatory zoned with alternating high Mg and low Mg bands

d = patchy zoned with high Mg areas and low Mg areas

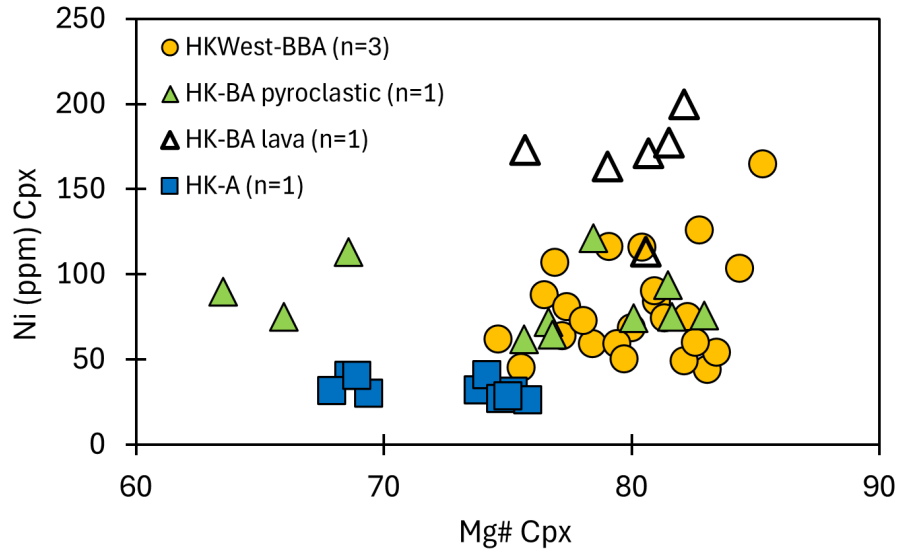
e = Atomic ratio (Mg)/(Mg+Fe<sup>2+</sup>)



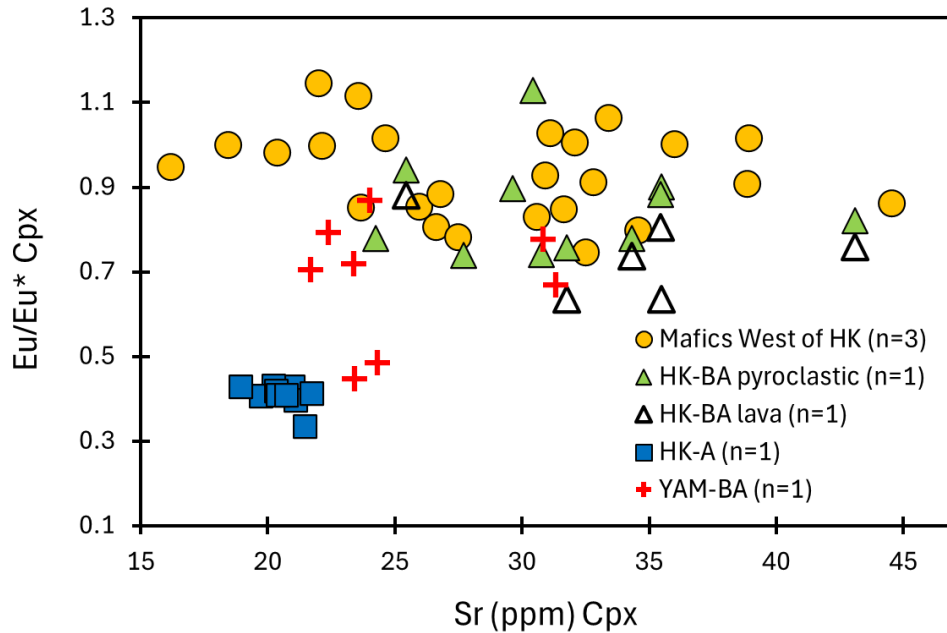
**Figure 19.** Trace element abundance of clinopyroxene normalized to primitive mantle in a) HK-BA (lava is represented by purple and green for pyroclastic), b) HK-A (blue), c) HKWest-BBA (yellow for basalts and orange for basaltic andesites) and d) YAM-BA (red). n = number of samples where several Cpx grains were analyzed. Each coloured line represents the trace element composition of a single Cpx grain determined by LA-ICP-MS and their corresponding bulk rock composition are represented by black lines.



**Figure 20.** Melt composition in equilibrium with Cpx relative to bulk rock composition for a) HK-BA, b) HK-A, c) HKWest-BBA and d) YAM-BA. Colour schemes are the same as Fig. 19. Melt composition was calculated using the distribution coefficients between Cpx and melt for elements Nb, La, Ce, Nd, Sr, Sm, Eu, Ti, Er, Y, Yb, Lu, V and Sc from Blundy et al. (1998) and Pb and Dy from Hauri et al. (1994). n = number of samples where several Cpx grains were analyzed. Each coloured line represents the trace element composition of a single Cpx grain determined by LA-ICP-MS and their corresponding bulk rock composition are represented by black line



**Figure 21.** Ni vs. Mg# contents in Cpx from HKWest-BBA (orange circles), HK-BA (green triangles for pyroclastic and hollow triangles for lava) and HK-A (blue squares). Each point represents an analysis of a single Cpx grain. n = number of samples from which several Cpx grains were analyzed. Each point represents an analysis of a single Cpx grain based on Ni contents determined by LA-ICP-MS and Mg contents determined by SEM.



**Figure 22.** Eu anomalies vs. Sr content (ppm) in Cpx of HKWest-BBA (orange circles,  $\text{Eu}/\text{Eu}^* = 0.76 - 1.1$ ), HK-BA pyroclastic (green triangles,  $\text{Eu}/\text{Eu}^* = 0.74 - 1.1$ ), HK-BA lava (hollow triangles,  $\text{Eu}/\text{Eu}^* = 0.64 - 0.88$ ), HK-A (blue squares,  $\text{Eu}/\text{Eu}^* \sim 0.4$ ) and YAM-BA (red crosses,  $\text{Eu}/\text{Eu}^* = 0.45 - 0.9$ ). n = number of samples from which several Cpx grains were analyzed. Each point represents an analysis of a single Cpx grain based on Sr and Eu contents determined by LA-ICP-MS.

## 5.4 Orthopyroxene Composition

Major element compositions of OPX are listed in Table 10. Orthopyroxene in HK-BA exhibit a variety of textures where the lava contains normally zoned Opx with Mg-rich cores (Mg#87) and Mg-poor rims (Mg#78) and oscillatory zoned Opx with bands ( $> 10\mu\text{m}$ ) alternating between Mg-rich (Mg#80) and Mg-poor (Mg#77). The pyroclastic contains homogenous Opx (Mg#67). Opx in the HK-A include reverse zoned Opx with Mg-poor cores (Mg#67) and Mg-rich rims (Mg#70) as well as homogenous Opx (Mg#67). Opx in HKWest-BBA include oscillatory zoned with bands (20-50 $\mu\text{m}$ ) alternating between Mg-rich (Mg#82) and Mg-poor (Mg#73), reverse zoned with Mg-rich (Mg#77) rims and Mg-poor (Mg#75) cores, patchy zoned with Mg-rich (Mg#73) areas and Mg-poor (Mg#70) areas, normal zoned Opx with Mg-rich cores (Mg#73) and Mg-poor (Mg#68) rims as well as homogenous Opx (Mg#72). Sample 220620-4 from HKWest-BBA contains Opx (Mg#64) rimming Ol. Opx in YAM-BA include oscillatory zoned with Mg-rich (Mg#75) and Mg-poor (Mg#73) bands, normal zoned (Core: Mg#74, Rim ~ Mg#68) and Opx inclusions (Mg#74) within Cpx. Opx texture and composition descriptions are shown in Appendix 4.5.

**Table 10.** Representative Opx major element composition

| Group                          | HK-A               |         |          | HK-BA lava          |         | HK-BA<br>pyroclastic | HKWest-BBA         |         |          | HKWest-BBA         |         |          | HKWest-BBA         |         |               | YAM-BA               |         |                      |
|--------------------------------|--------------------|---------|----------|---------------------|---------|----------------------|--------------------|---------|----------|--------------------|---------|----------|--------------------|---------|---------------|----------------------|---------|----------------------|
| Sample                         | 220621-6           |         |          | 220623-1            |         | 220621-5             | 220620-1           |         |          | 220620-3           |         |          | 220620-4           |         |               | YAM002               |         |                      |
| Lithology                      | andesite           |         |          | basaltic andesite   |         | basaltic andesite    | basalt             |         |          | basalt             |         |          | basaltic andesite  |         |               | basaltic andesite    |         |                      |
| #grains <sup>a</sup>           | <u>1</u>           |         | <u>2</u> | <u>4</u>            |         | <u>1</u>             | <u>1</u>           |         | <u>1</u> | <u>1</u>           |         | <u>1</u> | <u>1</u>           |         | <u>1</u>      | <u>5</u>             |         | <u>5</u>             |
|                                | zoned <sup>c</sup> |         | unzoned  | zoned <sup>df</sup> |         | unzoned              | zoned <sup>c</sup> |         | unzoned  | zoned <sup>c</sup> |         | unzoned  | zoned <sup>f</sup> |         | rim around Ol | zoned <sup>d,f</sup> |         | unzoned <sup>d</sup> |
|                                | Low Mg             | High Mg |          | Low Mg              | High Mg |                      | Low Mg             | High Mg |          | Low Mg             | High Mg |          | Low Mg             | High Mg |               | Low Mg               | High Mg |                      |
| SiO <sub>2</sub> wt%           | 52.10              | 53.01   | 53.44    | 54.01               | 54.50   | 53.89                | 53.49              | 53.52   | 54.03    | 52.79              | 54.22   | 53.09    | 53.37              | 53.49   | 52.45         | 53.19                | 53.90   | 53.83                |
| TiO <sub>2</sub>               | 0.27               | 0.29    | 0.27     | 0.23                | 0.20    | 0.14                 | 0.32               | 0.29    | 0.27     | 0.34               | 0.24    | 0.36     | 0.40               | 0.29    | 0.36          | 0.37                 | 0.28    | 0.29                 |
| Al <sub>2</sub> O <sub>3</sub> | 2.71               | 1.09    | 1.04     | 1.75                | 1.89    | 0.72                 | 1.86               | 2.12    | 1.52     | 2.61               | 1.35    | 2.42     | 0.99               | 1.79    | 0.58          | 2.14                 | 1.59    | 1.52                 |
| FeOT                           | 20.29              | 18.85   | 19.09    | 14.52               | 13.24   | 20.25                | 16.13              | 15.59   | 14.90    | 18.08              | 16.72   | 17.23    | 19.65              | 16.88   | 19.99         | 16.42                | 15.64   | 16.67                |
| MnO                            | 0.57               | 0.54    | 0.56     | 0.33                | 0.29    | 0.81                 | 0.39               | 0.39    | 0.41     | 0.43               | 0.39    | 0.39     | 0.50               | 0.42    | 0.63          | 0.43                 | 0.44    | 0.48                 |
| MgO                            | 23.25              | 24.96   | 24.46    | 26.96               | 28.06   | 23.46                | 26.03              | 26.65   | 26.84    | 24.16              | 25.51   | 24.72    | 23.07              | 25.14   | 20.36         | 25.65                | 26.69   | 25.76                |
| CaO                            | 1.24               | 1.36    | 1.43     | 1.89                | 1.77    | 0.96                 | 1.72               | 1.68    | 1.71     | 1.85               | 1.77    | 1.81     | 2.05               | 1.73    | 4.08          | 1.78                 | 1.54    | 1.63                 |
| Na <sub>2</sub> O              | 0.02               | 0.02    | 0.02     | 0.03                | 0.02    | 0.01                 | 0.02               | 0.03    | 0.02     | 0.04               | 0.05    | 0.02     | 0.05               | 0.03    | 0.05          | 0.02                 | 0.02    | 0.03                 |
| Total                          | 100.46             | 100.12  | 100.29   | 99.73               | 99.96   | 100.24               | 99.96              | 100.26  | 99.71    | 100.29             | 100.23  | 100.02   | 100.08             | 99.77   | 98.49         | 100.00               | 100.10  | 100.20               |
| Mineral formula based on 6O    |                    |         |          |                     |         |                      |                    |         |          |                    |         |          |                    |         |               |                      |         |                      |
| Si                             | 1.912              | 1.937   | 1.955    | 1.945               | 1.945   | 1.987                | 1.937              | 1.925   | 1.950    | 1.925              | 1.966   | 1.934    | 1.969              | 1.957   | 1.989         | 1.929                | 1.943   | 1.943                |
| Ti                             | 0.007              | 0.008   | 0.007    | 0.006               | 0.005   | 0.004                | 0.009              | 0.008   | 0.007    | 0.009              | 0.006   | 0.010    | 0.011              | 0.009   | 0.010         | 0.010                | 0.008   | 0.010                |
| Al                             | 0.117              | 0.047   | 0.045    | 0.074               | 0.079   | 0.031                | 0.079              | 0.090   | 0.065    | 0.112              | 0.058   | 0.104    | 0.043              | 0.066   | 0.026         | 0.091                | 0.068   | 0.025                |
| Fe <sup>3+</sup>               | 0.046              | 0.066   | 0.033    | 0.022               | 0.018   | 0.000                | 0.030              | 0.048   | 0.020    | 0.022              | 0.001   | 0.010    | 0.000              | 0.006   | 0.000         | 0.033                | 0.032   | 0.071                |
| Fe <sup>2+</sup>               | 0.577              | 0.510   | 0.551    | 0.415               | 0.377   | 0.624                | 0.459              | 0.421   | 0.430    | 0.529              | 0.505   | 0.515    | 0.606              | 0.539   | 0.634         | 0.465                | 0.439   | 0.445                |
| Mn                             | 0.018              | 0.017   | 0.017    | 0.010               | 0.009   | 0.025                | 0.012              | 0.012   | 0.012    | 0.013              | 0.012   | 0.012    | 0.016              | 0.014   | 0.020         | 0.013                | 0.013   | 0.015                |
| Mg                             | 1.272              | 1.359   | 1.334    | 1.448               | 1.493   | 1.289                | 1.405              | 1.429   | 1.445    | 1.313              | 1.379   | 1.343    | 1.269              | 1.334   | 1.151         | 1.387                | 1.435   | 1.423                |
| Ca                             | 0.049              | 0.053   | 0.056    | 0.073               | 0.068   | 0.038                | 0.067              | 0.065   | 0.066    | 0.072              | 0.069   | 0.071    | 0.081              | 0.072   | 0.166         | 0.069                | 0.059   | 0.065                |
| Na                             | 0.002              | 0.002   | 0.001    | 0.002               | 0.001   | 0.001                | 0.001              | 0.002   | 0.002    | 0.003              | 0.003   | 0.001    | 0.003              | 0.003   | 0.003         | 0.002                | 0.001   | 0.002                |
| total                          | 4.000              | 4.000   | 4.000    | 4.000               | 4.000   | 4.000                | 4.000              | 4.000   | 4.000    | 4.000              | 4.000   | 4.000    | 4.000              | 4.000   | 4.000         | 4.000                | 4.000   | 4.000                |
| Mg <sup>#g</sup>               | 67                 | 70      | 70       | 77                  | 79      | 67                   | 74                 | 75      | 76       | 70                 | 73      | 72       | 68                 | 73      | 64            | 74                   | 75      | 74                   |

#grains<sup>a</sup> = number of grains used to obtain average Opx major element composition determined by EPMA. If only 1 grain was analyzed, the table shows the average composition of analyses of that grain. The composition of each Opx grain was determined using  $\geq 3$  analysis, so that the averages of high-Mg and low-Mg areas of the grain was obtained. Opx major element data and detection limits can be found in Appendix 4.3.

b = Atomic ratio (Mg)/(Mg+Fe<sup>2+</sup>)

c = reverse zoned with high Mg rims and low Mg cores

d = oscillatory zoned with alternating high Mg and low Mg bands

e = patchy zoned with high Mg areas and low Mg areas

f = normal zoned with high Mg core and low Mg rim

## 5.5 Oxide Composition

Magnetite phenocrysts in samples from the Hishikari mine area (HK-BA and HK-A) are V-bearing (1.3 - 5.2 wt% V) and Ti-bearing (~9-11 wt% TiO<sub>2</sub>). Rare ilmenite grains were observed in samples 220621-7, 220621-8 and 220622-5. Magnetite phenocrysts in Yamagano basaltic andesite (YAM-BA) have similar TiO<sub>2</sub> composition (~9 wt%) to Hishikari mine samples and are also V-bearing (~2.4 wt% V), but contain very low MgO, 0.02 wt%. Magnetite in HKWest-BBA is more Ti-rich (~18 wt% TiO<sub>2</sub>) and are also V-bearing (1.4 – 3.4 wt.% V).

**Table 11.** Representative magnetite major element compositions

| Sample                      | 220621-6   | 220622-1   | 220621-5          | 220621-5          | 119-05            | 119-05            | 220620-3   | 220620-4          | 220620-4          | YAM002            |
|-----------------------------|------------|------------|-------------------|-------------------|-------------------|-------------------|------------|-------------------|-------------------|-------------------|
| Type                        | phenocryst | phenocryst | phenocryst        | inclusion in Ol   | phenocryst        | Inclusion in Ol   | phenocryst | phenocryst        | inclusion         | phenocryst        |
| Lithology                   | andesite   | andesite   | basaltic andesite | basaltic andesite | basaltic andesite | basaltic andesite | basalt     | basaltic andesite | basaltic andesite | basaltic andesite |
| Group                       | HK-A       | HK-A       | HK-BA             | HK-BA             | HK-BA             | HK-BA             | HKWest-BBA | HKWest-BBA        | HKWest-BBA        | YAM-BA            |
| #grains <sup>a</sup>        | <u>2</u>   | <u>2</u>   | <u>2</u>          | <u>1</u>          | <u>1</u>          | <u>2</u>          | <u>1</u>   | <u>4</u>          | <u>5</u>          | <u>3</u>          |
| FeOb wt%                    | 39.21      | 39.18      | 36.91             | 30.56             | 37.2              | 30.79             | 45.60      | 44.97             | 38.55             | 40.96             |
| Fe2O3 b                     | 45.65      | 46.66      | 48.76             | 49.95             | 48.75             | 53.1              | 32.39      | 31.91             | 40.17             | 41.90             |
| TiO2                        | 10.84      | 10.48      | 9.39              | 4.50              | 9.64              | 4.28              | 17.90      | 17.89             | 12.59             | 9.13              |
| MgO                         | 1.50       | 1.30       | 2.11              | 3.73              | 2.34              | 3.78              | 1.52       | 1.70              | 3.06              | 0.02              |
| MnO                         | 0.41       | 0.44       | 0.40              | 0.28              | 0.4               | 0.27              | 0.47       | 0.50              | 0.41              | 0.03              |
| Cr2O3                       | 0.08       | 0.10       | 0.05              | 2.40              | 0.4               | 1.58              | 0.13       | 0.05              | 0.18              | 0.25              |
| V2O3                        | 0.68       | 0.71       | 0.69              | 0.66              | 0.02              | 0.7               | 1.03       | 0.94              | 0.97              | 0.77              |
| Al2O3                       | 2.63       | 2.31       | 2.63              | 7.69              | 2.88              | 7.11              | 2.16       | 2.11              | 3.84              | 3.30              |
| SiO2                        | 0.08       | 0.07       | 0.05              | 0.07              | 0.07              | 0.1               | 0.09       | 0.11              | 0.22              | 1.48              |
| Total                       | 101.07     | 101.26     | 100.98            | 99.84             | 101.70            | 101.71            | 101.29     | 100.18            | 99.99             | 97.83             |
| Mineral Formula based on 4O |            |            |                   |                   |                   |                   |            |                   |                   |                   |
| Si                          | 0.003      | 0.002      | 0.002             | 0.003             | 0.003             | 0.003             | 0.003      | 0.004             | 0.008             | 0.057             |
| Ti                          | 0.301      | 0.292      | 0.261             | 0.122             | 0.264             | 0.114             | 0.496      | 0.500             | 0.350             | 0.263             |
| Al                          | 0.115      | 0.101      | 0.114             | 0.326             | 0.124             | 0.297             | 0.094      | 0.092             | 0.167             | 0.149             |
| Cr                          | 0.002      | 0.000      | 0.001             | 0.068             | 0.000             | 0.044             | 0.004      | 0.001             | 0.005             | 0.007             |
| Fe <sup>3+</sup>            | 1.274      | 1.307      | 1.359             | 1.357             | 1.342             | 1.423             | 0.903      | 0.898             | 1.112             | 1.208             |
| Fe <sup>2+</sup>            | 1.209      | 1.209      | 1.134             | 0.916             | 1.127             | 0.910             | 1.401      | 1.394             | 1.176             | 1.312             |
| Mn                          | 0.013      | 0.014      | 0.012             | 0.009             | 0.012             | 0.008             | 0.015      | 0.016             | 0.013             | 0.001             |
| Mg                          | 0.083      | 0.072      | 0.116             | 0.200             | 0.127             | 0.200             | 0.084      | 0.095             | 0.169             | 0.001             |
| total                       | 3.000      | 2.997      | 2.999             | 3.001             | 2.999             | 2.999             | 3.000      | 3.000             | 3.000             | 2.998             |

#grains<sup>a</sup> = number of grains used to obtain average major element composition of magnetite determined by EPMA. The composition of each grain was determined by 2 – 5 analyses. Magnetite major element compositions and detection limits are in Appendix 4.3.

b = Ferrous and ferric Fe contents, calculated based on stoichiometry.



## 5.5 Mineral Thermobarometry

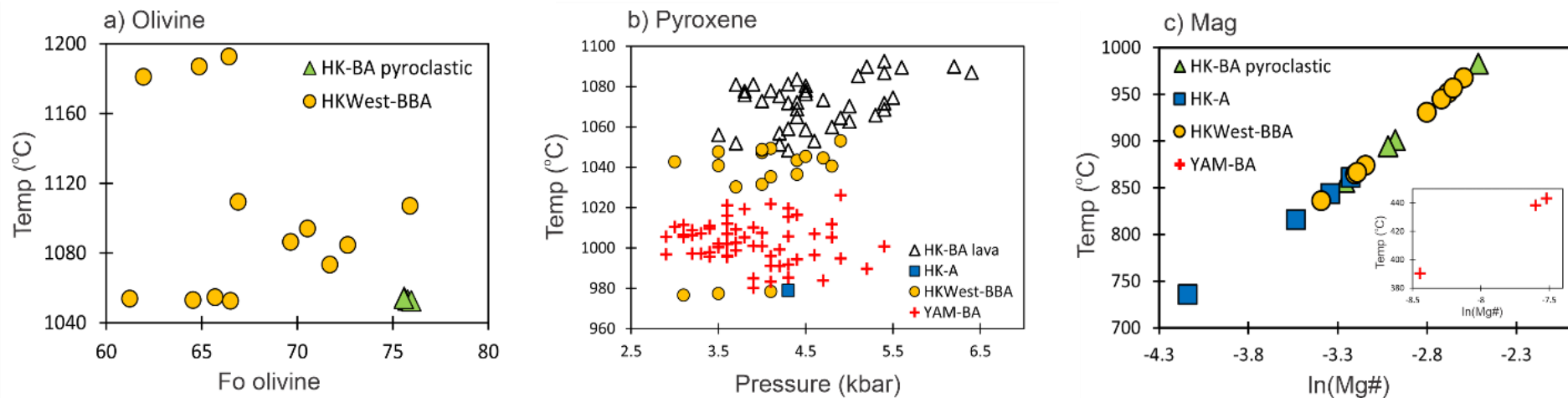
The olivine equilibrium temperatures were evaluated using the Mg-based geothermometer of Pu et al., (2017), which suggests an error of  $\pm 50^\circ\text{C}$ . The thermometer is based on the experimental and empirical data of olivine containing NiO above 0.1 wt% and melt with high MgO. Since all olivine grains in our samples contain less than 0.1 wt% NiO (0.01 to 0.06 wt% NiO, Table 12), The extrapolation of the thermometry likely gives larger uncertainty. Olivine from Hishikari basaltic andesite (HK-BA) yielded equilibrium temperatures of approximately  $1055^\circ\text{C}$  for the pyroclastic unit. Olivine from basalt and basaltic andesite west of Hishikari mine (HKWest-BBA) yielded temperatures ranging from  $1166^\circ\text{C}$  to  $1200^\circ\text{C}$  for basalts and  $1075^\circ\text{C}$  to  $1110^\circ\text{C}$  for basaltic andesites.

Pyroxene equilibrium temperatures and pressures were evaluated using the empirical equations of Purтика (2008) which has an error of  $\pm 45 - 55^\circ\text{C}$  for temperature and  $\pm 2.8\text{kbar}$  for pressure. Since many of the observed pyroxenes exhibit various zoning textures (oscillatory, reverse, normal and homogenous), pairs for the calculation were carefully selected based on their proximity and texture. For example, the calculation used a pair between an Mg-rich Cpx rim and homogenous Opx. To assess whether the coexisting Opx and Cpx were in equilibrium, the Fe-Mg exchange coefficient between Opx and Cpx ( $K_D^{Fe^{2+}-Mg} = \frac{(Fe^{2+}/Mg)_{Opx}}{(Fe^{2+}/Mg)_{Cpx}}$ ) was calculated following the approach of Purтика (2008). At equilibrium, this coefficient is  $1.09 \pm 0.14$  where Opx and Cpx pairs used for the calculation yielded values within this range. The results are listed in Table 14.

In Hishikari basaltic andesite, two-pyx thermobarometry yielded temperatures ranging from  $1050^\circ\text{C}$  to  $1110^\circ\text{C}$  and pressures ranging from 3.5kbar to 6.4kbar for the lava. Hishikari andesite (HK-A) yielded  $\sim 1000^\circ\text{C}$  and 4.3kbar. Basalt and basaltic andesite west of Hishikari mine (HKWest-BBA) yielded temperatures ranging from  $975^\circ\text{C}$  to  $1050^\circ\text{C}$  and pressures ranging from 3kbar to 5kbar. Yamagano basaltic andesite (YAM-BA) yielded  $980^\circ\text{C}$  to  $1030^\circ\text{C}$  for temperature and 1.8 to 5.4 kbar for pressure.

Magnetite crystallization temperatures were evaluated based on Mg# ( $\text{Mg\#} = \text{Mg} / (\text{Mg} + \text{Fe}^{\text{tot}})$ ) of magnetite using the empirical equations of Canil and Lacourse (2020) which has an error of  $\pm 50^\circ\text{C}$ . Hishikari basaltic andesite (HK-BA) yielded temperatures ranging from  $\sim 850^\circ\text{C}$  to  $1000^\circ\text{C}$  for the pyroclastic unit. Hishikari andesite (HK-A) yielded temperatures ranging from

~730°C to 860°C. Basalt and basaltic andesite west of Hishikari mine (HKWest-BBA) yielded ~850°C for the basalt and 835°C to 970°C for the basaltic andesite. Yamagano basaltic andesite (YAM-BA) yielded unrealistically low temperatures, 390°C to 443°C. These magnetite grains contain very low MgO (<0.02 wt%, Table 13). The empirical relationship between MgO and temperatures by Canil and Lacourse (2020) show a large scatter at temperatures below 800°C, suggesting that low Mg magnetite does not yield reliable temperatures. Therefore, the calculated values for magnetite in YAM-BA was not considered to be the crystallization temperatures of magnetite



**Figure 23.** a) Olivine equilibrium temperatures ( $\pm 50^{\circ}\text{C}$ ) using the Mg-based thermometer of Pu et al. (2017). Each point represents a single olivine grain. Temperatures were calculated using the average composition of each olivine grain determined by EPMA. Each grain had  $>3$  analysis. b) Two-Pyx equilibrium temperatures after Purтика (2008) of chemically equilibrium pyroxenes. Since many of the observed pyroxenes exhibit various zoning textures (oscillatory, reverse, normal and homogenous), each point represents an equilibrium pair between a homogenous part of a pyroxene. For example, one point may represent a pair between an Mg rich Cpx rim and homogenous Opx. Error on temperature is  $\pm 45\text{--}55^{\circ}\text{C}$  and  $\pm 2.8$  kbar for pressure (Purtika, 2008). c) Magnetite equilibrium temperatures from each group based on Mg# using the empirical equations of Canil and Lacourse (2020). Each point represents the temperature calculated from a single magnetite grain as a microphenocryst or mineral inclusion. Each grain/inclusion included  $>2$  analyses by EPMA. Error on temperature is  $\pm 50^{\circ}\text{C}$  (Canil and Lacourse, 2020).  $\text{Mg\#} = \text{Mg}/(\text{Mg} + \text{Fe}^{\text{tot}})$ .

**Table 12.** Olivine crystallization temperatures ( $\pm 50^{\circ}\text{C}$ ) using the Mg-based thermometer of Pu et al. (2017). Since our olivine contains less than 0.1 wt% NiO, the extrapolated calculation gives the temperatures with larger uncertainty. Each entry represents the composition of one olivine grain determined by EPMA.

| Group             | Sample   | Lithology         | T <sub>Mg</sub> (°C) | Fo | NiO (wt%) |
|-------------------|----------|-------------------|----------------------|----|-----------|
| HK-BA pyroclastic | 220621-5 | basaltic andesite | 1053                 | 76 | 0.05      |
|                   | 220621-5 | basaltic andesite | 1055                 | 76 | 0.05      |
|                   | 220621-5 | basaltic andesite | 1053                 | 76 | 0.04      |
|                   | 220621-5 | basaltic andesite | 1054                 | 76 | 0.06      |
| HKWest-BBA        | 220620-3 | basalt            | 1193                 | 65 | 0.02      |
|                   | 220620-3 | basalt            | 1187                 | 66 | 0.02      |
|                   | 220620-3 | basalt            | 1181                 | 66 | 0.03      |
|                   | 220620-4 | basaltic andesite | 1109                 | 61 | 0.02      |
|                   | 220620-4 | basaltic andesite | 1086                 | 66 | 0.02      |
|                   | 220620-4 | basaltic andesite | 1094                 | 65 | 0.02      |
|                   | 220620-4 | basaltic andesite | 1107                 | 62 | 0.02      |
|                   | 220620-4 | basaltic andesite | 1085                 | 67 | 0.02      |
|                   | 220620-4 | basaltic andesite | 1073                 | 70 | 0.02      |
|                   | 220620-1 | basaltic andesite | 1193                 | 71 | 0.04      |
|                   | 220620-1 | basaltic andesite | 1166                 | 76 | 0.04      |
|                   | 220620-1 | basaltic andesite | 1181                 | 73 | 0.04      |
|                   | 220620-1 | basaltic andesite | 1185                 | 72 | 0.03      |

**Table 13.** Magnetite equilibrium temperatures based on Mg# using the empirical equations of Canil and Lacourse (2020). Each entry represents a single magnetite phenocryst or inclusion. Error on temperature is  $\pm 50^{\circ}\text{C}$ .

| Group             | SAMPLE   | Lithology         | Type                  | TMg-Mag (C) | MgO (wt%) |
|-------------------|----------|-------------------|-----------------------|-------------|-----------|
| YAM-BA            | YAM002   | basaltic andesite | phenocryst            | 438         | 0.02      |
|                   | YAM002   | basaltic andesite | phenocryst            | 390         | 0.001     |
|                   | YAM002   | basaltic andesite | phenocryst            | 443         | 0.02      |
| HK-A              | 220621-6 | andesite          | phenocryst            | 816         | 1.35      |
|                   | 220621-6 | andesite          | phenocryst            | 844         | 1.65      |
|                   | 220622-1 | andesite          | phenocryst            | 861         | 1.86      |
|                   | 220622-1 | andesite          | phenocryst            | 736         | 0.74      |
| HKWest-BBA        | 220620-4 | basaltic andesite | phenocryst            | 836         | 1.43      |
|                   | 220620-4 | basaltic andesite | phenocryst            | 874         | 1.85      |
|                   | 220620-4 | basaltic andesite | phenocryst            | 865         | 1.76      |
|                   | 220620-4 | basaltic andesite | phenocryst            | 867         | 1.78      |
|                   | 220620-4 | basaltic andesite | inclusion in olivine  | 952         | 3.11      |
|                   | 220620-4 | basaltic andesite | inclusion in olivine  | 968         | 3.42      |
|                   | 220620-4 | basaltic andesite | inclusion in olivine  | 931         | 2.69      |
|                   | 220620-4 | basaltic andesite | inclusion in olivine  | 945         | 2.91      |
|                   | 220620-4 | basaltic andesite | inclusion in olivine  | 957         | 3.16      |
|                   | 220320-3 | basalt            | phenocryst            | 842         | 1.52      |
| HK-BA pyroclastic | 220621-5 | basaltic andesite | inclusions in olivine | 983         | 3.73      |
|                   | 220621-5 | basaltic andesite | phenocryst            | 901         | 2.39      |
|                   | 220621-5 | basaltic andesite | phenocryst            | 856         | 1.83      |
|                   | 119-05   | basaltic andesite | phenocryst            | 894         | 2.33      |

**Table 14.** Two-Pyx equilibrium temperatures after Purтика (2008). Each line represents a Opx and Cpx pair that is chemically in equilibrium. Equilibrium was evaluated by calculating the Fe-Mg exchange coefficient between Opx and Cpx. Opx and Cpx pairs that yielded a value of  $1.09 \pm 0.14$  were used for the calculation. Error on temperature is  $\pm 45\text{-}55^\circ\text{C}$  and  $\pm 2.8$  kbar for pressure (Purтика, 2008).

| Group  | Sample | Lithology         | T ( $^\circ\text{C}$ ) | kbar |
|--------|--------|-------------------|------------------------|------|
| YAM-BA | YAM002 | basaltic andesite | 1008                   | 4    |
|        | YAM002 | basaltic andesite | 1005                   | 3.8  |
|        | YAM002 | basaltic andesite | 1007                   | 3.6  |
|        | YAM002 | basaltic andesite | 1003                   | 3.7  |
|        | YAM002 | basaltic andesite | 1008                   | 2.3  |
|        | YAM002 | basaltic andesite | 1006                   | 4.3  |
|        | YAM002 | basaltic andesite | 1012                   | 4.8  |
|        | YAM002 | basaltic andesite | 1002                   | 3.6  |
|        | YAM002 | basaltic andesite | 1002                   | 3.5  |
|        | YAM002 | basaltic andesite | 1003                   | 3.7  |
|        | YAM002 | basaltic andesite | 1000                   | 3.5  |
|        | YAM002 | basaltic andesite | 998                    | 3.4  |
|        | YAM002 | basaltic andesite | 1003                   | 2    |
|        | YAM002 | basaltic andesite | 1001                   | 4    |
|        | YAM002 | basaltic andesite | 1007                   | 4.6  |
|        | YAM002 | basaltic andesite | 997                    | 3.3  |
|        | YAM002 | basaltic andesite | 997                    | 3.2  |
|        | YAM002 | basaltic andesite | 1022                   | 4.1  |
|        | YAM002 | basaltic andesite | 1019                   | 3.8  |
|        | YAM002 | basaltic andesite | 1021                   | 3.6  |
|        | YAM002 | basaltic andesite | 1020                   | 4.3  |
|        | YAM002 | basaltic andesite | 1026                   | 4.9  |
|        | YAM002 | basaltic andesite | 1016                   | 3.6  |
|        | YAM002 | basaltic andesite | 1001                   | 3.9  |
|        | YAM002 | basaltic andesite | 999                    | 3.7  |
|        | YAM002 | basaltic andesite | 1001                   | 3.5  |
|        | YAM002 | basaltic andesite | 996                    | 3.6  |
|        | YAM002 | basaltic andesite | 1001                   | 2.2  |
|        | YAM002 | basaltic andesite | 999                    | 4.2  |
|        | YAM002 | basaltic andesite | 1005                   | 4.8  |
|        | YAM002 | basaltic andesite | 996                    | 3.6  |
|        | YAM002 | basaltic andesite | 996                    | 3.4  |
|        | YAM002 | basaltic andesite | 997                    | 4.6  |
|        | YAM002 | basaltic andesite | 994                    | 4.4  |
|        | YAM002 | basaltic andesite | 996                    | 4.1  |
|        | YAM002 | basaltic andesite | 992                    | 4.3  |
|        | YAM002 | basaltic andesite | 997                    | 2.9  |
|        | YAM002 | basaltic andesite | 995                    | 4.9  |
|        | YAM002 | basaltic andesite | 1001                   | 5.4  |
|        | YAM002 | basaltic andesite | 991                    | 4.2  |
|        | YAM002 | basaltic andesite | 991                    | 4.1  |
|        | YAM002 | basaltic andesite | 985                    | 4.3  |
|        | YAM002 | basaltic andesite | 983                    | 4.1  |
|        | YAM002 | basaltic andesite | 985                    | 3.9  |
|        | YAM002 | basaltic andesite | 984                    | 4.7  |
|        | YAM002 | basaltic andesite | 990                    | 5.2  |
|        | YAM002 | basaltic andesite | 980                    | 3.9  |
|        | YAM002 | basaltic andesite | 1011                   | 3.4  |
|        | YAM002 | basaltic andesite | 1009                   | 3.2  |
|        | YAM002 | basaltic andesite | 1011                   | 3    |
|        | YAM002 | basaltic andesite | 1006                   | 3.1  |
|        | YAM002 | basaltic andesite | 1012                   | 1.8  |
|        | YAM002 | basaltic andesite | 1009                   | 3.7  |
|        | YAM002 | basaltic andesite | 1015                   | 4.3  |
|        | YAM002 | basaltic andesite | 1006                   | 3.1  |
|        | YAM002 | basaltic andesite | 1006                   | 2.9  |
|        | YAM002 | basaltic andesite | 1012                   | 3.6  |
|        | YAM002 | basaltic andesite | 1010                   | 3.4  |
|        | YAM002 | basaltic andesite | 1012                   | 3.1  |
|        | YAM002 | basaltic andesite | 1007                   | 3.3  |

|            |          |                   |      |     |
|------------|----------|-------------------|------|-----|
|            | YAM002   | basaltic andesite | 1013 | 1.9 |
|            | YAM002   | basaltic andesite | 1010 | 3.9 |
|            | YAM002   | basaltic andesite | 1016 | 4.4 |
|            | YAM002   | basaltic andesite | 1006 | 3.2 |
|            | YAM002   | basaltic andesite | 1007 | 3.1 |
| HK-A       | 220621-6 | andesite          | 979  | 4.3 |
| HK-BA lava | 220623-1 | basaltic andesite | 1059 | 4.3 |
|            | 220623-1 | basaltic andesite | 1069 | 5.4 |
|            | 220623-1 | basaltic andesite | 1049 | 4.3 |
|            | 220623-1 | basaltic andesite | 1056 | 3.5 |
|            | 220623-1 | basaltic andesite | 1066 | 5.3 |
|            | 220623-1 | basaltic andesite | 1053 | 4.6 |
|            | 220623-1 | basaltic andesite | 1052 | 3.7 |
|            | 220623-1 | basaltic andesite | 1057 | 4.2 |
|            | 220623-1 | basaltic andesite | 1051 | 4.2 |
|            | 220623-1 | basaltic andesite | 1065 | 4.9 |
|            | 220623-1 | basaltic andesite | 1080 | 4.5 |
|            | 220623-1 | basaltic andesite | 1087 | 6.4 |
|            | 220623-1 | basaltic andesite | 1090 | 5.6 |
|            | 220623-1 | basaltic andesite | 1069 | 4.4 |
|            | 220623-1 | basaltic andesite | 1078 | 3.8 |
|            | 220623-1 | basaltic andesite | 1087 | 5.4 |
|            | 220623-1 | basaltic andesite | 1073 | 4.7 |
|            | 220623-1 | basaltic andesite | 1078 | 4.1 |
|            | 220623-1 | basaltic andesite | 1073 | 4   |
|            | 220623-1 | basaltic andesite | 1078 | 4.5 |
|            | 220623-1 | basaltic andesite | 1072 | 4.4 |
|            | 220623-1 | basaltic andesite | 1085 | 5.1 |
|            | 220623-1 | basaltic andesite | 1063 | 5   |
|            | 220623-1 | basaltic andesite | 1060 | 4.8 |
|            | 220623-1 | basaltic andesite | 1059 | 4.5 |
|            | 220623-1 | basaltic andesite | 1065 | 4.4 |
|            | 220623-1 | basaltic andesite | 1075 | 5.5 |
|            | 220623-1 | basaltic andesite | 1072 | 5.4 |
|            | 220623-1 | basaltic andesite | 1070 | 5   |
|            | 220623-1 | basaltic andesite | 1084 | 4.4 |
|            | 220623-1 | basaltic andesite | 1090 | 6.2 |
|            | 220623-1 | basaltic andesite | 1093 | 5.4 |
|            | 220623-1 | basaltic andesite | 1072 | 4.3 |
|            | 220623-1 | basaltic andesite | 1081 | 3.7 |
|            | 220623-1 | basaltic andesite | 1090 | 5.2 |
|            | 220623-1 | basaltic andesite | 1076 | 4.5 |
|            | 220623-1 | basaltic andesite | 1081 | 3.9 |
|            | 220623-1 | basaltic andesite | 1076 | 3.8 |
|            | 220623-1 | basaltic andesite | 1081 | 4.3 |
|            | 220623-1 | basaltic andesite | 1075 | 4.2 |
| HKWest-BBA | 220620-1 | basalt            | 1047 | 4   |
|            | 220620-1 | basalt            | 1043 | 3   |
|            | 220620-1 | basalt            | 1049 | 4.1 |
|            | 220620-1 | basalt            | 1053 | 4.9 |
|            | 220620-1 | basalt            | 1049 | 4   |
|            | 220620-1 | basalt            | 1045 | 4.5 |
|            | 220620-1 | basalt            | 1041 | 3.5 |
|            | 220620-1 | basalt            | 1049 | 4   |
|            | 220620-1 | basalt            | 1048 | 3.5 |
|            | 220620-1 | basalt            | 978  | 4.1 |
|            | 220620-1 | basalt            | 977  | 3.5 |
|            | 220620-1 | basalt            | 977  | 3.1 |
|            | 220620-3 | basalt            | 1030 | 3.7 |
|            | 220620-3 | basalt            | 1032 | 4   |
|            | 220620-3 | basalt            | 1043 | 4.4 |
|            | 220620-3 | basalt            | 1045 | 4.7 |
|            | 220620-3 | basalt            | 1041 | 4.8 |
|            | 220620-3 | basalt            | 1035 | 4.1 |
|            | 220620-3 | basalt            | 1037 | 4.4 |

## Chapter 6: Discussion

### 6.1 Olivine as a Phenocryst

Two groups of rocks contain olivine: HK-BA and HKWest-BBA. Olivine in HK-BA (Fo77) is homogenous and occurs in the pyroclastic basaltic andesites (3.3wt% MgO bulk rock). Olivine in the HKWest-BBA (Fo ~ 76 - 64) is normally zoned and occurs in both the basalts (5 – 5.7wt% MgO bulk rock) and basaltic andesites (2.7 – 3.4wt% MgO bulk rock). Olivine in both localities contain high Mn (2000-3500 ppm) and Ca (600-1025ppm) and low Ni (<600ppm) which are different from mantle olivine that are characterized by ~1000ppm Mn, low Ca (<700ppm) and 2200 – 3400ppm Ni (De Hoog et al., 2010). Furthermore, low Ni/Co (~ 1.3) and Ni/Mn (~ 0.1) in olivine may suggest olivine as a phenocryst because mantle olivine shows high ratios of Ni/Co (>20) and Ni/Mn (>2) (Wang et al. 2021).

Using the olivine liquid exchange coefficient ( $K_{D_{Ol-Liq}}^{Mg-Fe} = \frac{x_{Liq}^{Mg} / x_{Ol}^{Mg}}{x_{Liq}^{Fe^{2+}} / x_{Ol}^{Fe^{2+}}} = 0.3$ ) by Toplis (2005), the melt in equilibrium with olivine (Fo77) in the HK-BA is calculated to have a  $Fe^{2+}/Mg$  ratio of 1.0. The  $Fe^{2+}/Mg$  ratio of the bulk rock composition is 1.1, assuming 90% of Fe is  $Fe^{2+}$ . The similar  $Fe^{2+}/Mg$  ratios of the olivine equilibrium melt, and the bulk rock suggest the olivine was in equilibrium with the melt during the early solidification of the HK-BA. In contrast, olivine in HKWest-BBA exhibit normal zoning, where the  $Fe^{2+}/Mg$  ratios of olivine increase from 0.7 in the cores to 1.6 in the rim. The  $Fe^{2+}/Mg$  ratio of the melt in equilibrium with the most Mg-rich olivine core (Fo76, sample 220620-1) is 0.95. The corresponding bulk rock composition has a lower  $Fe^{2+}/Mg$  ratio of 0.8, suggesting that olivine formed in a more evolved composition than the bulk rock. The  $Fe^{2+}/Mg$  ratio of the olivine equilibrium melt represents the composition of the melt at the time olivine was crystallizing, whereas the  $Fe^{2+}/Mg$  ratio of the bulk rock composition reflects the overall magma composition, including both the melt and crystallized minerals. As discussed in chapter 6.6, decreasing Sc content with decreasing Ni in Cpx possibly suggest early crystallization of Cpx. It is possible that the crystallization of clinopyroxene before olivine resulted in the olivine equilibrium melt recording a more evolved composition than the bulk rock.

## 6.2 Olivine-bearing Basaltic Andesite

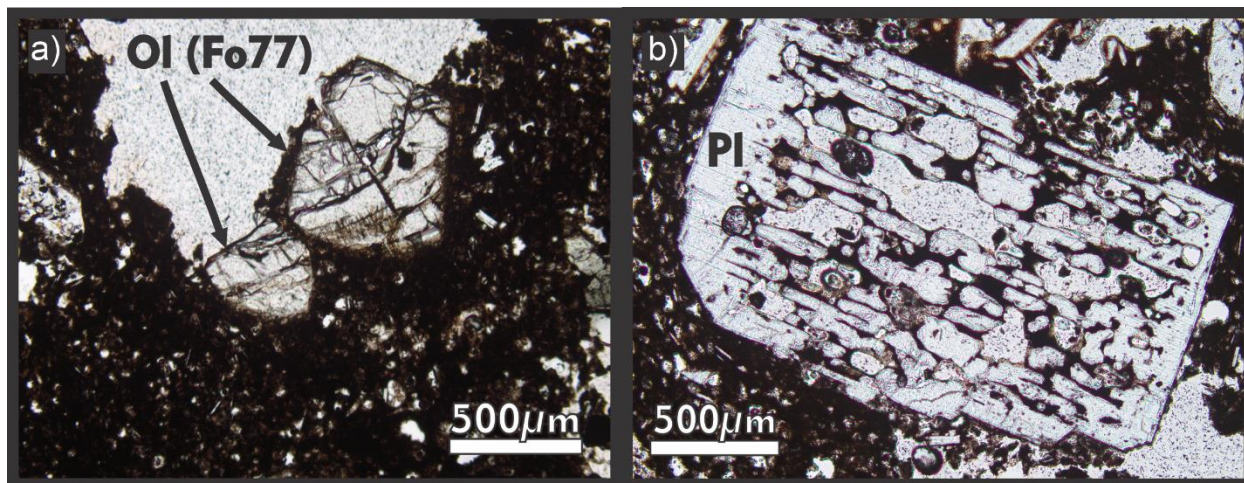
Olivine phenocrysts occur in both basalt and basaltic andesite samples collected west of Hishikari (HKWest-BBA) and show distinct compositional differences between the two. Olivine in the basalts displays a higher forsterite content (Fo 68 - 78) and elevated Ni concentrations (267 - 623 ppm) than the olivine within basaltic andesites (~Fo63, with 177 ppm Ni). Additionally, olivine in the basalts exhibits lower Ca (882 – 1200 ppm) and Mn (2090 – 3070 ppm) concentrations than that in the basaltic andesites (which contain up to 1470 ppm Ca and 4260 ppm Mn). Furthermore, olivine phenocrysts in the basalts occur in higher abundances (~10 vol%) than the basaltic andesites (5–10 vol%). Olivine also displays a systematic decrease in Mg# and Ni content from basalt to basaltic andesite (Fig. 14). These compositional differences, in addition to normal zoning in olivine, suggest that olivine in the basaltic andesites formed by the crystallization of olivine from basalt that stayed in equilibrium with the surrounding evolving magma.

In the Hishikari mine area, mafic rocks consist primarily of basaltic andesite pyroclastics and lavas (HK-BA). The lavas contain no olivine and exhibit a more mafic bulk rock composition (MgO = 7.3 wt%; Ni = 62ppm bulk rock) than the pyroclastics (MgO = 3.2 wt%; Ni = 13ppm bulk rock) which contain coarse olivine phenocrysts (Fo77, up to 2 mm). The basaltic andesite lava (sample 220623-1) is slightly altered where some alteration phases may have been olivine. It is also possible that olivine reacted with the melt to form Opx. However, no texture suggesting the transformation of Ol to Opx is observed in the basaltic andesite lava. It is also possible an injection of mafic magma may have resulted in high MgO bulk rock content. However, there is a lack of evidence for this such as Ca-rich rims on plagioclase. Additionally, pyroxene in the basaltic andesite lava contains elevated Ni concentrations (113 – 211ppm) compared to the pyroclastics (62 – 121ppm), suggesting early crystallization of Cpx. It is possible that pyroxenes in the basaltic andesite lava were incorporated from an earlier magma, explaining the different textures and compositions (oscillatory, normal and patchy zoning) in the sample. The reason for the lack of olivine in the basaltic andesite lava with a more mafic composition than the olivine-bearing pyroclastics remains unclear.

The olivine-bearing basaltic andesite pyroclastic rocks exhibits a vesicular texture (Fig 24.a) and coarsely sieved plagioclase (Fig 24.b) which are consistent with rapid decompression during magma ascent (Nelson, 1992). Furthermore, clinopyroxene Ni concentrations do not



systematically change with decreasing Mg# values (Fig. 21), suggesting that the magma for the pyroclastic rocks quickly solidified before further fractional crystallization. The rapid ascent likely preserved olivine, preventing resorption or reaction with the surrounding melt. This is evidenced by coarse euhedral olivine crystals with sharp boundaries with no reaction rims (Figs 7c and 24a) that show no compositional zoning. Similar cases of olivine preservation in basaltic andesites due to rapid ascent and quenching have been observed in the Pelagatos scoria cone (Guilbaud, 2009).



**Figure 24.** a) Euhedral olivine with sharp boundaries and vesicular groundmass (sample 220621-5) and b) heavily sieved plagioclase in Ol-bearing pyroclastic basaltic andesite (sample 220621-5).

### 6.3 Calc-alkaline vs Tholeiitic Evolution of Samples

All samples from the Hishikari mine area (HK-BA, HK-A, and HK-FEL) and Yamagano mine area (YAM-BA) plot in the calc-alkaline field whereas the samples collected west of Hishikari mine (HKWest-BBA) plot in the tholeiitic field on the  $\text{SiO}_2$  vs  $\text{FeO}^*/\text{MgO}$  diagram (Fig. 11) following the classification of Miyashiro (1974). However, all samples plot within the calc-alkaline field on the AFM diagram (Fig. 12) following the classification of Irvine and Baragar (1971) and on the Jensen cation diagram (Fig. 13).

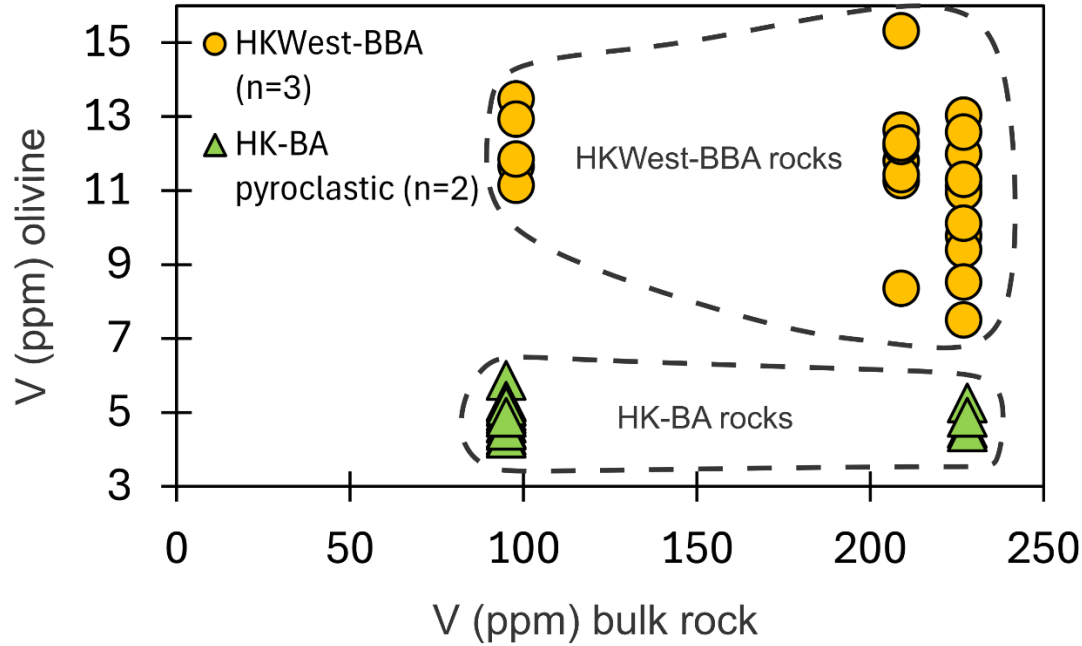
On the  $\text{SiO}_2$  vs  $\text{FeO}^*/\text{MgO}$  diagram (Fig. 11), all rocks show Fe enrichment where HKWest-BBA shows a stronger tholeiitic character ( $\text{THI} = 0.81$  (THI is discussed in chapter 5.1.2 and the calculation is in Appendix 4.1)) and contains higher  $\text{Al}_2\text{O}_3$  contents ( $<19.5\text{wt}\%$   $\text{Al}_2\text{O}_3$  bulk rock (Fig. 9) than samples collected in the Hishikari mine area ( $\text{THI} = 0.66$ ,  $<17.8\text{wt}\%$   $\text{Al}_2\text{O}_3$  bulk rock (Fig. 9)). However, as described in chapter 6.6, the mineral chemistry of HK-BA and

HKWest-BBA suggests early crystallization of magnetite and the late crystallization of plagioclase which is consistent with calc-alkaline magmas rather than tholeiitic.

### 6.3.1 Oxidation Conditions of Parental Magmas

Mineral chemistry can reflect the oxidation state of the parental magmas. For instance, V and Ti can exist in multiple oxidation states depending on the magma's oxygen fugacity. This variability influences how these elements partition between minerals and the melt, Vanadium content in olivine differs between HK-BA and HKWest-BBA at a given bulk rock V content (Fig. 25). Olivine in HKWest-BBA contains higher vanadium (8.35 – 15.3 ppm) than olivine from HK-BA (4.3 – 5.64 ppm V). Vanadium forms  $V^{3+}$  and  $V^{5+}$ , where  $V^{5+}$  is less compatible to minerals (Canil, 2002). Therefore, the higher V content in olivine from HKWest-BBA suggests that these magmas were less oxidized compared to the magmas for HK-BA, considering similar bulk rock V contents between the HKWest-BBA (95 - 227 ppm V bulk rock) and the olivine bearing rocks of HK-BA (95 - 228 ppm V bulk rock) (Fig. 25).

Magnetite in the HKWest-BBA contain higher  $TiO_2$  (~18wt%) than magnetite in HK-BA (~9 - 11 wt%). The experiments of a Fe-Ti-rich melt by Shepherd et al. (2022) show that  $TiO_2$  content increases in magnetite with decreasing oxygen fugacity. The higher  $TiO_2$  content in magnetite in HKWest-BBA than those in HK-BA suggests that the former crystallized from less oxidized magmas, considering that the two parental magmas contain similar  $TiO_2$  contents, ~0.97 and 0.67 wt%  $TiO_2$  bulk rock, respectively. Additionally, HKWest-BBA contain a lower abundance of Fe-Ti oxides (<5 vol.%) compared to HK-BA (<10 vol.%), reinforcing the different oxygen fugacity between the two (Table. 5). Moreover, the V/Sc ratios of the most Mg-rich samples from HKWest-BBA and HK BA are compared. The V/Sc ratio of the most Mg-rich sample (sample 220620-1, 5.68wt% MgO) is 7.83 which is significantly higher than the V/Sc ratio of the most Mg-rich HK-BA sample (sample 220623-1, 7.27wt% MgO; V/Sc = 3.17). Thus, the higher V/Sc ratios in the HKWest-BBA suggests that parental magmas were under lower  $fO_2$  conditions than those for HK-BA.



**Figure 25.** Olivine V contents (ppm) vs. bulk rock V content (ppm). Note that only Ol-bearing rocks are shown. The orange circle points represent the HKWest-BBA and green triangle points represent HK-BA. n = number of samples from which several olivine grains were analyzed. Each data point represents an analysis of a single olivine grain based on V contents determined by LA-ICP-MS and their corresponding V bulk rock content determined by XRF.

Cpx in HK-BA exhibit weak Eu anomalies ( $\text{Eu}/\text{Eu}^* = 0.74 - 1.1$  for the pyroclastic unit and  $0.64 - 0.88$  for the lava). Similarly, HKWest-BBA also exhibit weak Cpx Eu anomalies ( $\text{Eu}/\text{Eu}^* = 0.75 - 1.1$ ). Since both  $\text{Sr}^{2+}$  and  $\text{Eu}^{2+}$  strongly partition into plagioclase, a correlation between Sr and Eu anomalies would be expected during plagioclase crystallization. However, in our samples, Eu anomalies remain relatively unchanged with decreasing Sr contents in Cpx (Fig. 22). This suggests that Eu was predominately present as  $\text{Eu}^{3+}$  in the melt, suggesting that the parental magmas for HK-BA and HKWest-BBA were relatively oxidized to contain high  $\text{Eu}^{3+}/\text{Eu}$ .

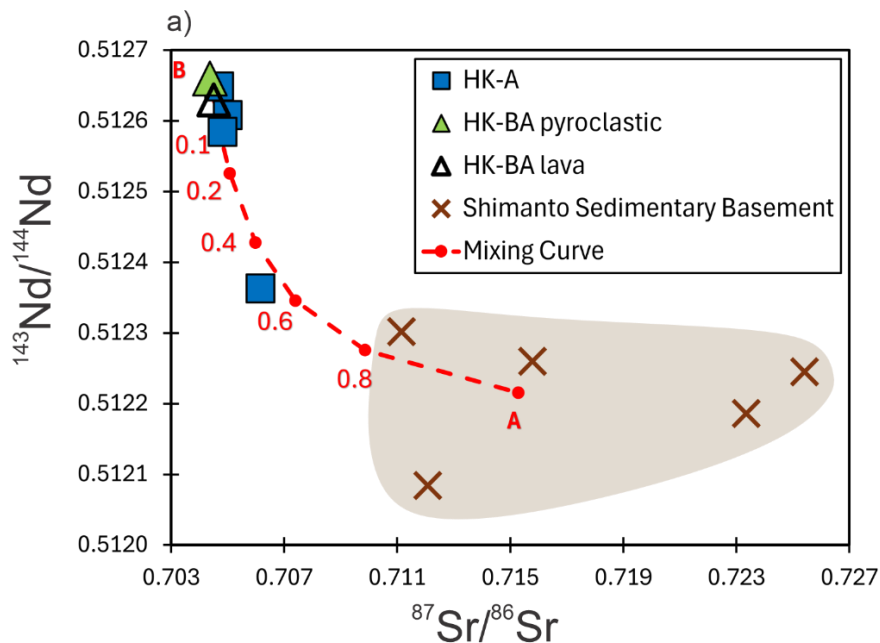
## 6.4 Hishikari Lower Andesite: Magma Sources

The basement underlying the Hishikari Lower Andesites is thick ( $> 20$  km, Iwasaki et al., 1990) and consists of metasedimentary rocks of the Shimanto Supergroup. Partial melting of sedimentary rocks cannot produce mafic magmas. Therefore, the parental magmas of the Hishikari Lower Andesites originated from the mantle. The rocks exhibit high bulk rock LILE/HFSE weight ratios (Figs. 14 and 15), suggesting that the mantle source was enriched in fluid-mobile elements before partial melting.

The Hishikari basaltic andesites (HK-BA) may have formed by fractional crystallization of a basaltic melt or by assimilation of Si-rich rocks or Si-rich melt into a primitive basaltic magma. The Hishikari andesites (HK-A) may be explained by the fractional crystallization of the basaltic andesites based on major element variation diagrams (Fig. 9). However, Sr-Nd isotopic data reveal deviations between the two groups: the andesites show slightly elevated  $^{87}\text{Sr}/^{86}\text{Sr}$  and lower  $^{143}\text{Nd}/^{144}\text{Nd}$  compared to the basaltic andesites (Fig. 16). The differences could be interpreted as various assimilation of the Shimanto sedimentary rocks into the parental magma for andesites. This is evidenced by the Sr-Nd isotopic compositions of the andesites aligning closely with a mixing hyperbola between the basaltic andesites and the Shimanto sedimentary rocks at up to  $\sim 50\%$  of the mix (Fig. 26a). 50% of the mix between component A (Shimanto sedimentary rocks) and component B (HK-BA) has  $\sim 63\text{wt}\%$   $\text{SiO}_2$  and  $3.5\text{wt}\%$   $\text{MgO}$  which is an andesite composition (Le Bas et al., 1986). Their alignment along a straight line on the  $1/\text{Sr}$  vs.  $^{87}\text{Sr}/^{86}\text{Sr}$  plot (Fig. 26b) further supports this interpretation. The isotopic variations in the andesites could result from various assimilation of sedimentary rocks or incorporation of a partial melt of the Shimanto sedimentary rocks into the parental magmas.

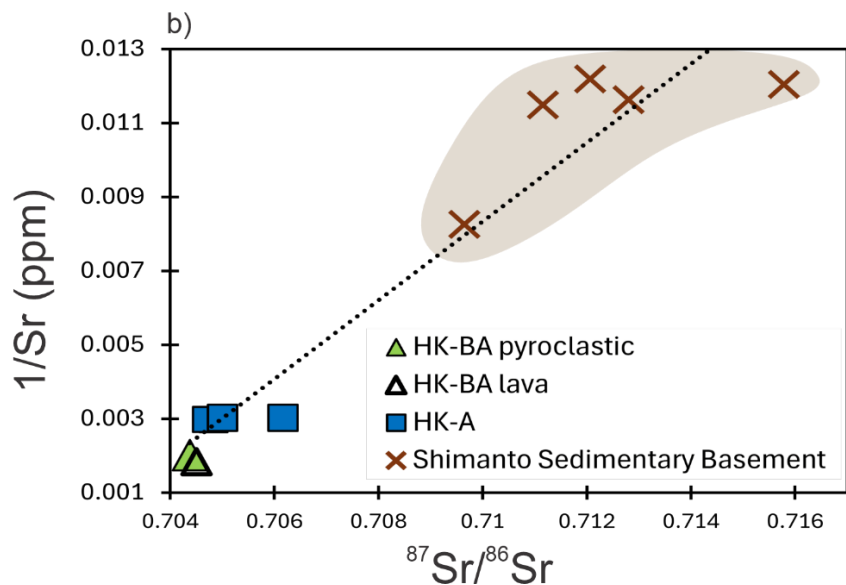
**Table 15.** Composition of end member components A and B used for the bulk mixing curve calculated in Figure 26. Component A was obtained using the average Sr, Nd, and Sr-Nd isotopic composition of the Shimanto Sedimentary Basement using the values of Hosono et al. (2003) and Hattori's unpublished data. Component B was obtained using the average Sr, Nd and Sr-Nd isotopic composition of the mafic samples in the Hishikari mine area (HK-BA) from this study.

| Source (Sample ID)                                                 | Sr (ppm) | Nd (ppm) | $^{87}\text{Sr}/^{86}\text{Sr}$ | $^{143}\text{Nd}/^{144}\text{Nd}$ |
|--------------------------------------------------------------------|----------|----------|---------------------------------|-----------------------------------|
| <u>Values used for component B (Hishikari basaltic andesite)</u>   |          |          |                                 |                                   |
| This Study (220621-5)                                              | 14.5     | 496      | 0.70437501                      | 0.51265982                        |
| This Study (220623-1)                                              | 14.1     | 544      | 0.70450183                      | 0.51262968                        |
| Average (component B)                                              | 14.3     | 520      | 0.704436                        | 0.512651                          |
| <u>Values used for Component A (Shimanto sedimentary basement)</u> |          |          |                                 |                                   |
| Hosono et al., 2003 (1WL1)                                         | 15       | 86       | 0.712801                        | n/a                               |
| Hosono et al., 2003 (1WL2)                                         | 20       | 82       | 0.712062                        | n/a                               |
| Hosono et al., 2003 (1WL3)                                         | 17       | 87       | 0.711155                        | 0.512302                          |
| Hosono et al., 2003 (1WL4)                                         | 24       | 83       | 0.715784                        | 0.512260                          |
| Hosono et al., 2003 (H204)                                         | 19       | 121      | 0.709651                        | n/a                               |
| Hosono et al., 2003 (4W4)                                          | 26       | 99       | 0.725411                        | 0.512245                          |
| Hattori's unpublished data (OH72)                                  | 29       | 117      | 0.723350                        | 0.512186                          |
| Hattori's unpublished data (OH10)                                  | 26       | 366      | 0.712080                        | 0.512084                          |
| Average (component A)                                              | 22       | 130      | 0.715287                        | 0.512216                          |

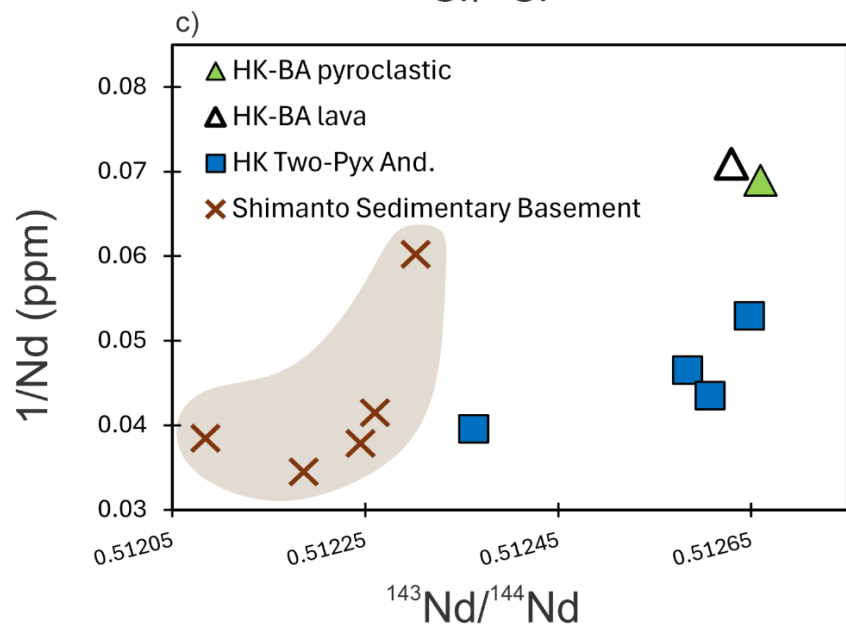


**Figure 26.**

a) Bulk Mixing hyperbola of mixtures of component A (Shimanto Sedimentary Basement) and component B (Basaltic Andesite). The compositions of component A and B are in Table 15. The mixing hyperbola was calculated using the equations of Faure (1977). HK-BA and HK-A are represented by triangles and squares respectively. Shimanto Sedimentary Basement is represented by the brown area. An additional data point for HK-A was plotted from Hattori's unpublished data.



b)  $^{87}\text{Sr}/^{86}\text{Sr}$  values and the reciprocals of Sr (ppm) bulk rock compositions. The data fits on a straight line ( $r = 0.96$ ).



c)  $^{143}\text{Nd}/^{144}\text{Nd}$  values and the reciprocals of Nd (ppm) bulk rock compositions.

## 6.5. Volatile Contents of Magmas

Ni in olivine in HK-BA and HKWest-BBA show a clear positive relationship with Fo components (Fig. 18). This can be interpreted as low contents of S in the magma or continuous precipitation of sulphides as Ni partitions into sulphides. The lack of sulphides observed in thin section and the low S content in the bulk rock ( $<0.01\text{wt}\%$  S) strongly suggest that S contents were very low in the magma

The  $\text{Fe}^{2+}/\text{Mg}$  ratios of olivine (discussed in chapter 6.1) and the decreasing Sc content in Cpx (discussed in chapter 6.6) in HKWest-BBA suggests the early crystallization of Cpx. This interpretation suggests that the parental magmas for HKWest-BBA either had elevated  $\text{H}_2\text{O}$  contents to suppress Ol crystallization or formed under high pressure conditions. Elevated  $\text{H}_2\text{O}$  contents in magmas increases the field for Cpx as the first crystallizing phase (Sisson and Grove, 1993) favouring the early crystallization of clinopyroxene before olivine in HKWest-BBA. It is also possible that Cpx crystallized under high pressures. It is known, that Cpx can crystallize before olivine in mafic magmas at pressures greater than 10 kbar (Kushiro, 1969). However, two-pyroxene thermobarometry yielded pressures up to 6.2kbar (Fig. 23, Table 14).

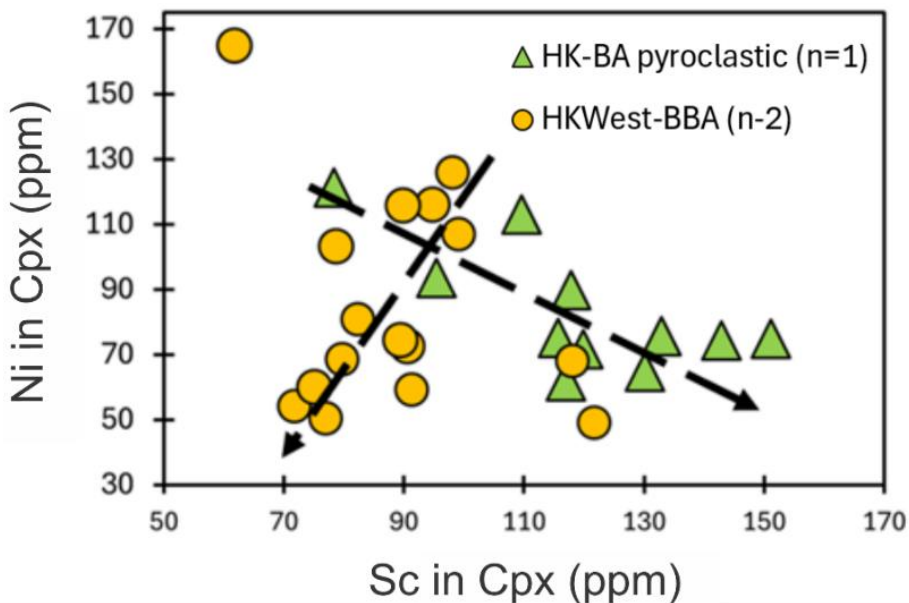
## 6.6 Crystallization Sequence Inferred by Mineral Chemistry

The crystallization sequence for the Hishikari basaltic andesite (HK-BA) and the samples collected west of Hishikari (HKWest-BBA) is evaluated using the mineral chemistry of olivine, clinopyroxene and magnetite in these groups.

$\text{Sr}^{2+}$  is highly compatible to plagioclase (Blundy and Wood, 1991). The Sr composition of a hypothetical melt in equilibrium with Cpx for HK-BA and HKWest-BBA was calculated using the distribution coefficient between Sr and basaltic melt from Blundy et al. 1998. The hypothetical melt in equilibrium with Cpx for both parental magmas exhibit no Sr anomalies relative to the bulk rock composition (Fig. 20). This suggests late crystallization of plagioclase as plagioclase would have depleted Sr from the melt during Cpx crystallization if plagioclase crystallized early.

Sc is highly compatible to Cpx (Hill et al., 2011), but it is not compatible to olivine. Thus, Sc content in the melt increases during olivine crystallization. In HK-BA, Sc content increases in Cpx during crystallization (Fig. 27), possibly suggesting that olivine was crystallizing during Cpx. In contrast, Sc content in Cpx decreases during crystallization in HKWest-BBA. This suggests

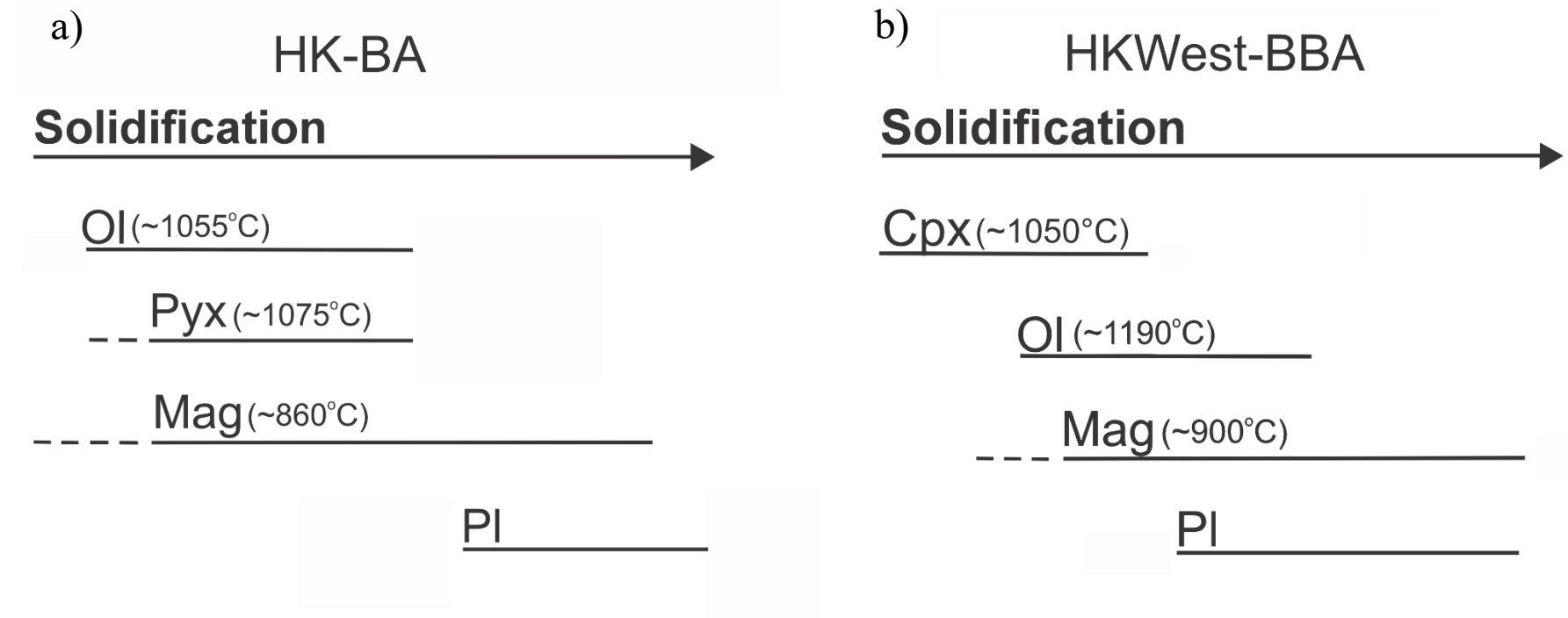
early crystallization of Cpx as the melt was not being enriched by Sc during olivine crystallization. Furthermore,  $\text{Fe}^{2+}/\text{Mg}$  ratios of olivine in HKWest-BBA suggests that olivine formed in a more evolved composition than the bulk rock (as discussed in chapter 6.1).



**Figure 27.** Ni vs Sc (ppm) in Cpx for HKWest-BBA and HK-BA

Oxides preferentially incorporate V from melt (Canil, 2002). Olivine in both groups (HK-BA and HKWest-BBA) contain magnetite inclusions with significant amounts of V (0.45wt% V in HK-BA and 0.66wt% V in HKWest-BBA), suggesting that oxides were crystallizing before and/or simultaneously with olivine to deplete V in the melt.





**Figure 28.** a) Crystallization sequence for Hishikari basaltic andesite (HK-BA) and b) Basalts and basaltic andesites west of Hishikari (HKWest-BBA) using mineral and bulk rock composition. Olivine equilibrium temperatures were calculated using the Mg content in olivine based on the empirical equations of Pu et al. (2017) and have an uncertainty greater than  $\pm 50^{\circ}\text{C}$ . Pyroxene equilibrium temperatures are based on Perttunen's Two-Pyx thermobarometer (2008) and has an error of  $\pm 45\text{-}55^{\circ}\text{C}$ . Fe-Ti Oxide equilibrium temperatures are calculated using the Mg content in magnetite based on the empirical equations of Canil and Lacourse (2020) and have an uncertainty of  $\pm 50^{\circ}\text{C}$ . Solid lines represent assumed duration of crystallization and dashed lines represent uncertain duration of crystallization. Cpx and Opx are assumed to have crystallized at the same time given they are chemically in equilibrium.

## **6.7 Comparison with Other Volcanic Rocks in the Area**

### **6.7.1 Yamagano Kinzan Andesite**

The Yamagano Kinzan Andesite samples (YAM-BA) examined in this study are similar in lithology, mineralogy and bulk rock composition to the Hishikari Lower Andesites within the Hishikari area (HK-BA and HK-A). Both contain medium K calc-alkaline rocks (Figs. 10, 11, 12 and 13) and show similar primitive mantle normalized trace element patterns (Fig. 15), including a typical subduction geochemical signature with depletions in Nb and Ti. The Yamagano Kinzan Andesite (YAM-BA) also contain Mg rich Cpx ( $Mg\# \leq 81$ ), like Cpx in the Hishikari Lower Andesite (Cpx  $Mg\# < 84$ ) and both show evidence for late crystallization of plagioclase. YAM-BA also show similar  $^{87}Sr/^{86}Sr$  (0.704334) to the HK-BA (0.704375 – 0.704502). Since partial melting of sediments cannot produce basaltic melt, the parental magma for the Yamagano Kinzan Andesite formed by partial melting in the mantle during mineralization, similar to what is seen in the Hishikari rocks. However, the Hishikari Lower Andesite contain olivine-bearing rocks in HK-BA whereas olivine was not observed within two samples of Yamagano Kinzan Andesite, examined in this study. Two-pyx thermobarometry yielded higher temperatures for the parental magmas of the Hishikari Lower Andesite ( $\sim 1080^{\circ}C$ ) than Yamagano Kinzan Andesites ( $\sim 1000^{\circ}C$ ) (Fig. 23, Table 14) suggesting that the magmas during pyroxene crystallization at Hishikari were hotter than at Yamagano. Pressures determined by Two-pyx thermobarometry of both parental magmas overlap, where Yamagano Kinzan Andesite yielded pressures ranging from 1.8 to 5.4 kbar and Hishikari Lower Andesite yielded pressures ranging from 3.2 to 6.4 kbar (Fig. 23, Table 14), suggesting pyroxene crystallized at similar depths.

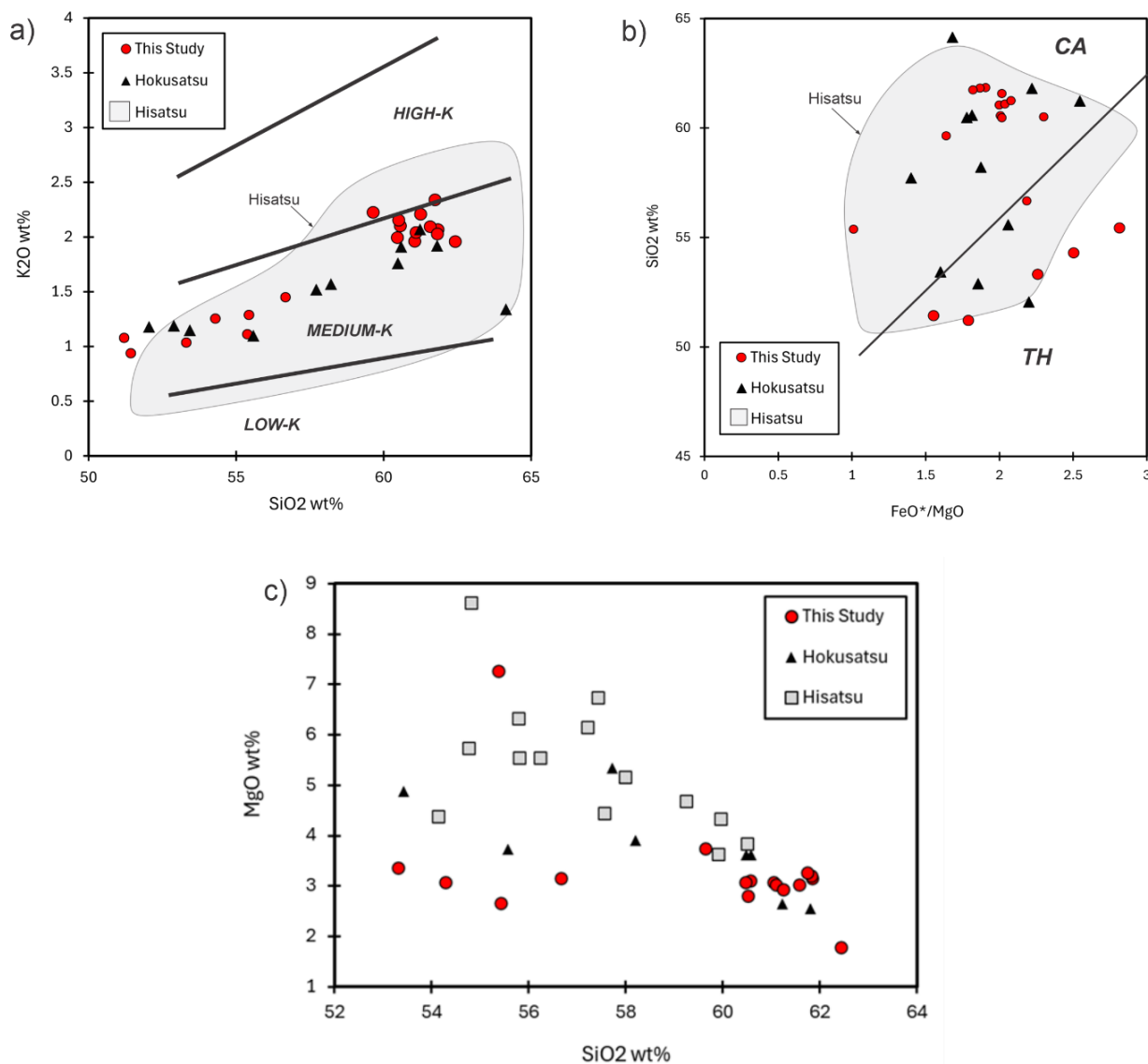
### **6.7.2 Pliocene-Pleistocene Volcanic Rocks in Kyushu Island**

The Hishikari mine is located in the Pliocene-Pleistocene volcanic area consisting of the Hisatsu and Hokusatsu volcanic districts (orange, Fig. 2). The Hisatsu district is a  $\sim 100$  km long and 25 km wide belt with an average thickness of more than 400 m. The volume of the volcanic rocks is estimated to be  $560 \text{ km}^3$  (Nagao et al., 1999). Some lava flows are very thick, ranging from 100 - 200 m in thickness. The same is seen in the Hokusatsu volcanic district where the Kushikino andesites (Fig. 2) are  $>600$  m thick in the center of mining area (Izawa and Zeng, 2001). Nagao et al. (1995) proposed the term “flood andesites” for the Hisatsu and Hokusatsu andesites as they are very voluminous where some developed platy joints throughout the lava flow and

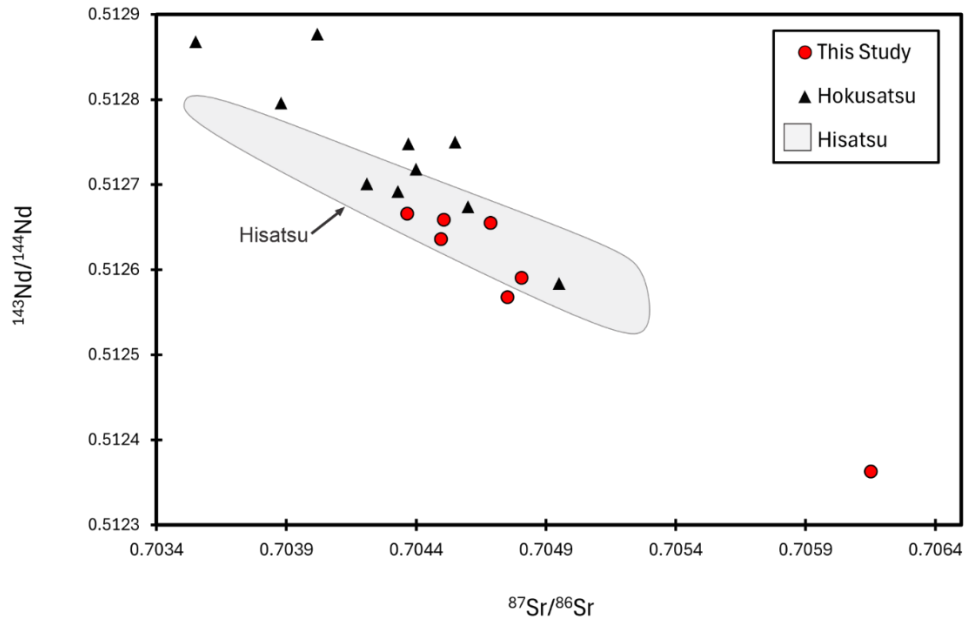
glassy andesite on the top and bottom of the lava flow. They are laterally extensive where ratios of average thickness to horizontal extent of the lava flows are low (Nagao et al., 1995). In the Hishikari mine area, the Hishikari Lower Andesites are up to 700 m thick (Seto et al., 2020).

All Pliocene-Pleistocene volcanic rocks in the area including Hisatsu and Hokusatsu volcanic rocks are similar in lithology, mineralogy and bulk rock compositions to the samples from the Hishikari area. All are medium to high K volcanic rocks (Fig 29a) and contain calc-alkaline Mg-rich andesites/basaltic andesites ( $\text{MgO} < 7.5 \text{ wt\%}$  (this study),  $< 8.63 \text{ wt\%}$  (Hisatsu; Nagao et al., 1999),  $< 5.34 \text{ wt\%}$  (Hokusatsu; Hosono et al., 2008)) (Fig 26c). The two areas also contain tholeiitic basalts and basaltic andesites (Fig 29b). They also have similar primitive mantle normalized trace element patterns with enrichments in LREE (up to 100 times the primitive mantle values) and flat HREE patterns (up to 10 times the primitive mantle values) as well as similar Sr-Nd isotopic compositions (Fig 30).

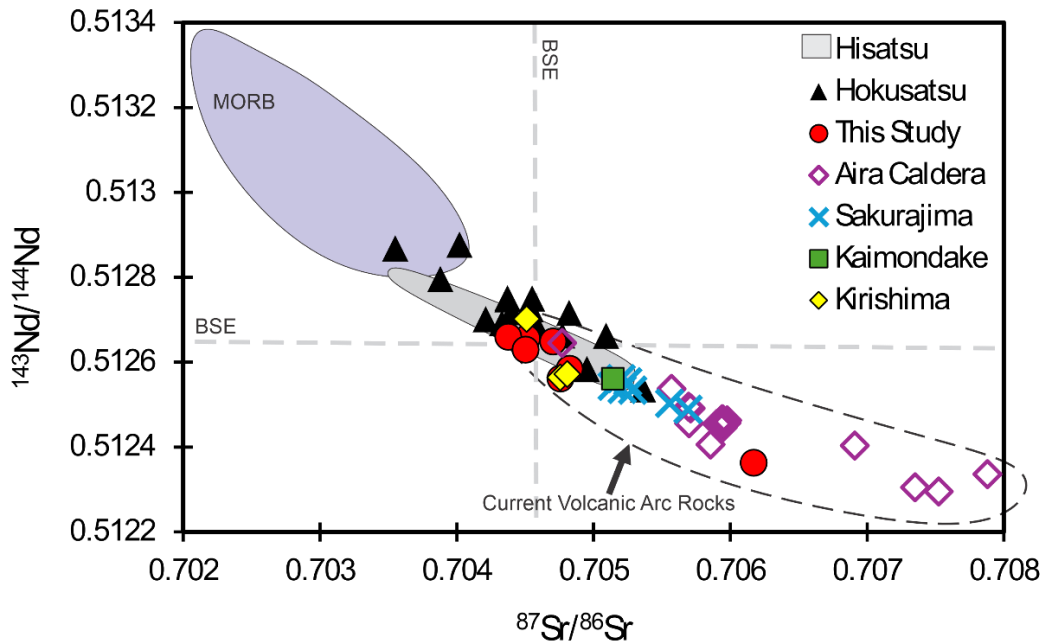
The geochemical similarities between the Pliocene-Pleistocene volcanic rocks of Hisatsu and Hokusatsu districts including those near the Hishikari mine suggests a similar mantle source. Hosono et al. (2008) and Nagao et al. (1999) suggested that the rocks formed by mantle upwelling. Geophysical studies have suggested the presence of an upwelling mantle in southwestern Kyushu. Seno (1999) observed a gradient in horizontal stresses in southwestern Kyushu (East-west stress decreases to the west and the north-south stress increases to the south) that cannot be explained by plate interactions alone. These rocks are also situated in an extensional tectonic setting (Seto et al., 2020). In Addition, the rocks from Hokusatsu and Hisatsu, including Hishikari have lower  $^{87}\text{Sr}/^{86}\text{Sr}$  and higher  $^{143}\text{Nd}/^{144}\text{Nd}$  values than Quaternary rocks from the current volcanic front in Kyushu (Fig. 31).



**Figure 29.** a) Bulk rock  $K_2O$  vs.  $SiO_2$  following the classification of Gill (1981) and b)  $SiO_2$  vs.  $FeO^*/MgO$  diagram following the classification of Miyashiro (1974) and c)  $MgO$  vs.  $SiO_2$  of basalt to andesite rocks from this study (HK-BA, HK-A. and HKWest-BBA) in comparison to Hisatsu and Hokusatsu basalt to andesite rocks. Red circles represent samples from this study, black triangles represent Hokusatsu rocks, and the grey field represents Hisatsu rocks. Hisatsu data is from Nagao et al. (1999) and Hokusatsu data is from Hosono et al. (2008).



**Figure 30.**  $^{143}\text{Nd}/^{144}\text{Nd}$  vs.  $^{87}\text{Sr}/^{86}\text{Sr}$  for our samples (HK-BA, HK-A and HKWest-BBA) in comparison with other Pliocene-Pleistocene rocks in the area (Hisatsu and Hokusatsu volcanic districts). Hokusatsu and Hisatsu data ( $n = 13$ ) is from Hosono et al., 2003 and Hosono et al., 2008. Symbols are the same as Figure 29.



**Figure 31.**  $^{143}\text{Nd}/^{144}\text{Nd}$  vs.  $^{87}\text{Sr}/^{86}\text{Sr}$  for our samples (HK-BA, HK-A and HKWest-BBA) as well as Hisatsu and Hokusatsu (Hosono et al., 2003 and Hosono et al., 2008) in comparison to global MORB (Stracke et al., 2022), and Quaternary rocks from the current volcanic arc in Kyushu (Kirishima: Hosono et al., 2008 and Shinjo et al., 2000; Sakurajima: Shibata et al., 2013; Aira Caldera: Hosono et al., 2008, Arakawa et al., 1998 and Shinjo et al., 2000; Kaimondake: Shinjo et al., 2000). MORB = mid ocean ridge basalt. BSE = bulk silicate earth.

## Chapter 7: Conclusions

Samples of the Hisikari Lower Andesite examined in this study were grouped based on composition and location: Samples collected in the Hishikari mine area (within ~3 km of the mine) consists of basaltic andesites (HK-BA), andesites (HK-A), and dacites (HK-FEL). Samples collected ~11km west of Hishikari consists of basalt and basaltic andesite (HKWest-BBA). Two samples of the Yamagano Kinzan Andesite examined in this study consists of basaltic andesite (YAM-BA). Primitive mantle normalized bulk rock compositions of all samples show a subduction geochemical signature with depletions in Nb and Ti.

All rocks plot in the calc-alkaline field on the AFM and Jensen cation plot but show Fe/Mg enrichment on the  $\text{SiO}_2$  vs  $\text{FeO}^*/\text{MgO}$  diagram (Fig. 11) where HKWest-BBA plot in the tholeiitic field near the boundary with calc-alkaline field following the classification of Miyashiro (1974). Mineral chemistry of HK-BA and HKWest-BBA suggest early crystallization of magnetite and late crystallization of plagioclase, consistent with calc-alkaline magmas rather than tholeiitic.

Similar  $^{87}\text{Sr}/^{86}\text{Sr}$  and  $\epsilon\text{Nd}$  values between HKWest-BBA ( $^{87}\text{Sr}/^{86}\text{Sr} = 0.704510 - 0.704754$ ;  $\epsilon\text{Nd} = -1.4$  to  $+0.4$ ) and HK-BA ( $^{87}\text{Sr}/^{86}\text{Sr} = 0.704373 - 0.704754$ ;  $\epsilon\text{Nd} = -0.04$  to  $+0.4$ ) suggest a similar mantle source. Furthermore, HKWest-BBA exhibit elevated V concentrations in olivine (8.35 – 15.3ppm), high  $\text{TiO}_2$  content in magnetite (~18 wt%  $\text{TiO}_2$ ), and high bulk rock V/Sc ratios (7.83 in the most Mg-rich tholeiitic sample) than the HK-BA (4.3 – 5.64 ppm V in Ol, ~10wt%  $\text{TiO}_2$  in Mag and bulk rock V/Sc ratio = 3.17) suggesting that the HKWest-BBA formed under less oxidized conditions than HK BBA.

Cpx in the mafic rocks (HK-BA and HKWest-BBA) exhibit weak Eu anomalies ( $\text{Eu}/\text{Eu}^* = 0.64 - 1.1$  for HK-BA and  $0.75 - 1.1$  for HKWest-BBA) and no correlation with decreasing Sr content, suggesting that the parental magmas for HK-BA and HKWest-BBA were likely oxidized as Eu was predominately present as  $\text{Eu}^{3+}$  in the melt.

Olivine in all samples contain elevated Ca (600 – 1500ppm) and Mn concentrations (2000 - 3500ppm).  $\text{Fe}^{2+}/\text{Mg}$  ratios of the olivine equilibrium melt of HK-BA, confirm that olivine is a phenocryst. In contrast,  $\text{Fe}^{2+}/\text{Mg}$  ratios the olivine equilibrium melt of HKWest-BBA suggests that olivine formed in a more evolved composition than the bulk rock, likely due to elevated water contents in the parental magmas.

A clear positive relationship between Ni and Fo contents in olivine (Fig. 14) suggests low sulphur in the magmas, which is supported by the lack of sulphides in samples and low S bulk rock content (<0.01wt% S).

Mg-rich (3.3 to 7.3 wt% MgO) mafic samples directly overlying the basement rocks indicate partial melting in the mantle to produce the parental magmas. In the Hishikari mine area, the andesites (HK-A) show slightly higher  $^{87}\text{Sr}/^{86}\text{Sr}$  values and lower  $\epsilon\text{Nd}$  values ( $^{87}\text{Sr}/^{86}\text{Sr} = 0.704703 - 0.706170$ ;  $\epsilon\text{Nd} = -5.4$  to  $-1$ ) compared to the basaltic andesites (HK-BA:  $^{87}\text{Sr}/^{86}\text{Sr} = 0.704375 - 0.704502$ ;  $\epsilon\text{Nd} = -0.2$  to  $+0.4$ ). The Sr-Nd isotopic composition of the andesites align with a binary mixing hyperbola between the basaltic andesites and the metasedimentary rocks of the Shimanto Basement suggesting that the basaltic parental magmas interacted with the Shimanto basement to produce andesite.

Samples of Hishikari Lower Andesite from this study are similar in lithology, mineralogy and bulk rock composition to two samples of Yamagano Kinzan Andesite as well as other Pliocene-Pleistocene volcanic rocks in Kyushu Island including the Hisatsu and Hokusatsu volcanic fields. These geochemical similarities could possibly be evidence for a similar mantle source originating from an upwelling mantle beneath Kyushu as suggested by previous researchers

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## **APPENDIX 1. Conference Abstracts**

1. Oral presentation by C. Suclan at Annual meeting of Resource Geology, Tokyo. June 28-July 1, 2022.

### **Olivine Andesite Contemporaneous with Mineralization at the Hishikari Deposit**

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The Hishikari epithermal gold deposit is one of the highest-grade gold deposits in the world (409t Au) among currently mined. The Cretaceous Shimanto metasedimentary rocks form the basement and are overlain by the Hishikari Lower Andesites (1.62-0.84 Ma), Hishikari Middle Andesites (~0.78Ma), Shishimano Dacites (1.1-0.66 Ma), Hannyaji Rhyodacites (0.7-0.6Ma) and Hishikari Upper Andesites (0.58-0.51Ma). The Hishikari Lower Andesite is Mg-rich (MgO  $\geq$  ~ 3.0 wt%) compared to other volcanic rocks. It contains olivine-bearing pyroclastic rock and two pyroxene lava. The two pyroxene lava contains phenocrysts of plagioclase (~An64), augite (Mg #64), hypersthene (Mg#60, En61, 1.42wt% CaO), magnetite (~12.0 wt% TiO<sub>2</sub>, 28.1% ulvospinel component), ilmenite (13.6 % hematite component) and apatite. Ratios of Mg and Mn in oxides show that magnetite and ilmenite are in equilibrium, yielding ~ 820 °C. The data suggests slow cooling of the lava. The oxidation conditions, FMQ+1.1, are lower than fO<sub>2</sub> values of ~ FMQ+2, obtained for younger units in the area, such as Hannyaji Rhyodacite. The olivine bearing pyroclastic unit is dark grey, fine to medium grained containing Mg-rich olivine (Fo76, 0.05wt% Ni, 0.13wt% CaO, ~0.35wt% Mn), plagioclase (~An60), augite (Mg#77), hypersthene (Mg#67, En65, 0.96wt% CaO), magnetite (9.64wt% TiO<sub>2</sub>, 27.8 % ulvospinel component) and apatite phenocrysts in a groundmass of glass, plagioclase laths, and two pyroxenes. The Fe<sup>2+</sup>/Mg ratio of a melt in equilibrium with olivine (Fo76) is 1.0. The Fe<sup>2+</sup>/Mg ratio of the bulk rock composition is 0.98 using the fraction of Fe<sup>2+</sup> as 90%, suggesting that olivine is a phenocryst crystallized in the magma. Inclusions of Cr-magnetite (1.58 %Cr<sub>2</sub>O<sub>3</sub>, 4.3wt% TiO<sub>2</sub>, 7.1wt% Al<sub>2</sub>O<sub>3</sub>) in olivine and high Mg in olivine suggest an injection of a high temperature, mantle-derived parental magma during mineralization.

2. Poster presentation at SEG-PDAC Minerals Colloquium, Toronto. March 2023.

**Characterization of the parental magmas associated with the Hishikari epithermal deposit, Japan**

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The Hishikari epithermal gold deposit (409t Au) is a high-grade low-sulphidation epithermal gold deposit where the high grade veins of Honko and Sanjin Zones formed 1.11-0.75 Ma. The gold veins are hosted by the Cretaceous Shimanto metasedimentary rocks, which are overlain by the Hishikari Lower Andesites (1.62-0.84 Ma), Hishikari Middle Andesites (~0.78Ma), Shishimano Dacites (1.1-0.66 Ma), Hannyaji Rhyodacites (0.7-0.6Ma) and Hishikari Upper Andesites (0.58-0.51Ma). The Hishikari Lower Andesite is contemporaneous with mineralization and is composed of lavas and pyroclastic rocks with andesite and basaltic andesite composition. Samples show a negative sloped chondrite-normalized REE pattern with elevated light REE up to 100 times of chondrite value. The basaltic andesite is Mg-rich ( $\text{MgO} \geq \sim 3.0\text{wt}\%$ ) where olivine phenocrysts (76Fo, 0.05wt% NiO, 0.13wt% CaO,  $\sim 0.35\text{wt}\%$  MnO) are common in the pyroclastic rocks 1.5 km east of the mine and lavas  $\sim 12$  km west of the mine. These volcanic rocks also contain phenocrysts of plagioclase ( $\sim \text{An}_{60}$ ), zoned augite (Mg#77), hypersthene (Mg#67, En65), magnetite (9.64wt%  $\text{TiO}_2$ ) and apatite in a groundmass of glass, plagioclase laths, and two pyroxenes. The andesite lavas contain phenocrysts of plagioclase ( $\sim \text{An}_{64}$ ), compositionally zoned augite (Mg#64) and hypersthene (Mg#60, En61), magnetite ( $\sim 12.0\text{wt}\%$   $\text{TiO}_2$ ), ilmenite (13.6 % hematite component) and apatite. Abundance of Mg and Mn show that Fe-Ti oxides are in equilibrium, yielding  $\sim 820$  °C. The data suggests slow cooling of lava. The oxidation conditions, FMQ+1.1, based on Fe-Ti-oxides, are lower than fO<sub>2</sub> values of  $\sim \text{FMQ}+2$ , for younger units in the area, such as Hannyaji Rhyodacite. The  $\text{Fe}^{2+}/\text{Mg}$  ratio of olivine (Fo76) is in equilibrium with that of the bulk rock composition assuming 90%  $\text{Fe}^{2+}$ , confirming that olivine is a phenocryst. Inclusions of Cr-magnetite (1.58 %  $\text{Cr}_2\text{O}_3$ ) in olivine and high Mg contents of olivine suggest an injection of a high temperature, mantle-derived mafic melt during mineralization.

3. Poster presentation at SEG-PDAC Minerals Colloquium, Toronto. March 2024.

### **Volcanism During the Mineralization at the Hishikari Gold Deposit, Japan**

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The Hishikari deposit (> 409t Au) is a high-grade low-sulphidation epithermal gold deposit on the southern Kyushu Island of Japan. The high-grade veins of the Honko and Sanjin Zones formed at 1.11-0.75 Ma and are hosted by the Cretaceous Shimanto metasedimentary rocks. The Shimanto rocks are overlain by the Hishikari Lower Andesite (1.62-0.84 Ma), Hishikari Middle Andesite (~0.78Ma), Shishimano Dacite (1.1-0.66 Ma), Hannyaji Rhyodacite (0.7-0.6Ma) and Hishikari Upper Andesite (0.58-0.51Ma). The Hishikari Lower Andesite is contemporaneous with the mineralization. It is composed of lavas and pyroclastic rocks with basaltic andesite composition and some andesite lavas. They show initial  $^{87}\text{Sr}/^{86}\text{Sr}$  values of 0.704398 (pyroclastic) and 0.705868 (andesite lava), suggesting that the parental magmas significantly assimilated basement Shimanto sedimentary rocks especially for lavas. The pyroclastic rocks are Mg-rich ( $\text{MgO} \geq 3.3\text{wt}\%$ ) containing olivine phenocrysts (77Fo, Ni (<500ppm), Mn (<3600ppm), Ca (<1030ppm), Ti (<45ppm) and Al (<130ppm)). Al contents of olivine suggest its crystallization at temperatures over 800 °C using the thermometry of De Hoog et al (2010). The pyroclastic rocks and lavas contain phenocrysts of plagioclase (~An60), zoned augite (Mg#84-73), zoned hypersthene (Mg#87-76), magnetite (9.64wt%  $\text{TiO}_2$ ) and apatite. The andesite lavas contain phenocrysts of plagioclase (~An64), zoned augite (Mg#84-73), hypersthene (Mg#~70), magnetite (~12.0wt%  $\text{TiO}_2$ ), ilmenite (13.6 % hematite component) and apatite. Primitive mantle-normalized patterns of trace elements for augite are similar to those for bulk rocks where LREE in the bulk rocks are 100 times and augite is 10 times the primitive mantle values. Oxide pairs yield ~ 820 °C, and FMQ+1.1, suggesting slow cooling of lavas. Inclusions of Cr-magnetite (1.58 %  $\text{Cr}_2\text{O}_3$ ) in Mg-rich olivine, high Mg# (<87) of pyroxenes, and bulk rock suggest partial melting in the mantle for volcanism during the gold mineralization.

4. Oral presentation at the Geological Association of Canada Annual meeting in Ottawa, in May 2025

### **Volcanism During the Mineralization at the Hishikari Gold Deposit, Japan**

*Catherine Suclan<sup>1</sup>, Keiko Hattori<sup>1</sup>*

*<sup>1</sup>Department of Earth and Environmental Sciences, University of Ottawa, Ottawa, Canada*

The Hishikari deposit is a high-grade low-sulphidation epithermal gold deposit in southern Kyushu, Japan. The high-grade veins are hosted by the Cretaceous Shimanto metasedimentary basement and low-grade veins in the overlying Hishikari Lower Andesites (1.62 -0.84 Ma). The mineralization (1.25 – 0.61 Ma) was contemporaneous with the andesitic volcanism. Samples of the Hishikari Lower Andesites include tholeiitic basalts and basaltic andesite lavas ( $\text{MgO} \leq 5.7 \text{ wt\%}$ ) which contain Mg-rich clinopyroxene ( $\text{Mg\#} \leq 82$ ) and olivine phenocrysts ( $\sim \text{Fo}_{64-73}$ ) with magnetite inclusions. Samples also include calc-alkaline andesite lavas, Mg-rich basaltic andesite lavas ( $\text{MgO} \leq 7.3 \text{ wt\%}$ ) and pyroclastic rocks ( $\text{MgO} \leq 3.3 \text{ wt\%}$ ). The pyroclastic samples contain Mg-rich clinopyroxene ( $\text{Mg\#} \leq 84$ ) and olivine phenocrysts ( $\sim \text{Fo}_{77}$ ) with Cr-bearing ( $\sim 1.6 \text{ wt\% Cr}$ ) magnetite inclusions. Both tholeiitic and calc-alkaline rocks show similar  $^{87}\text{Sr}/^{86}\text{Sr}$  between 0.704 and 0.705 and  $\epsilon\text{Nd}$  between -1.4 and +0.5. The data suggests partial melting of a similar mantle source during the mineralization. The calc-alkaline andesites show slightly higher  $^{87}\text{Sr}/^{86}\text{Sr}$  and lower  $\epsilon\text{Nd}$ , where the data plots along a mixing hyperbola between the basaltic andesites and the Shimanto basement rocks, suggesting that the parental magmas assimilated crustal material from the Shimanto basement. Elevated Ni content in clinopyroxene ( $\leq 211 \text{ ppm}$ ) and V/Sc ratios increasing with decreasing Fo values in olivine in the calc-alkaline basaltic andesites suggest clinopyroxene crystallization before and/or during olivine which is consistent with high water contents in the parental magmas. A clear positive relationship between Ni and Fo components in olivine, the lack of sulphides observed in samples and low bulk rock S content ( $< 0.01 \text{ wt\%}$ ) suggests low sulphur contents in the parental magmas. Our samples are similar in lithology, mineralogy and bulk rock compositions to other Pliocene-Pleistocene volcanic rocks in Kyushu Island including Hokusatsu and Hisatsu volcanic fields, providing possible evidence for partial melting of a similar mantle source from an upwelling mantle beneath the area.



## **APPENDIX 2. Supplementary Data for Chapter 3**

### **APPENDIX 2.1. LA-ICPMS Analysis**

#### **Run parameters**

##### **Instruments:**

Photon Machines Analyte Excite 193 nm excimer laser

Agilent 7700x ICP-MS

##### **Data Reduction Software:**

LADR v1.1.08

##### **Gas flow:**

He carrier gas: 1.00L/min

Ar make up gas: 0.75L/min

##### **Laser Parameter**

| Parameter                                                   | Olivine and Cpx |
|-------------------------------------------------------------|-----------------|
| Repetition rate (Hz)                                        | 15              |
| Spot size (um)                                              | 52              |
| Ablation sequence (s)<br>(background – ablation<br>– flush) | 15 – 30 – 30    |

##### **Quantification Scheme**

Data reduction using the count ratios of elements to <sup>29</sup>Si, calibration using GSE-1G. The accuracy was checked by examining BCR-2G and GSD

All reference material values used those listed in GEOREM (<http://georem.mpch-mainz.gwdg.de/>).

## **Dwell Times**

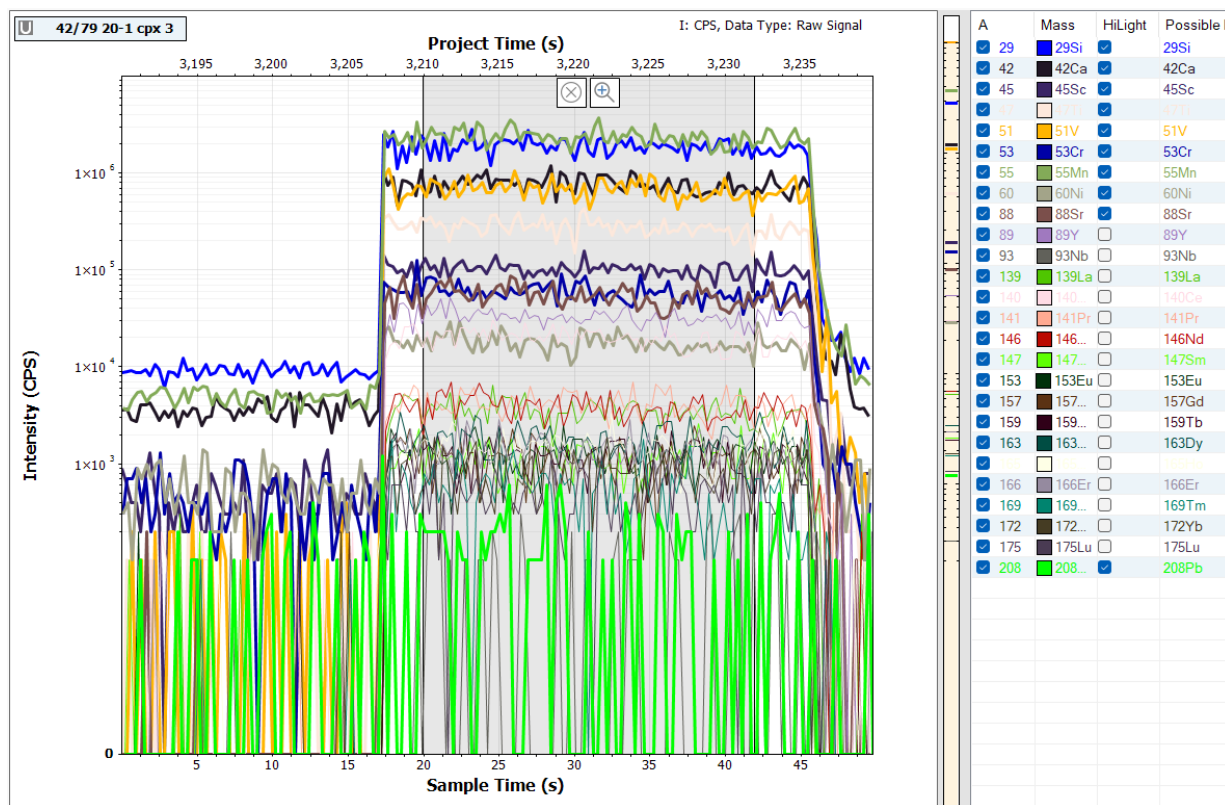
| Olivine |                 |
|---------|-----------------|
| Mass    | dwell time (ms) |
| 7Li     | 10              |
| 23Na    | 10              |
| 27Al    | 10              |
| 29Si    | 10              |
| 42Ca    | 10              |
| 45Sc    | 10              |
| 47Ti    | 10              |
| 51V     | 10              |
| 53Cr    | 10              |
| 55Mn    | 10              |
| 59Co    | 10              |
| 60Ni    | 10              |
| 66Zn    | 10              |

| Clinopyroxene |                 |
|---------------|-----------------|
| Mass          | dwell time (ms) |
| 29Si          | 10              |
| 42Ca          | 10              |
| 45Sc          | 10              |
| 47Ti          | 10              |
| 51V           | 10              |
| 53Cr          | 10              |
| 55Mn          | 10              |
| 60Ni          | 10              |
| 88Sr          | 10              |
| 89Y           | 10              |
| 93Nb          | 10              |
| 139La         | 10              |
| 140Ce         | 10              |
| 141Pr         | 10              |
| 146Nd         | 10              |
| 147Sm         | 10              |
| 153Eu         | 10              |
| 157Gd         | 10              |
| 159Tb         | 10              |
| 163Dy         | 10              |
| 165Ho         | 10              |
| 166Er         | 10              |
| 169Tm         | 10              |
| 172Yb         | 10              |
| 175Lu         | 10              |
| 208Pb         | 10              |

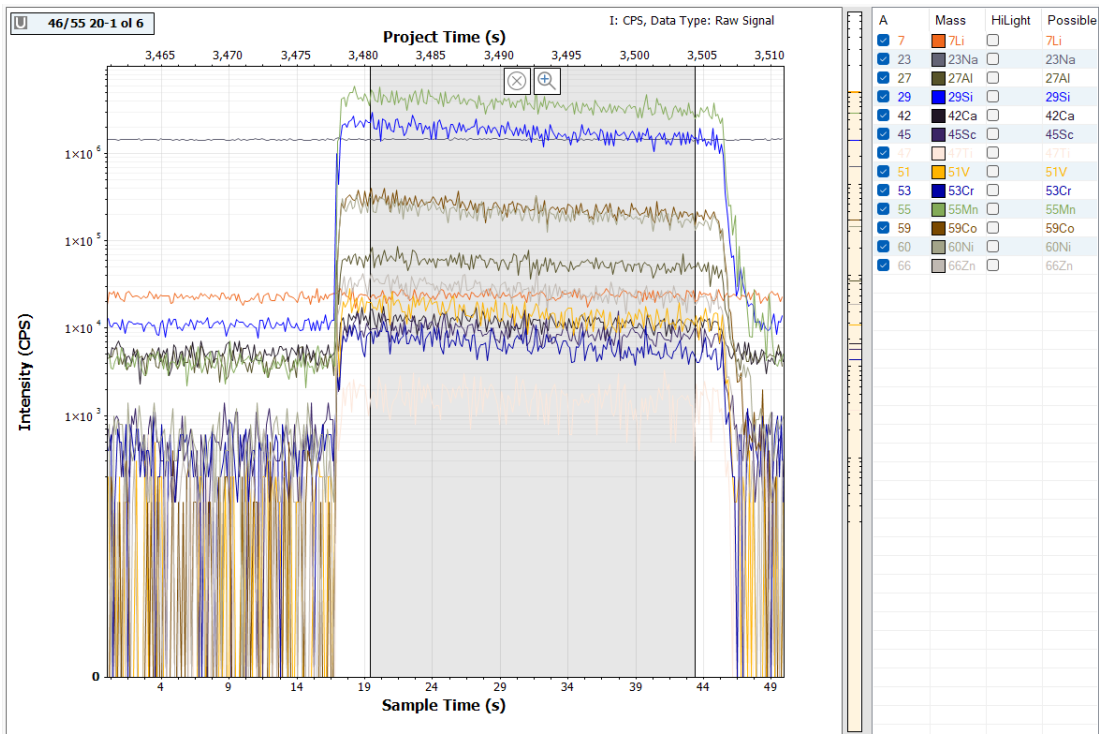
## Examples of LA-ICPMS Profiles for Each Sample

### Sample 220620-1 examples

#### SAMPLE 220620-1 CPX

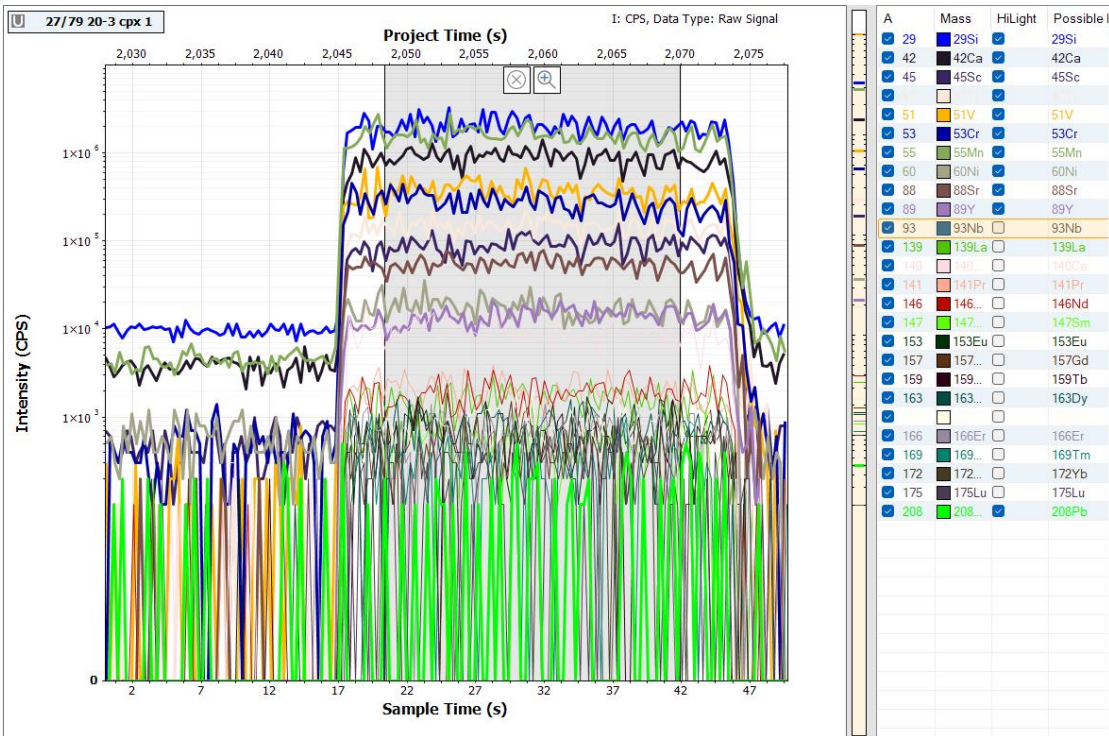


SAMPLE 220620-1 OLIVINE

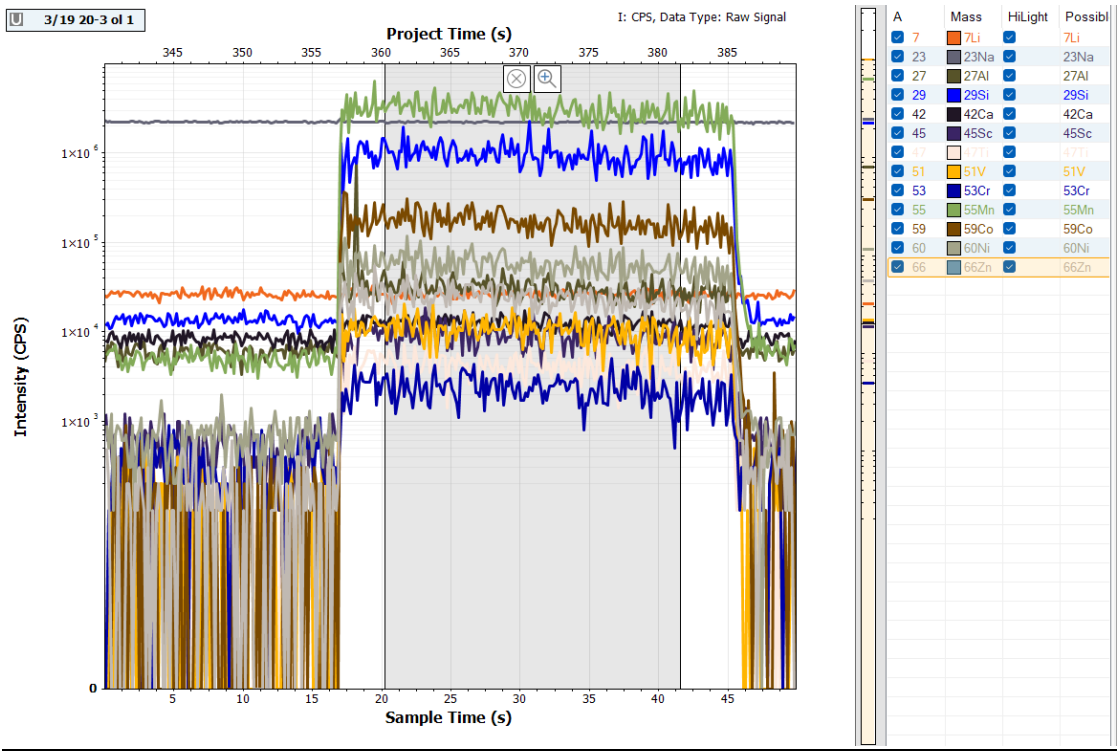


Sample 220620-3 examples

SAMPLE 220620-3 CPX

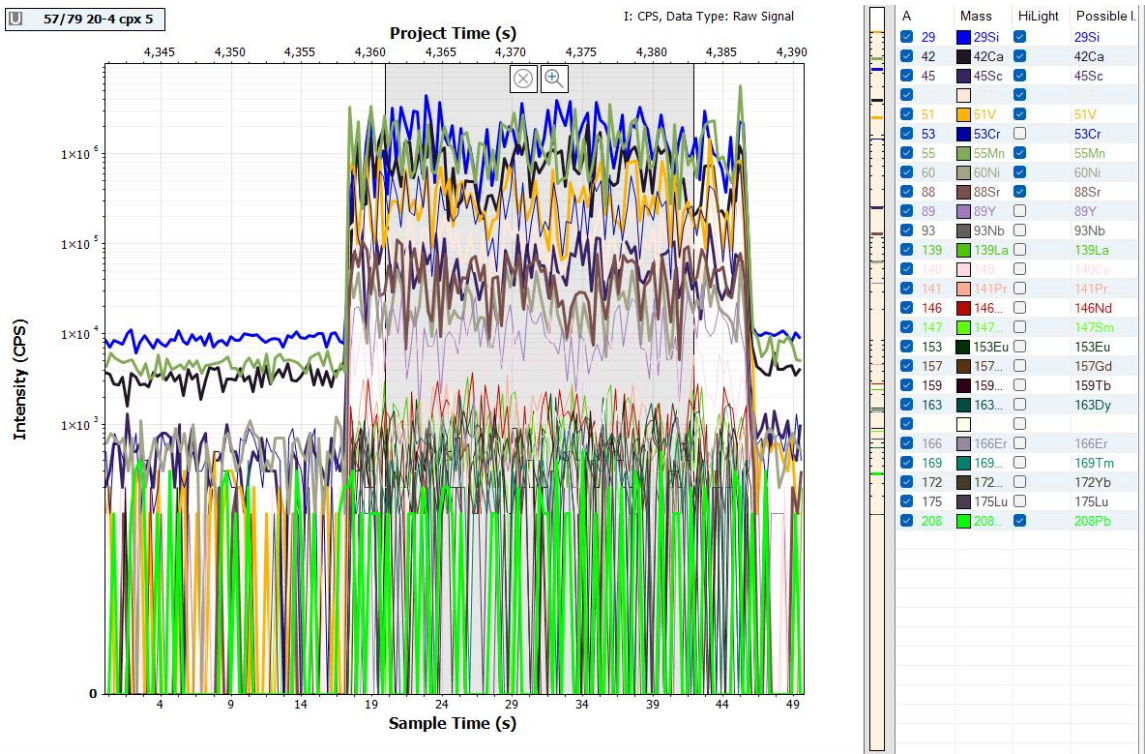


SAMPLE 220620-3 OLIVINE



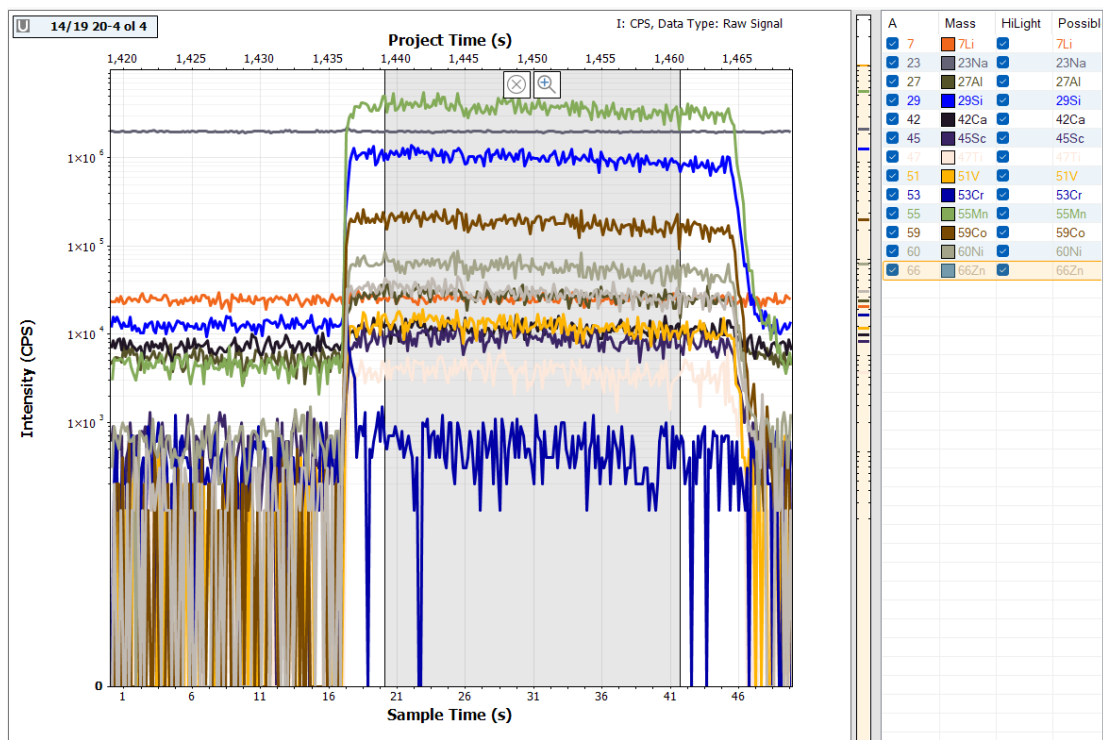
Sample 220620-4 examples

SAMPLE 220620-4 CPX



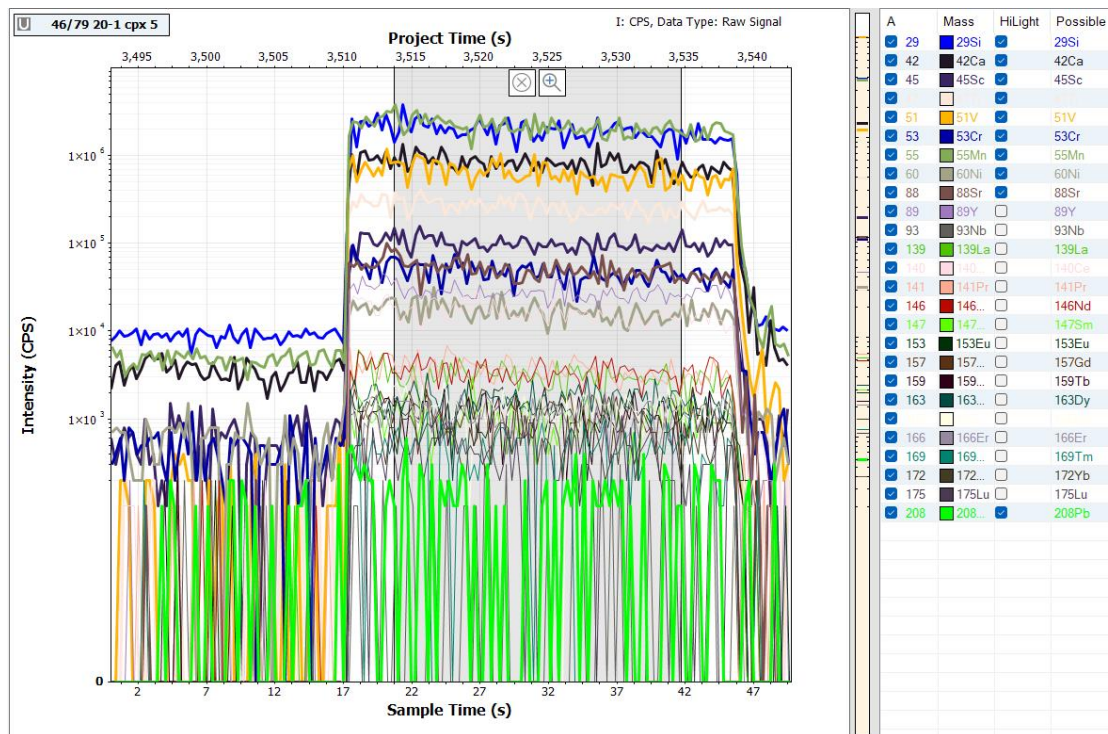


## SAMPLE 220620-4 OLIVINE

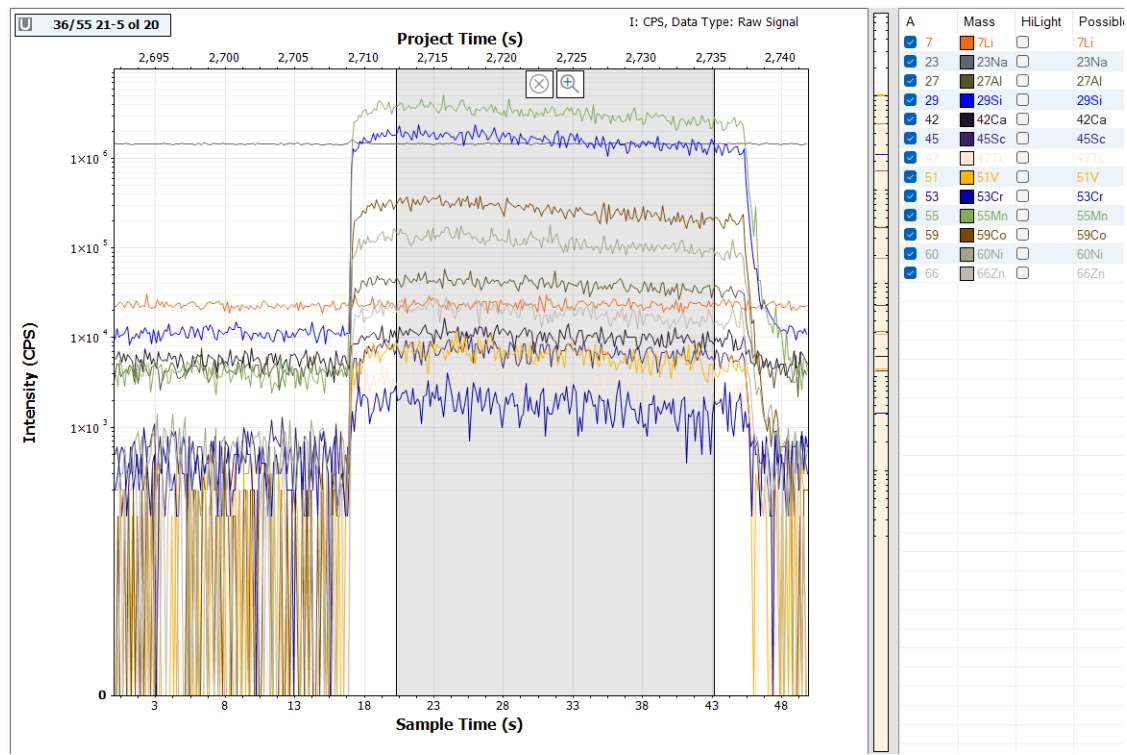


## Sample 220621-5 examples

## SAMPLE 220621-5 CPX

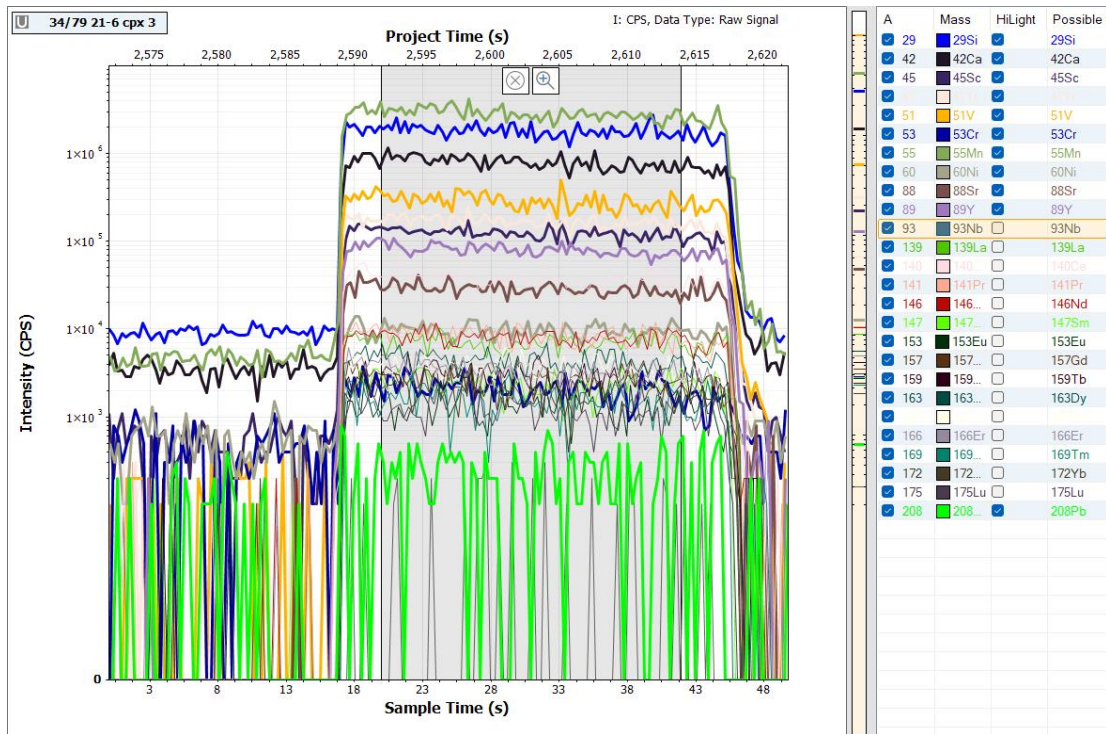


## SAMPLE 220621-5 OLIVINE



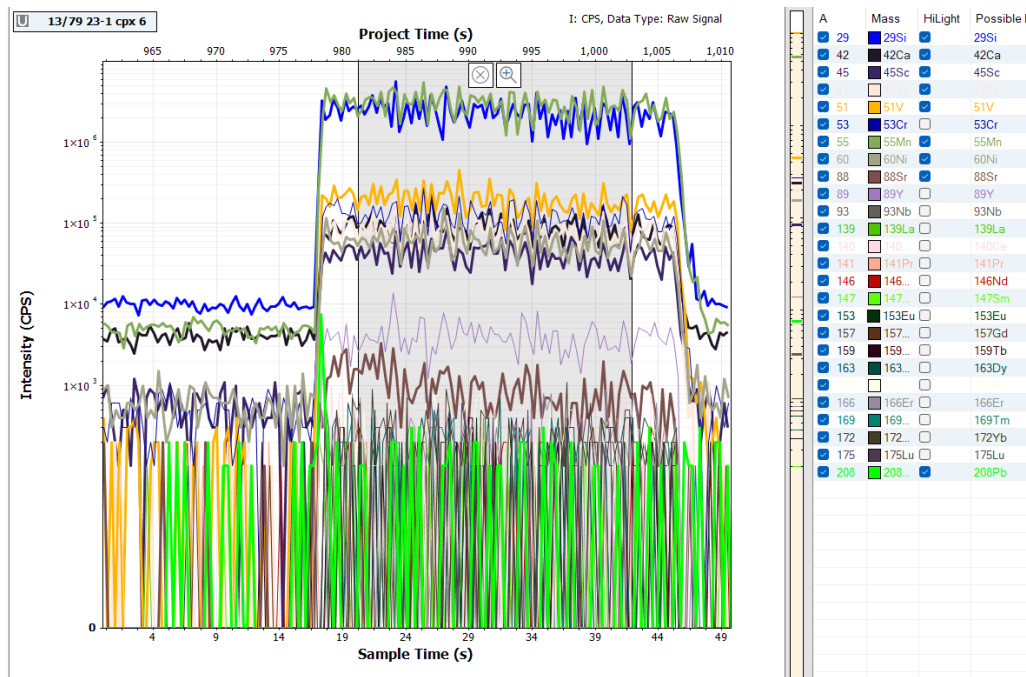
## Sample 220621-6 examples

## SAMPLE 220621-6 CPX



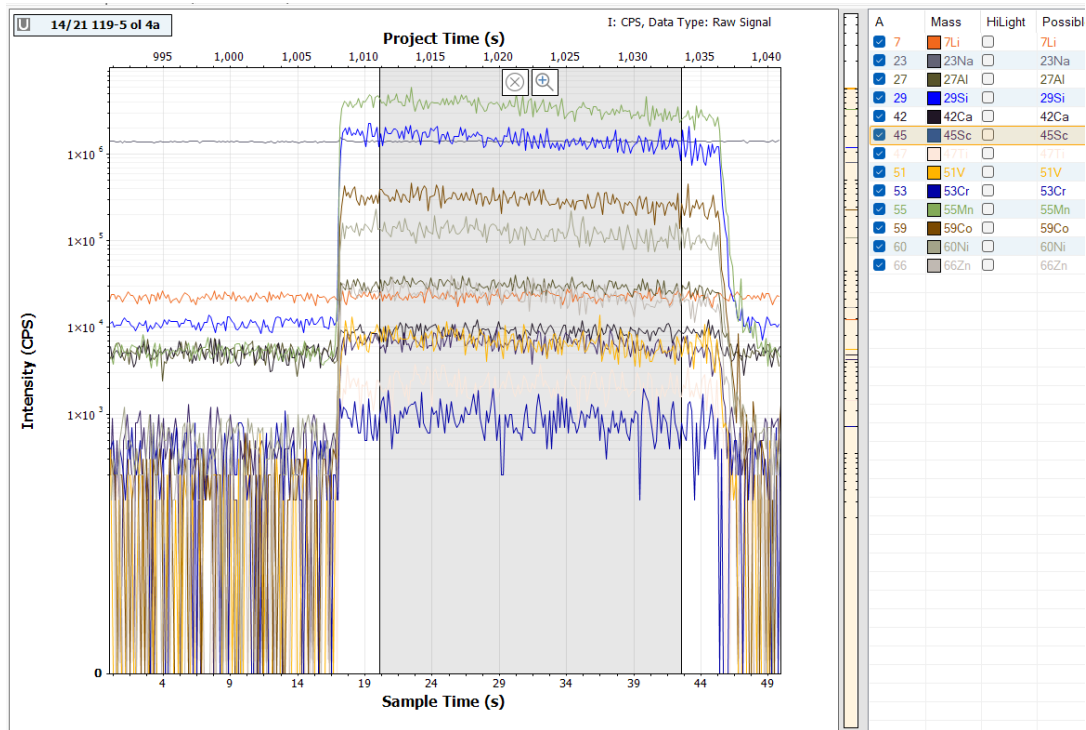
## Sample 220623-1 examples

### SAMPLE 220623-1 CPX



## Sample 119-05 examples

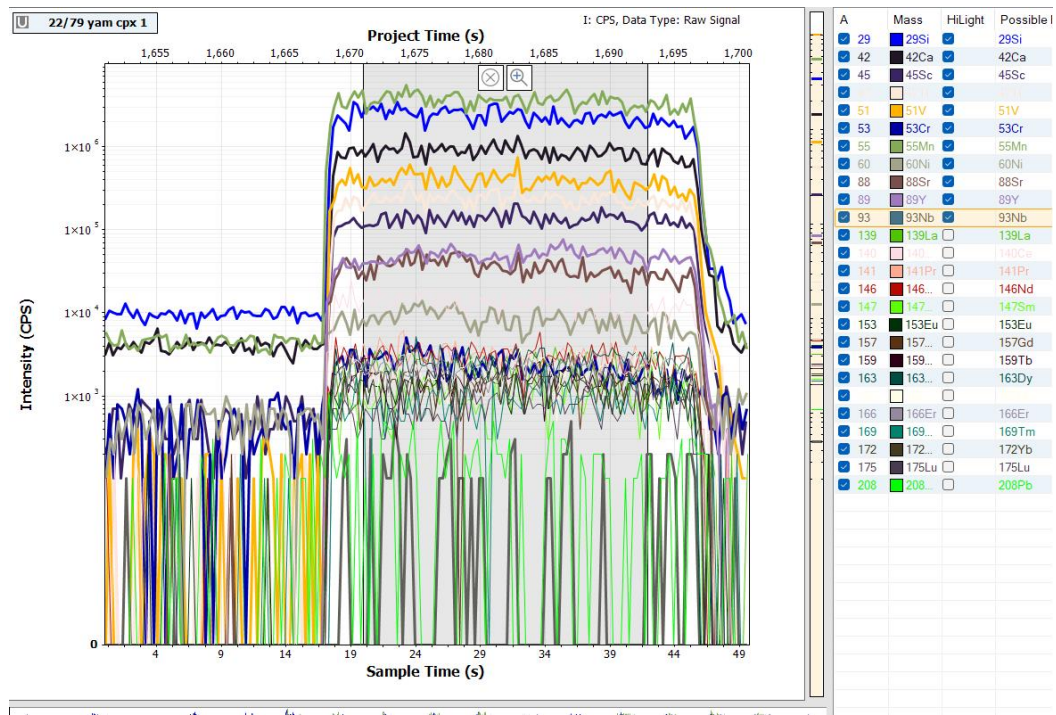
### SAMPLE 119-05 OLIVINE





## Sample YAM002 examples

### SAMPLE YAM002 CPX



## **APPENDIX 2.2. Sr-Nd Isotope Analysis**

### **Digestion:**

100 - 200mg of sample was dissolved in HF and HNO<sub>3</sub> for 3 days at 120 degrees and then dried overnight. 6N HCL was added to the sample and dried overnight again.

### **Sr and LREE collection:**

0.7 mm x 20cm glass columns were filled with 12cm of AG50w - XB 200 - 400 mesh resin and cleaned with 40ml of 6N HCl. Conditioning was done with 17ml of 2.5N HCl. The samples in 2.5 N HCl were centrifuged for 4 1/2 minutes to load clear solution of 2 ml into the resin. A 28ml wash of 2.5N HCl was done before collecting 9ml of Sr fraction, followed by a 3ml 2.5N HCl wash. A 6ml wash of 6N HCl was done before collecting 7ml of LREE fraction. The columns were cleaned with 40ml of 6N HCl.

### **Nd collection:**

Nd collection was done using pre-packed Eichron columns containing 2ml of LN spec resin (100 - 150 mesh) in 0.05M HNO<sub>3</sub>. The HNO<sub>3</sub> was drained completely and washed with ~4ml of Milli Q. Conditioning was done with 4 ml of 0.25N HCl. 0.5ml of 0.25N HCl was added to each LREE fraction and left for 30mintes, which was then loaded into the columns. A 6.5ml wash of 0.25N HCl was done in increments of 0.5ml. Finally, 4.5ml of 0.25N HCl was added for Nd collection. The Nd samples were dried for transport.

### **Sr Purification:**

Sr purification was done using Bio-Rad polypropylene columns (inside diameter of 7mm). About 3mm of Eichron's 50 - 100 mm Sr-spec resin in Milli Q was placed in the columns and then cleaned with 1ml of 0.05M HNO<sub>3</sub>. Conditioning was done with 0.5ml of 6M HNO<sub>3</sub>. 2ml of 6N HNO<sub>3</sub> was added to each Sr fraction and only 0.5ml of the Sr fraction was loaded into the column. A 1ml 6N HNO<sub>3</sub> rinse was done in 0.5ml increments. Sr was collected by added 0.5ml of 0.05M HNO<sub>3</sub> twice and 0.5ml of MilliQ.

| <u>Sample</u> | <u>Group</u>      | <u>Sample weight (mg)</u> |
|---------------|-------------------|---------------------------|
| 220620-1      | HKWest-BBA        | 141.3                     |
| 220620-3      | HKWest-BBA        | 136.5                     |
| 220621-5      | HK-BA pyroclastic | 132.4                     |
| 220623-1      | HK-BA lava        | 143.8                     |
| 220622-5      | HK-A              | 124.3                     |
| 220621-7      | HK-A              | 175.2                     |
| 220622-4      | HK-A              | 127                       |

**Table A2.2-1.** Sample weight used for analysis

|              | $^{87}\text{Sr}/^{86}\text{Sr}$<br>(measured) | Error (2 $\sigma$ ) | $^{87}\text{Sr}/^{86}\text{Sr}$<br>(normalized) |
|--------------|-----------------------------------------------|---------------------|-------------------------------------------------|
| Standard     |                                               |                     |                                                 |
| NIST SRM 987 | 0.710224                                      | 0.000010            |                                                 |
| Sample       |                                               |                     |                                                 |
| 220620-1     | 0.704510                                      | 0.000012            | 0.704512                                        |
| 220620-3     | 0.704754                                      | 0.000013            | 0.704756                                        |
| 220621-5     | 0.704373                                      | 0.000016            | 0.704375                                        |
| 220621-7     | 0.704823                                      | 0.000011            | 0.704825                                        |
| 220622-4     | 0.704701                                      | 0.000017            | 0.704703                                        |
| 220622-5     | 0.706168                                      | 0.000019            | 0.706170                                        |
| 220623-1     | 0.704500                                      | 0.000012            | 0.704502                                        |
| YAM002       | 0.704332                                      | 0.000014            | 0.704334                                        |

**Table A2.2-2.** All measured Sr isotope data are normalized to  $^{87}\text{Sr}/^{86}\text{Sr} = 0.11940$ , to correct for mass fractionation in the mass spectrometer. NIST SRM 987 measured an  $^{87}\text{Sr}/^{86}\text{Sr}$  value of 0.710224, which is 0.000021 less than the accepted NIST SRM 987 value of 0.710245. Thus, the data was normalized to  $^{87}\text{Sr}/^{86}\text{Sr} = 0.710245$  by adding 0.000021 to the measured values.

|              | $^{143}\text{Nd}/^{144}\text{Nd}$<br>(measured) | Error (2 $\sigma$ ) |
|--------------|-------------------------------------------------|---------------------|
| Standard     |                                                 |                     |
| JNdi-1       | 0.512087                                        | 0.000000            |
| JNdi-1       | 0.512103                                        | 0.000045            |
| JNdi-1       | 0.512092                                        | 0.000007            |
| JNdi-1 avg   | 0.512094                                        | 0.000017            |
| Sample       |                                                 |                     |
| 220620-1     | 0.512659                                        | 0.000007            |
| 220620-1     |                                                 |                     |
| 2ndrun       | 0.512653                                        | 0.000010            |
| 220620-1 avg | 0.512656                                        | 0.000008            |
| 220620-3     | 0.512561                                        | 0.000004            |
| 220621-5     | 0.512660                                        | 0.000006            |
| 220621-7     | 0.512584                                        | 0.000004            |
| 220622-4     | 0.512649                                        | 0.000005            |
| 220622-5     | 0.512363                                        | 0.000006            |
| 220623-1     | 0.512630                                        | 0.000005            |

**Table A2.2-3.** All measured ratios are normalized to a  $^{143}\text{Nd}/^{144}\text{Nd} = 0.71290$  to correct for the mass fractionation of the mass spectrometer. The average value measured for the Jndi-1 standard matched the agreed upon value of Garcon et al., (2018) and thus the  $^{143}\text{Nd}/^{144}\text{Nd}$  values are reported as measured.

### APPENDIX 3. Supplementary Data for Chapter 4

#### APPENDIX 3.1. Hand Sample Descriptions

| Sample # | Location                                   | Rock Name<br>(only based<br>on hand<br>sample) | Visible Minerals and<br>Crystal Abundance      | Grain size   | Texture/Structure                                                                                                                                                                       | Colour                 |
|----------|--------------------------------------------|------------------------------------------------|------------------------------------------------|--------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------|
| 220620-1 | North of<br>Pig farm,<br>along road<br>447 | Basaltic<br>andesite<br>lava                   | Pl (45-50 vol%, <2mm)<br>Mag ((10 vol%), <1mm) | Fine grained | Porphyritic<br>Slightly vesicular, irregularly shaped and<br>elongated (<2mm)<br>Disseminated Mag<br>Similar texture as sample 220620-3 but<br>much finer grained<br>1 Qz clast (1.7mm) | Medium to<br>dark Grey |



|                 |                                   |                        |                                                                           |                                                                 |                                                                                                                                                            |           |
|-----------------|-----------------------------------|------------------------|---------------------------------------------------------------------------|-----------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------|
| <b>220620-2</b> | North of Pig farm, along road 447 | Basaltic andesite lava | Pl (40 vol%, <2.5mm)<br>Mag (15 vol%, <1mm)<br>Pyroxene (5-10 vol%, <2mm) | Fine to medium grained phenocrysts in a fine-grained groundmass | Porphyritic<br>Pl is rounded to sub-rounded, and is mostly uniform in size (~2mm) making the rock appear “spotted” with Pl<br>Mag rounded and disseminated | Dark grey |
|-----------------|-----------------------------------|------------------------|---------------------------------------------------------------------------|-----------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------|





|          |                                   |                        |                                                                              |                                                                 |                                                                                                                                                                                                                                            |                     |
|----------|-----------------------------------|------------------------|------------------------------------------------------------------------------|-----------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------|
| 220620-3 | North of Pig farm, along road 447 | Basaltic andesite lava | Pl (55-60 vol%, <1.2mm)<br>Mag (10 vol%, <1mm)<br>Pyroxene (5-10 vol%, <2mm) | Fine to medium grained phenocrysts in a fine-grained groundmass | Porphyritic<br>Rounded disseminated Mag sometime forming small aggregates (~2mm)<br>Crystal rich (~75vol%), Pl rich<br>Vesicular, irregularly shaped (~8mm)<br>Pl is mostly uniform in size and is rounded making the rock look "spotted". | Medium to dark Grey |
|----------|-----------------------------------|------------------------|------------------------------------------------------------------------------|-----------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------|



|                                                                                    |                                   |                        |                                                                              |                                                                      |                                                                                                                                                                                 |           |
|------------------------------------------------------------------------------------|-----------------------------------|------------------------|------------------------------------------------------------------------------|----------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------|
| 220620-4                                                                           | North of Pig farm, along road 447 | Basaltic andesite lava | Pl (35-40 vol%, <3mm)<br>Pyroxene (5-10 vol%, <2mm)<br>Mag (5-10 vol%, <1mm) | Fine to medium grained phenocrysts in a very fine grained groundmass | Porphyritic<br>Crystal poor (40-50 vol%)<br>Disseminated rounded Mag<br>Pl are sub rounded to blocky<br>Weathered on the outside of sample, as plagioclase has weathered white. | Dark grey |
|  |                                   |                        |                                                                              |                                                                      |                                                                                                                                                                                 |           |



|          |                        |                                       |                                                                           |                                                      |                                                                                                                                                       |           |
|----------|------------------------|---------------------------------------|---------------------------------------------------------------------------|------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------|-----------|
| 220621-1 | North side of road 448 | Basaltic andesite (Shinkawa andesite) | Pl (50 vol%, <4.5mm)<br>Mag (10 vol%, <1mm)<br>Pyroxene (10 vol%, <1.5mm) | Fine to medium grained phenocrysts in a fine grained | Porphyritic<br>Crystal rich (70 vol%), Pl rich<br>Mag forms small aggregates and in groundmass<br>Pl is subrounded to blocky, rock is spotted with Pl | Dark grey |
|----------|------------------------|---------------------------------------|---------------------------------------------------------------------------|------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------|-----------|

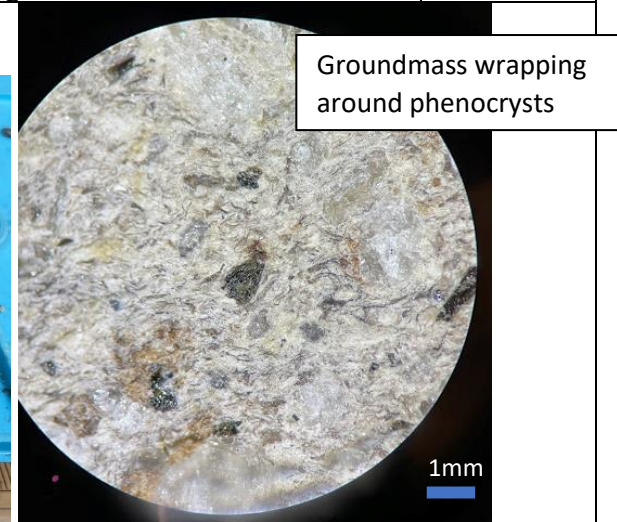




|                  |                                |                                                  |                                                                              |                                                                      |                                                                                                                                                       |           |
|------------------|--------------------------------|--------------------------------------------------|------------------------------------------------------------------------------|----------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------|-----------|
| <b>220621-2F</b> | Side of road 448, Uono Village | Upper andesite (but possibly Yamashita Andesite) | Pl (25 vol%, <2.5mm)<br>Mag (10-15 vol%, <1mm)<br>Pyroxene (25 vol%, <2.5mm) | Fine to medium grained phenocrysts in a very fine-grained groundmass | Porphyritic<br>Pl poor, pyroxene rich (more pyroxene rich and Pl poor than other lower andesites)<br>Rounded Mag forms clumps (2mm) and disseminated. | Dark grey |
|------------------|--------------------------------|--------------------------------------------------|------------------------------------------------------------------------------|----------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------|-----------|

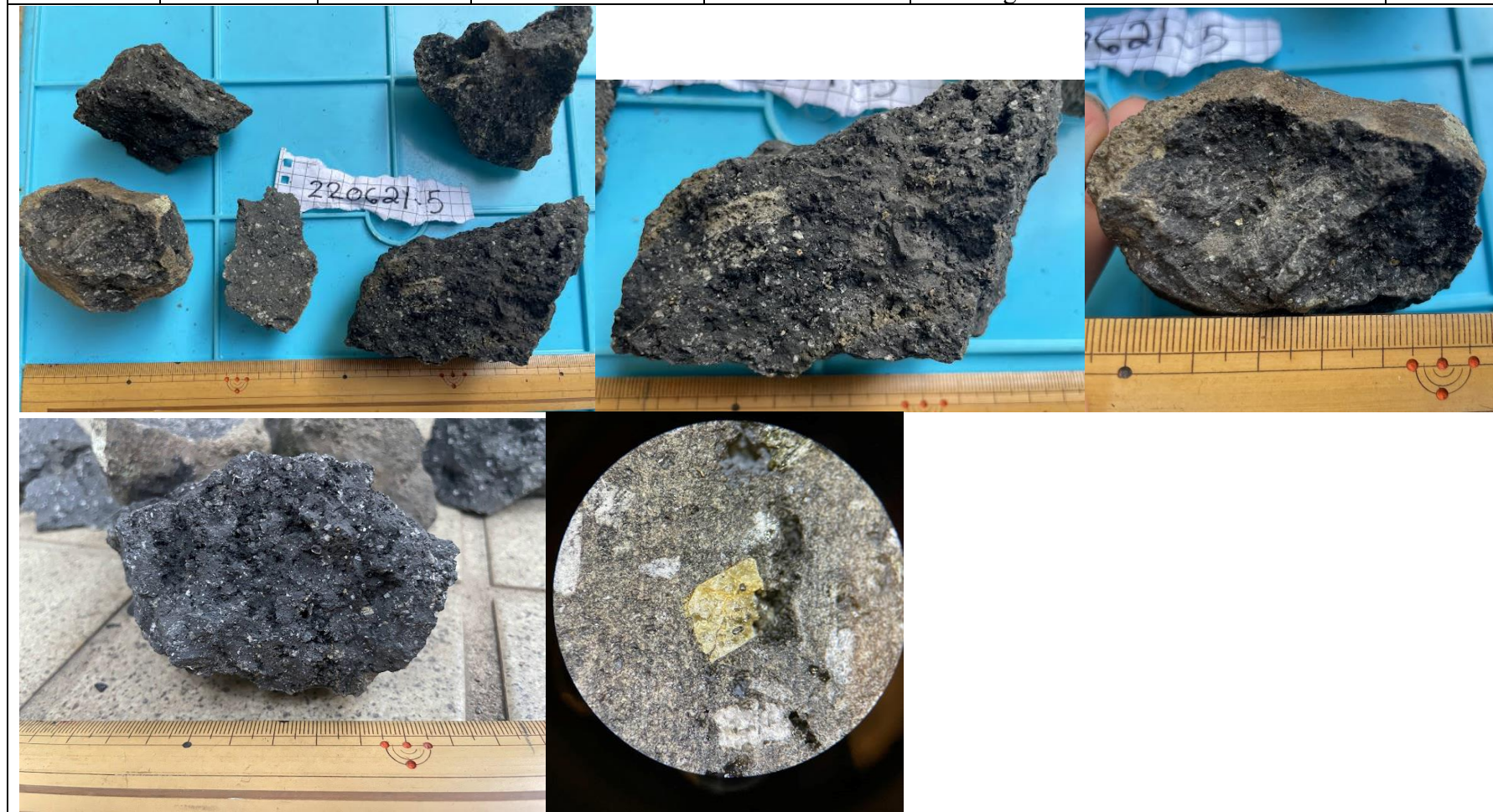


|          |              |                                      |                                                                                                                           |              |                                                                                                                                                                        |                     |
|----------|--------------|--------------------------------------|---------------------------------------------------------------------------------------------------------------------------|--------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------|
| 220621-4 | Goshiki town | volcanic breccia with dacitic matrix | Qz (15 vol%, <1.5mm)<br>Mag (10 vol%, <1mm)<br>Pl (25-30 vol%, <2mm)<br>Pyroxene (20 vol%, <3.5mm)<br>Amp (10 vol%, <1mm) | Fine grained | Slightly weathered brown<br>Qz is typically corroded<br>Groundmass looks welded and is wrapping around phenocrysts<br>Small Amp Grains aligned in direction of welding | light brownish grey |
|----------|--------------|--------------------------------------|---------------------------------------------------------------------------------------------------------------------------|--------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------|





|                                                              |                                        |             |                                                                                                |                                                                 |                                                                                                                                                                                                                                                                |                |
|--------------------------------------------------------------|----------------------------------------|-------------|------------------------------------------------------------------------------------------------|-----------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|
| <b>220621-5</b><br><b>Five fragments in the general area</b> | 150m west of intersection south of 448 | Ol Andesite | Pl (20 vol%, <2.5mm)<br>Ol (5-10 vol%, <2mm)<br>Mag (10vol%, <1mm)<br>Pyroxene (20 vol%, <4mm) | Fine to medium grained phenocrysts in a fine-grained groundmass | Pyroclastic<br>Porphyritic<br>Vesicular, irregularly shaped (0.5mm – 5mm)<br>Ol bearing and is weathered to yellow green.<br>Less Pl abundance compared to other Lower andesites)<br>More pyroxene than other andesite samples<br>Pl is aligned in some areas. | Very dark grey |
|--------------------------------------------------------------|----------------------------------------|-------------|------------------------------------------------------------------------------------------------|-----------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|



|                                                                                  |                 |                  |                                              |                                              |                                                                                                                              |           |
|----------------------------------------------------------------------------------|-----------------|------------------|----------------------------------------------|----------------------------------------------|------------------------------------------------------------------------------------------------------------------------------|-----------|
| 220621-6                                                                         | Town of Goshiki | Volcanic Breccia | Pl (~65 vol%, <5mm)<br>Mag (~10% vol%, <2mm) | Coarse grained clasts in fine grained matrix | Brecciated<br>Crystal rich (>75 vol%) and Pl rich<br>Clasts are subangular<br>Mag occurs as rounded disseminated phenocrysts | Dark grey |
|  |                 |                  |                                              |                                              |                                                                                                                              |           |

|                                                                                   |                               |                    |                                                                           |                                                                 |                                                                                                                |             |
|-----------------------------------------------------------------------------------|-------------------------------|--------------------|---------------------------------------------------------------------------|-----------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------|-------------|
| 220621-7                                                                          | Along trail south of road 448 | Kusumoto andesite? | Pl (~55 vol%, <5mm)<br>Mag (5-10 vol%, <1mm)<br>Pyroxene (~10 vol%, <4mm) | Fine to coarse grained phenocrysts in a fine grained groundmass | Porphyritic<br>Flow banded by crystal abundance<br>Pl forms subrounded to blocky crystals<br>Slightly oxidized | Medium grey |
|  |                               |                    |                                                                           |                                                                 |                                                                                                                |             |



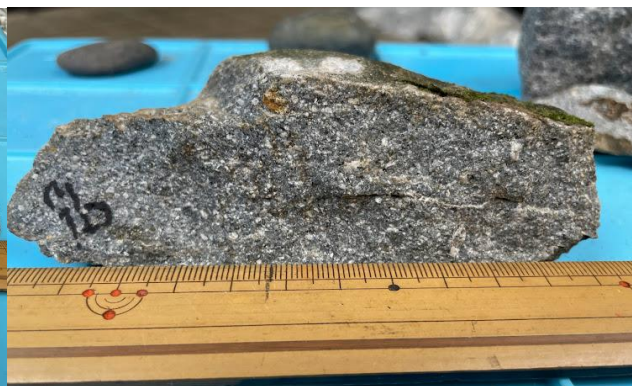
|          |                               |                   |                                           |                                                                 |                                                                              |             |
|----------|-------------------------------|-------------------|-------------------------------------------|-----------------------------------------------------------------|------------------------------------------------------------------------------|-------------|
| 220621-8 | Along trail south of road 448 | Kusumoto andesite | Pl (70 vol%, <6mm)<br>Mag (10 vol%, <2mm) | Fine to medium grained phenocrysts in a fine-grained groundmass | - Porphyritic<br>Very crystal rich (80-85 vol%)<br>Disseminated euhedral Mag | Medium grey |
|----------|-------------------------------|-------------------|-------------------------------------------|-----------------------------------------------------------------|------------------------------------------------------------------------------|-------------|



|                                                                                   |                                      |                      |                                                                              |                                                                             |                                                                                                                        |           |
|-----------------------------------------------------------------------------------|--------------------------------------|----------------------|------------------------------------------------------------------------------|-----------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------|-----------|
| <b>220621-9A</b>                                                                  | South of road 448<br>bottom of cliff | Kusumoto<br>Andesite | Pl (15-20 vol%, <4mm)<br>Mag (5-10 vol%, <2mm)<br>Pyroxene (5-10 vol%, <3mm) | Fine to medium<br>grained<br>phenocrysts in a<br>fine grained<br>groundmass | Porphyritic<br>Crystal poor (30% vol)<br>Slightly weathered<br>Disseminated euhedral Mag<br>Pl is subrounded to blocky | Dark grey |
|  |                                      |                      |                                                                              |                                                                             |                                                                                                                        |           |



|                  |                                   |                      |                                              |                                                                          |                                                                                                                                                                               |                |
|------------------|-----------------------------------|----------------------|----------------------------------------------|--------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|
| <b>220621-9B</b> | South of road 448<br>top of cliff | Kusumoto<br>Andesite | Pl (55 vol%, <4mm)<br>Mag (10-15 vol%, <2mm) | Fine to medium<br>grained phenocrysts<br>in a fine grained<br>groundmass | Porphyritic<br>Crystal rich (70% vol)<br>Pl crystals are aligned in the<br>same direction, looks like a lava<br>flow<br>Disseminated Mag<br>Slightly weathered<br>Flow Banded | Medium<br>grey |
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| 220622-1 | South of smelly pig farm along road 447 | Kuronsan Andesite – basaltic andesite | Pyroxene (25-30 vol%, <4mm)<br>Pl (20 vol%, <3.5mm)<br>Mag (~15 vol%, <1mm) | Fine to medium grained phenocrysts in a very fine grained groundmass | Porphyritic<br>Pl poor, pyroxene rich<br>Pl is typically rounded to subrounded<br>Well formed pyroxene crystals<br>Rounded subhedral Mag is disseminated<br>Possible Ol? (bronze yellow mineral that is subrounded and corroded, 5% vol, <1mm) | Dark grey |
|----------|-----------------------------------------|---------------------------------------|-----------------------------------------------------------------------------|----------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------|



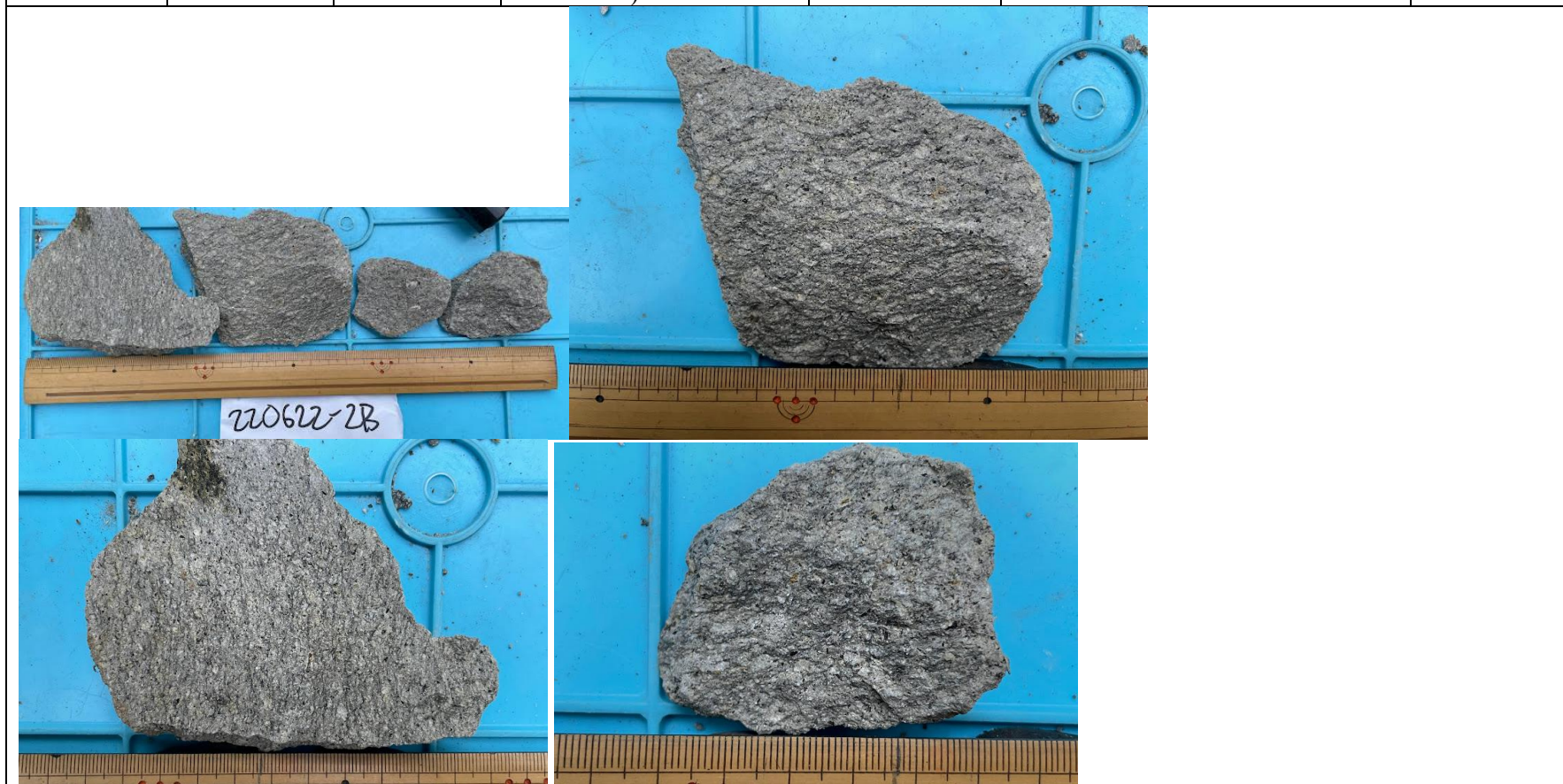
Porphyritic texture, outlining corroded bronze yellow mineral (<1mm)

|                  |                                                                |                   |                                                                    |                        |                                                                                                                                                                                                     |                     |
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| <b>220622-2A</b> | South of smelly pig farm along road 447 – along a small stream | Kuronsan andesite | Pl (50 vol%, <3mm)<br>Qz (15-20 vol%, <2mm)<br>Mag (10 vol%, <1mm) | Fine to medium grained | Disseminated Mag<br>Crystals are aligned in the same direction of flow/flow banded, especially Mag<br>Qz is rounded and corroded with a conchoidal fracture<br>In between aphanitic and porphyritic | Light brownish grey |
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| <b>220622-2B</b> | South of smelly pig farm along road 447 – along a small stream | Kuronsan andesite | Pl (50 vol%, <3mm)<br>Qz (15-20 vol%, <2mm)<br>Pyroxene (5 vol%, <3mm)<br>Mag (10 vol%, <1mm) | Fine to medium grained | Similar to sample 220622-2A<br>Flow banded, crystals are aligned in the same direction<br>Qz is rounded and corroded<br>In between aphanitic and porphyritic | Light brownish grey |
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|                 |                              |                   |                                                                        |                                                                 |                                                                                                                             |           |
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| <b>220622-4</b> | SW of pig farm along a river | Kuronsan Andesite | Pl (50 vol%, <5mm)<br>Mag ( 15 vol%, <1mm)<br>Pyroxene (10 vol%, <3mm) | Fine to medium grained phenocrysts in a fine grained groundmass | Porphyritic<br>Disseminated euhedral Mag<br>Crystals are almost aligned<br>Thin flow banding<br>Pl is rounded to subrounded | Dark grey |
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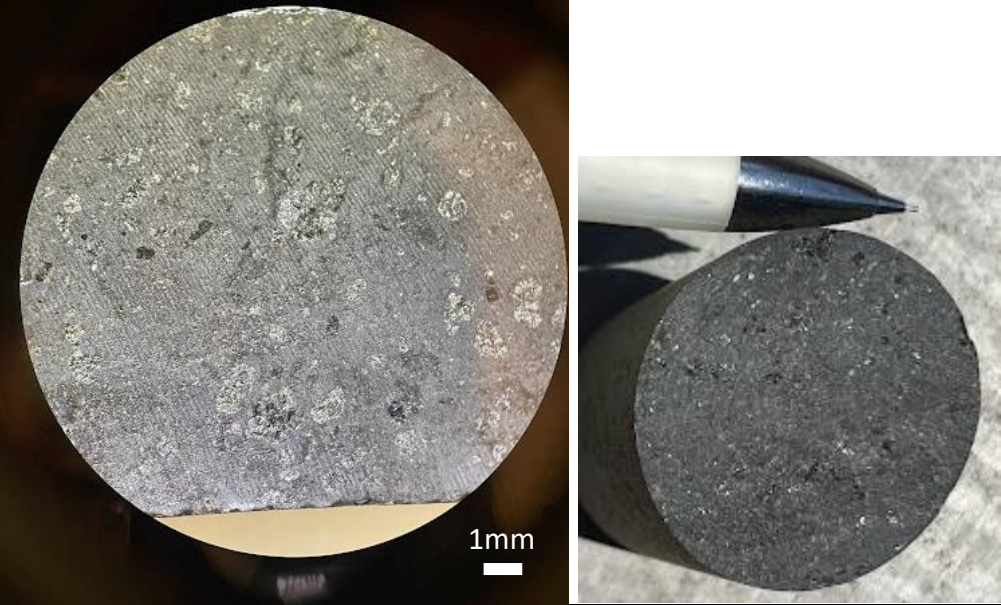
|          |                              |                   |                                                                             |                                                                 |                                                                                                                                                       |           |
|----------|------------------------------|-------------------|-----------------------------------------------------------------------------|-----------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------|-----------|
| 220622-5 | SW of pig farm along a river | Kuronsan andesite | Pl (45 vol%, <7mm)<br>Mag (5-10 vol%, <1.5mm)<br>Pyroxene (5-10 vol%, <5mm) | Fine to coarse grained phenocrysts in a fine grained groundmass | Porphyritic<br>Pl forms large blocky phenocrysts<br>Well formed coarse pyroxene with nice cleavage<br>Coarser phenocrysts compared to other andesites | Dark grey |
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|          |                        |                              |                                                                                             |              |                                                                                                             |            |
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| 220622-6 | North of Kusumoto Hill | Supposedly Kuronsan Andesite | Pl (60 vol%, <3mm)<br>Qz (10 vol%, <2mm)<br>Mag (10 vol%, <1mm)<br>Pyroxene (10 vol%, <2mm) | Fine grained | In between aphanitic to porphyritic<br>Less magnetic than darker coloured andesites<br>Mag forms aggregates | Light grey |
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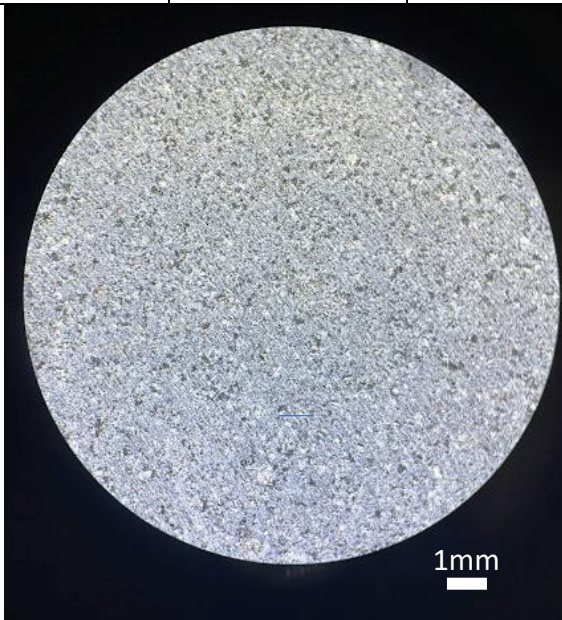




|                                                                                    |                                                      |                                                                              |                                                              |                                                                   |                    |
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| 220623-1                                                                           | DDH17MAHY-8 – supposedly intersects olivine andesite | Pl (20 vol%, <4mm)<br>Pyroxene (15-20 vol%, <2mm)<br>Mag - very fine grained | Fine to medium phenocrysts in a very fine grained groundmass | Porphyritic<br>Crystal poor (30% vol)<br>Pl subrounded to rounded | Dark blackish grey |
|  |                                                      |                                                                              |                                                              |                                                                   |                    |



|          |                                                                            |          |                                                                            |                        |                                                                                                                                                               |                      |
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| 220623-2 | DDH17MAHY-8, 695 m depth (total length of DDH is 700.7 m, inclination 25 d | andesite | Pl (50 vol%, <2mm)<br>Mag (10-15 vol%, <0.5mm)<br>Pyroxene (10 vol%, <1mm) | Fine to medium grained | Fine grained Mag is disseminated<br>In between aphanitic and porphyritic<br>Crystals do not typically vary in size<br>Texture is homogenous throughout sample | Medium to light grey |
|----------|----------------------------------------------------------------------------|----------|----------------------------------------------------------------------------|------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------|



|          |                                                                |          |                                                                                                                        |                                                                   |                                                                                                                                                                                                                                                                                        |           |
|----------|----------------------------------------------------------------|----------|------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------|
| 220623-3 | Yamada ore zone,<br>~100m below surface,<br>West 138 crosscut. | Andesite | Pyroxene (40 vol%, <5mm)<br>Mag (15 vol%, <1mm)<br>Pl (15-20 vol%, <2mm)<br>Chalcopryite? (<5 vol%, very fine grained) | Medium to coarse grained phenocrysts in a fine grained groundmass | Slightly oxidized<br>Porphyritic<br>Pyroxene rich - Well formed coarse pyroxene<br>Rounded Mag is disseminated, sometimes forming aggregates<br>Has less Pl and is more mafic than all the other andesites<br>Bonze yellow mineral forms clusters (<2mm) and is sometimes disseminated | Dark grey |
|----------|----------------------------------------------------------------|----------|------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------|



Chalcopryite cluster (2mm)





|          |                                        |                     |                                                                       |                                                                 |                                                                                                              |             |
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| 220623-4 | 1km North of the Hishikari mine office | Yamadagawa andesite | Pl (55 vol%, <5mm)<br>Mag (10 vol%, <2mm)<br>Pyroxene (10 vol%, <2mm) | Fine to medium grained phenocrysts in a fine grained groundmass | Crystal rich (75% vol), Pl rich<br>Porphyritic<br>Rounded disseminated Mag<br>Phenocrysts are almost aligned | Medium grey |
|----------|----------------------------------------|---------------------|-----------------------------------------------------------------------|-----------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------|-------------|

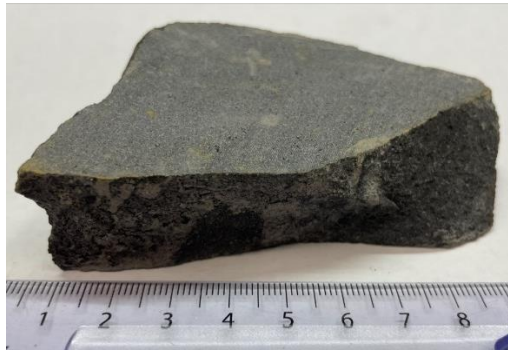


|          |                                |                        |                                                                             |                                                                 |                                                                                                                                                                                                                                |                              |
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| 220623-5 | South of Japan Farm (pig farm) | Basaltic andesite lava | Pl (50 vol%, <2.5mm)<br>Mag (5-10 vol%, ~0.5mm)<br>Pyroxene (10 vol%, <2mm) | Fine to medium grained phenocrysts in a fine grained groundmass | Porphyritic<br>Slightly weathered<br>Crystal rich (70% vol)<br>Pl almost uniform in size (0.5-2mm ) and typically corroded. Pl rounded to subrounded making the rock look “spotted”.<br>Mag very fine grained and disseminated | Dark to medium brownish grey |
|----------|--------------------------------|------------------------|-----------------------------------------------------------------------------|-----------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------|





|               |                  |                        |     |                                                                      |             |           |
|---------------|------------------|------------------------|-----|----------------------------------------------------------------------|-------------|-----------|
| <b>YAM001</b> | Yamagano deposit | Basaltic andesite lava | N/A | Fine to medium grained phenocrysts in a dark fine grained groundmass | porphyritic | Dark grey |
|---------------|------------------|------------------------|-----|----------------------------------------------------------------------|-------------|-----------|

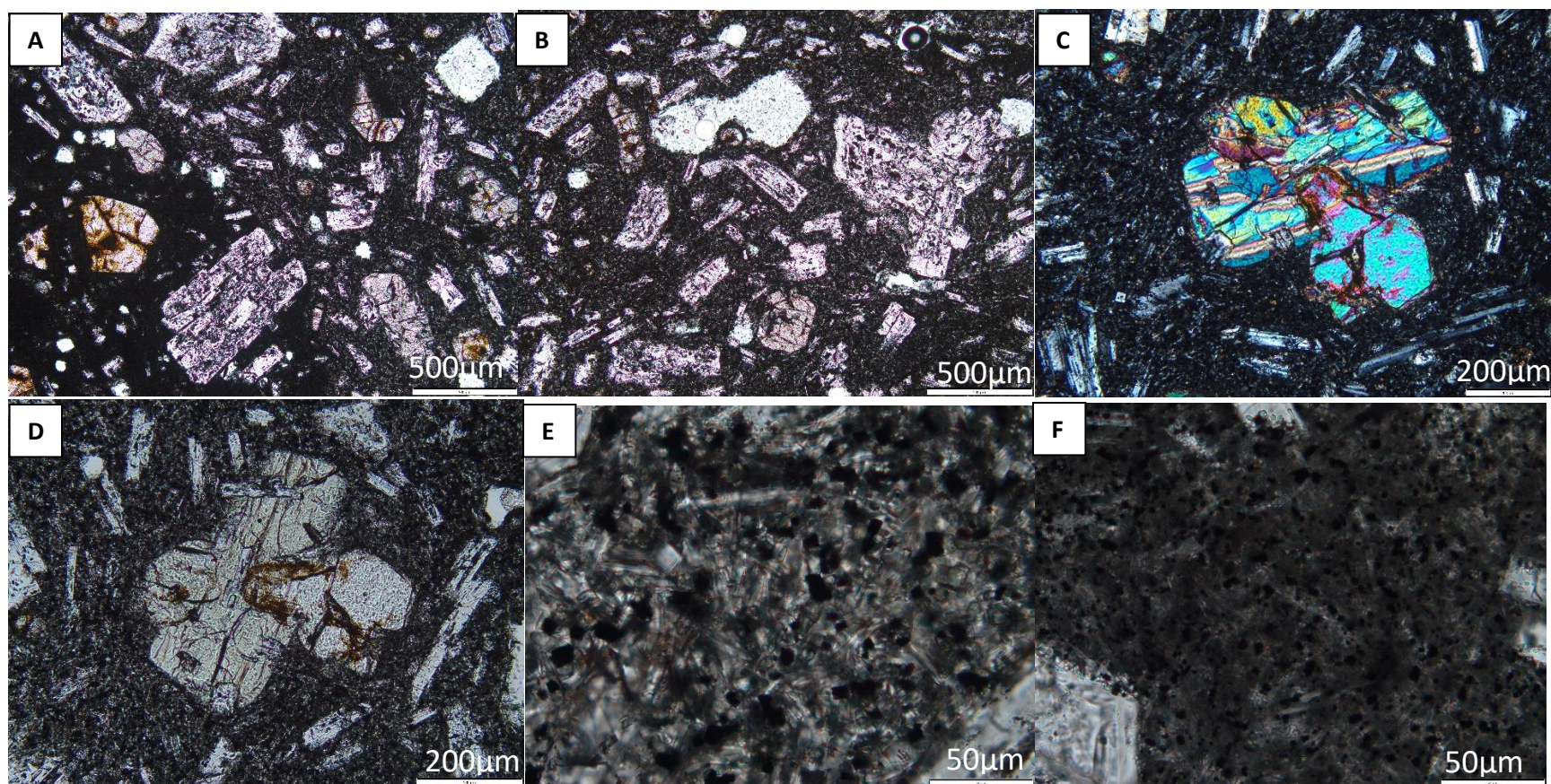


|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                  |                        |     |                                                                      |             |           |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------|------------------------|-----|----------------------------------------------------------------------|-------------|-----------|
| <b>YAM002</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | Yamagano deposit | Basaltic andesite lava | N/A | Fine to medium grained phenocrysts in a dark fine grained groundmass | porphyritic | Dark grey |
|  <p>The image contains three photographs of a dark grey, porphyritic basaltic andesite lava sample (YAM002). The leftmost photo shows a large, irregularly shaped rock fragment with a ruler below it, indicating a length of approximately 12 cm. The middle photo shows a smaller, rectangular rock fragment held by a hand, with a ruler below it indicating a length of approximately 9 cm. The rightmost photo shows a third rock fragment, also with a ruler below it, indicating a length of approximately 8 cm. All three photos show the characteristic dark grey color and fine-grained texture of the lava, with some lighter-colored phenocrysts visible in the groundmass.</p> |                  |                        |     |                                                                      |             |           |

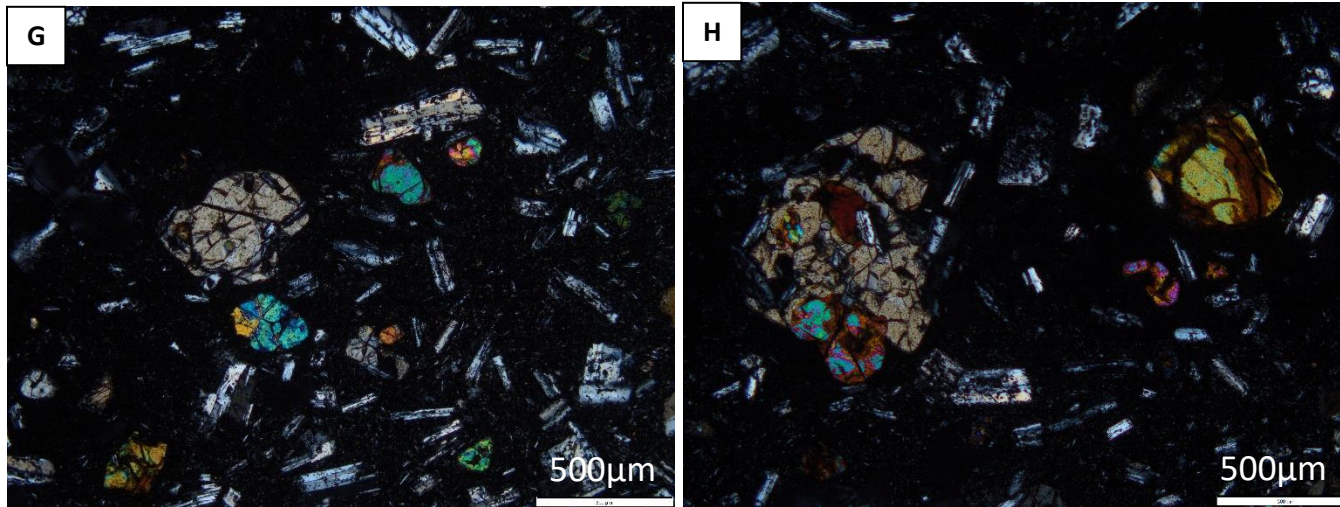


### **APPENDIX 3.2. Petrographic Descriptions**

| Sample 220620-1, north of Japan Farm, west of Isa city    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|-----------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Mineralogy                                                | Texture                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| Pl 45%<br>Cpx 10-15%<br>Opx 5-10%<br>Ol ~10%<br>Mag trace | The groundmass includes darker and lighter areas, both areas include microlites. At high magnification (50x), it appears that the lighter groundmass looks like in contains more lighter minerals. The darker areas at a high magnification (50x) contains fewer lighter minerals. Both are very fine-grained Ol is present in both areas. A few vesicles are also present. Ol commonly has a brown stain. Ol is colourless in PPL and are euhedral with no inclusions. Texture varies in Pl which commonly have sieve texture with overgrowth, and some are sieved with no overgrowth. There is a lack of mag which only occurs finely disseminated in the groundmass. |

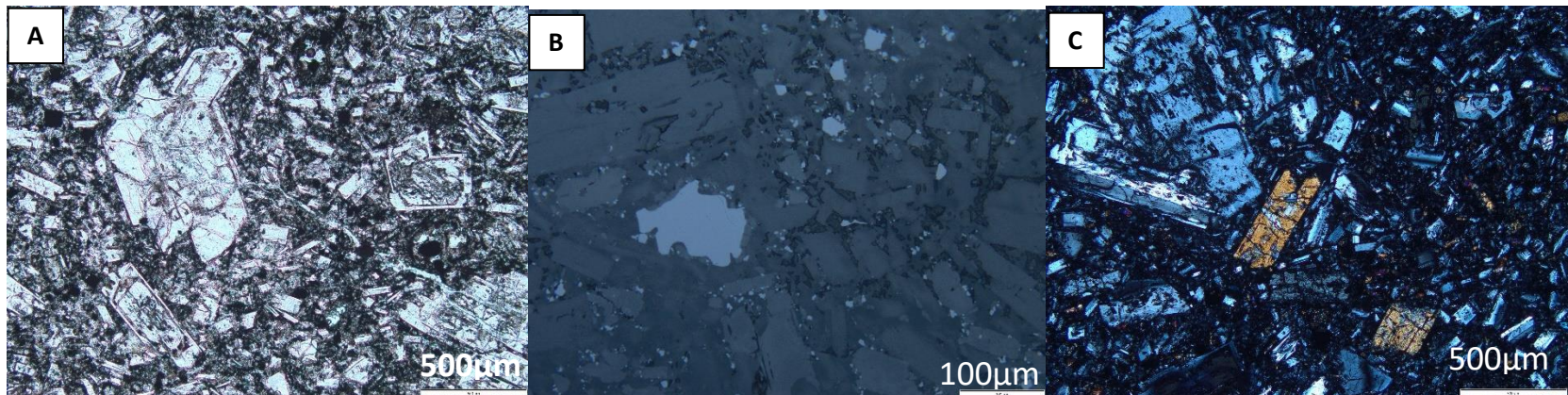






**Figure A3.2-1:** Sample 220620-1 A) Groundmass with darker area (left) and lighter area (right), Ol with brown stain and sieved Pl with overgrowth, B) Sieved Pl with overgrowth, C and D) Cpx and Ol aggregate and microlites in groundmass, E) Lighter groundmass at high magnification (50x), F) Darker groundmass at high magnification (50x), G) Opx and Ol phenocrysts, H) Opx and Ol aggregate (left) and Ol (right)

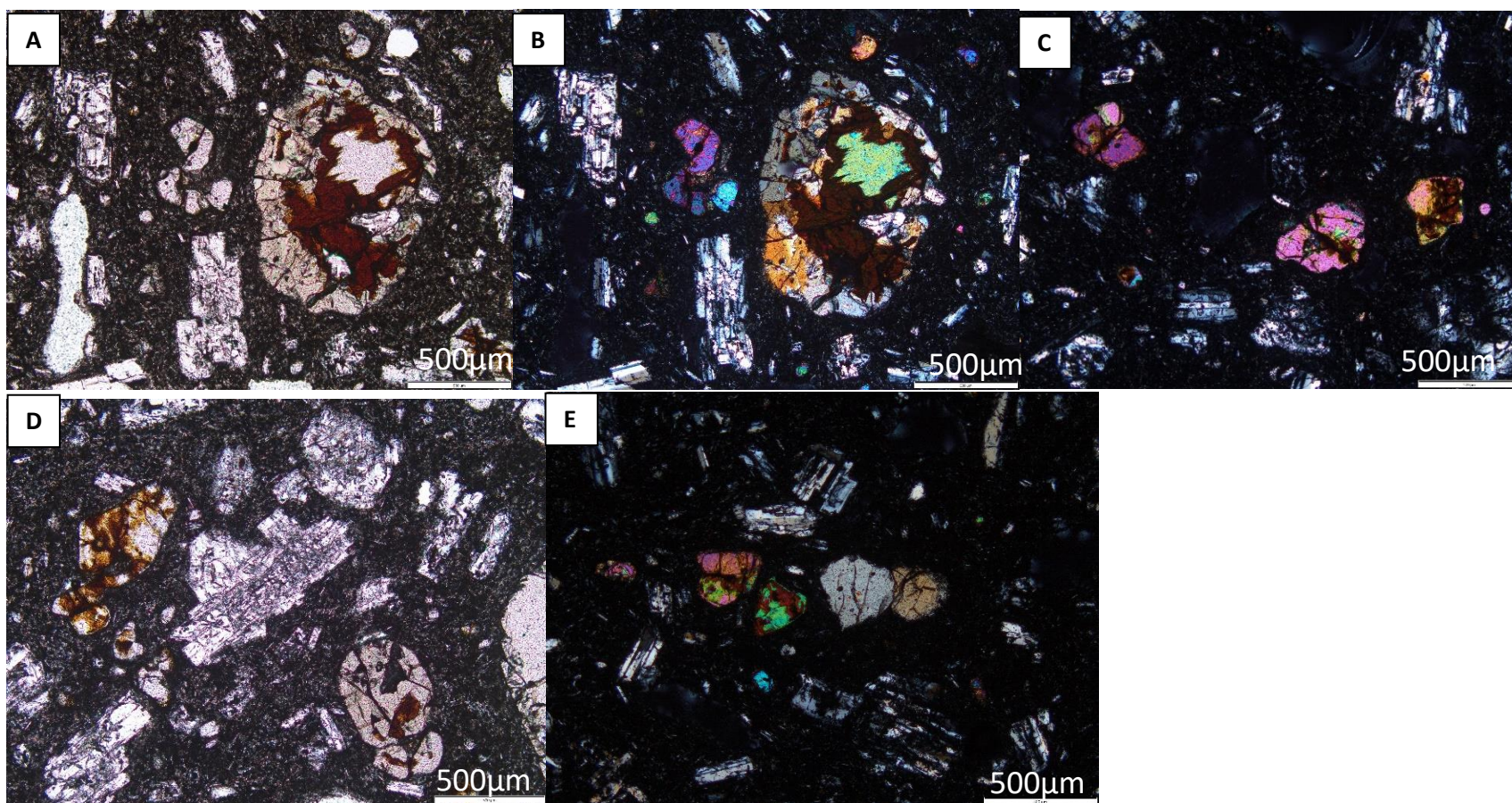
| Sample 220620-2, Andesite north of Japan Farm, west of Isa city |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|-----------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Mineralogy                                                      | Texture                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Pl >70%<br>Opx 10%<br>Cpx 5-10%<br>Mag Trace-4%                 | Very crystal rich (>85% total crystal volume) and Pl rich (>70% modal abundance) Pl is euhedral and exhibits many disequilibrium textures, commonly sieved Pl with overgrowth. There are also several Pl grains that are not sieved. The groundmass is very fine grained and is filled with microlites. The microlites align in the same general direction. Several Pl lathes are present. Cpx and Pl also form aggregates. Mag mainly occurs disseminated in groundmass or as inclusions in Opx or Cpx. Several Mag phenocrysts are also present but in trace amounts. These Mag phenocrysts have a homogenous internal texture. Opx is euhedral |



**Figure A3.2-2:** Sample 220620-2: Various textures in Pl, many sieved with overgrowth, B) Mag, C) Opx and Pl

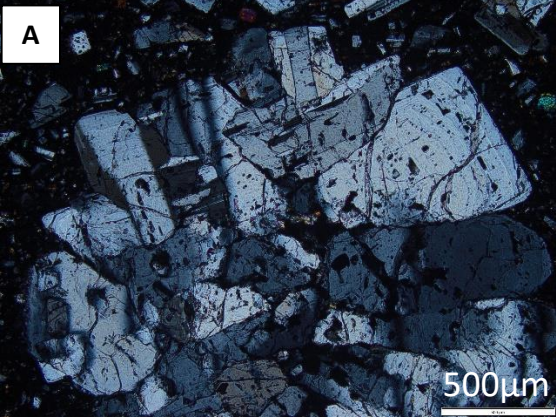
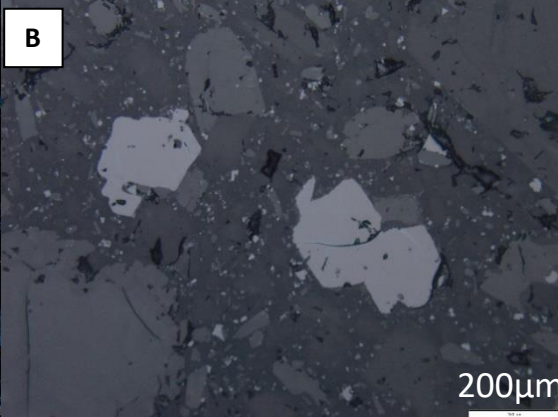
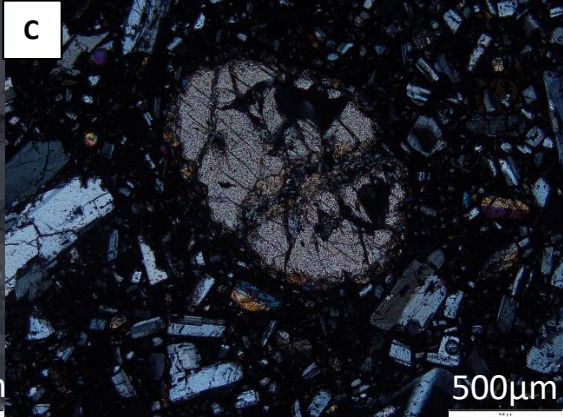
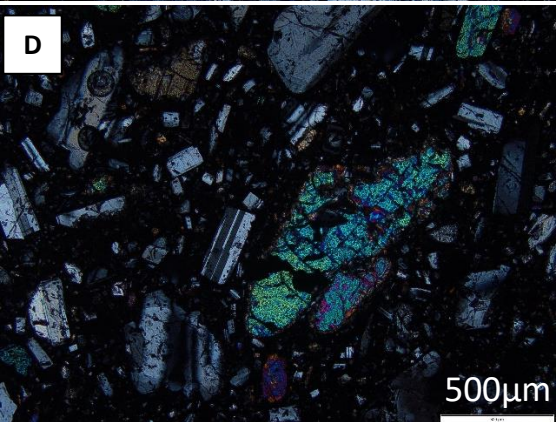
| Sample 220620-3 North of Japan Farm, west of Isa city    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|----------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Mineralogy                                               | Texture                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Opx 20%<br>Cpx 10-15%<br>Pl 30%<br>Ol 5-10%<br>Mag trace | Groundmass is dark and very fine grained containing coarse microlites. Opx grains are coarser and more abundant than Cpx. Ol is colourless in PPl and have high birefringence in XPL. Almost all Ol grains have an orange-brown stain and include no inclusions. Ol also occurs as cores within Opx, possible suggesting that Ol reacted with SiO <sub>2</sub> in the melt to crystallize Opx. The orange-brown stain and fills in fractures of several Opx, Cpx, and Ol grains. Pl is euhedral and commonly exhibits sieve texture. Several Pl grains are sieved and have overgrowth. Mag only occurs finely disseminated in the groundmass and not as inclusions. Mag grains also cluster in foreign fragments. The internal texture of mag is typically homogenous. Some vesicles are present – vesicular. Cpx and Opx form aggregates |





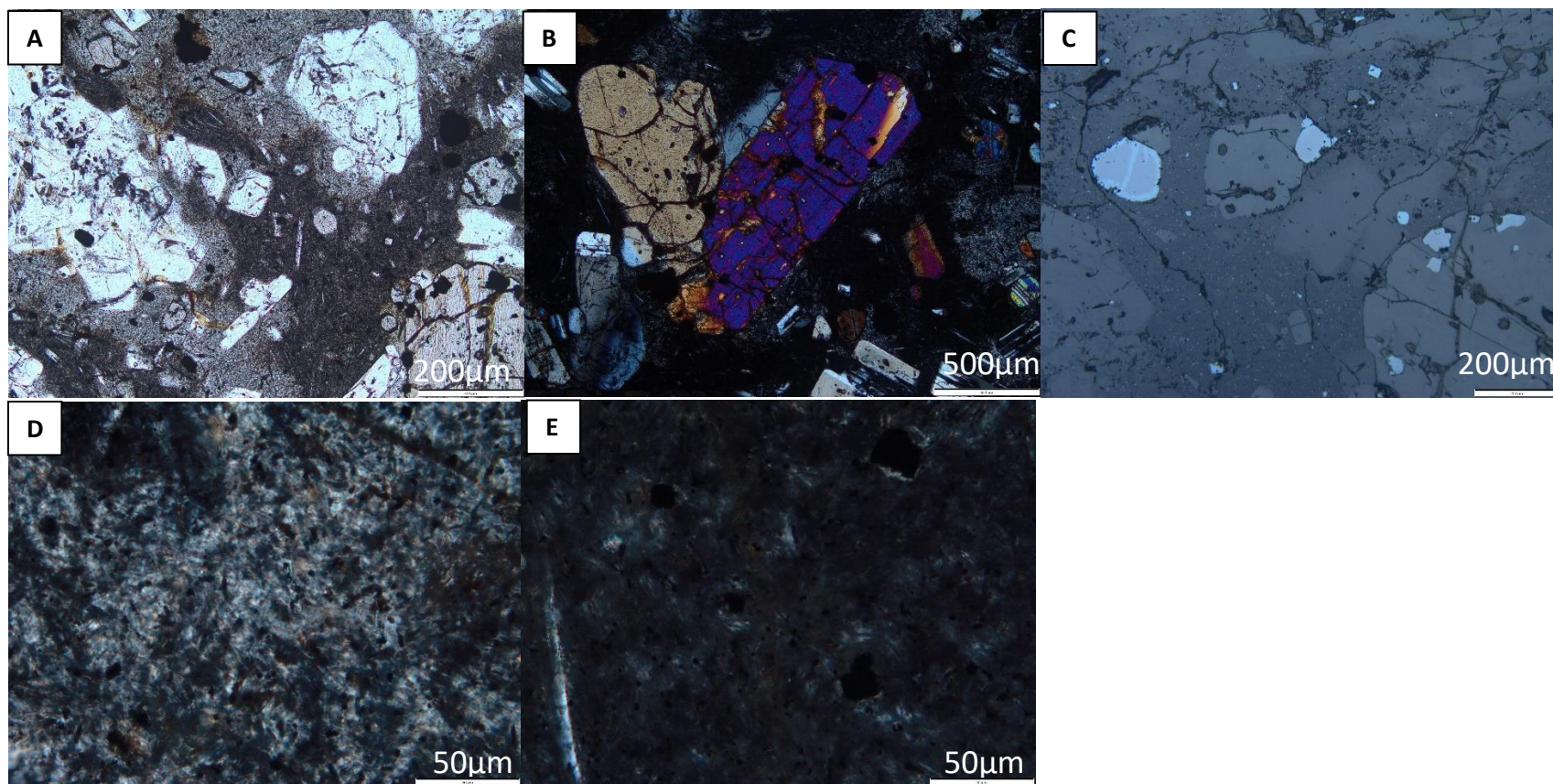
**Figure A3.2-3:** Sample 220620-3: A and B) Pl, Opx with orange-brown stain with Ol in the core, C) Ol phenocrysts, D) Opx and Ol with hydrothermal alteration and sieved Pl, E) Ol (left) and Opx (right)



| Sample 220620-4, north of Japan Farm, west of Isa city                                                                                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Mineralogy                                                                                                                                                                                                                                                                                                                                                                                                   | Texture                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Pl ~55%<br>Cpx 15%<br>Opx 10%<br>Mag trace - 5%<br>Ol 5-10%                                                                                                                                                                                                                                                                                                                                                  | Pl is euhedral where several Pl grains exhibit growth zoning. A few Pl grains are sieved with Pl overgrowth, but most are not sieved. Twinning is also very common. Many Pl grains form aggregates and/or include fluid inclusions. The internal texture of Mag is mostly homogenous, some with exsolution that resemble cracks. Mag occurs mostly as phenocrysts or disseminated in the groundmass. Several Pl and Cpx grains include Mag inclusions. Ol is colourless in PPL. |
| <div> <div>  </div> <div>  </div> <div>  </div> <div>  </div> </div> |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |

**Figure A3.2-4:** Sample 220620-4, A) Pl aggregate, B) Mag phenocrysts, C) Opx, D) Cpx, Opx and Pl with fluid inclusions

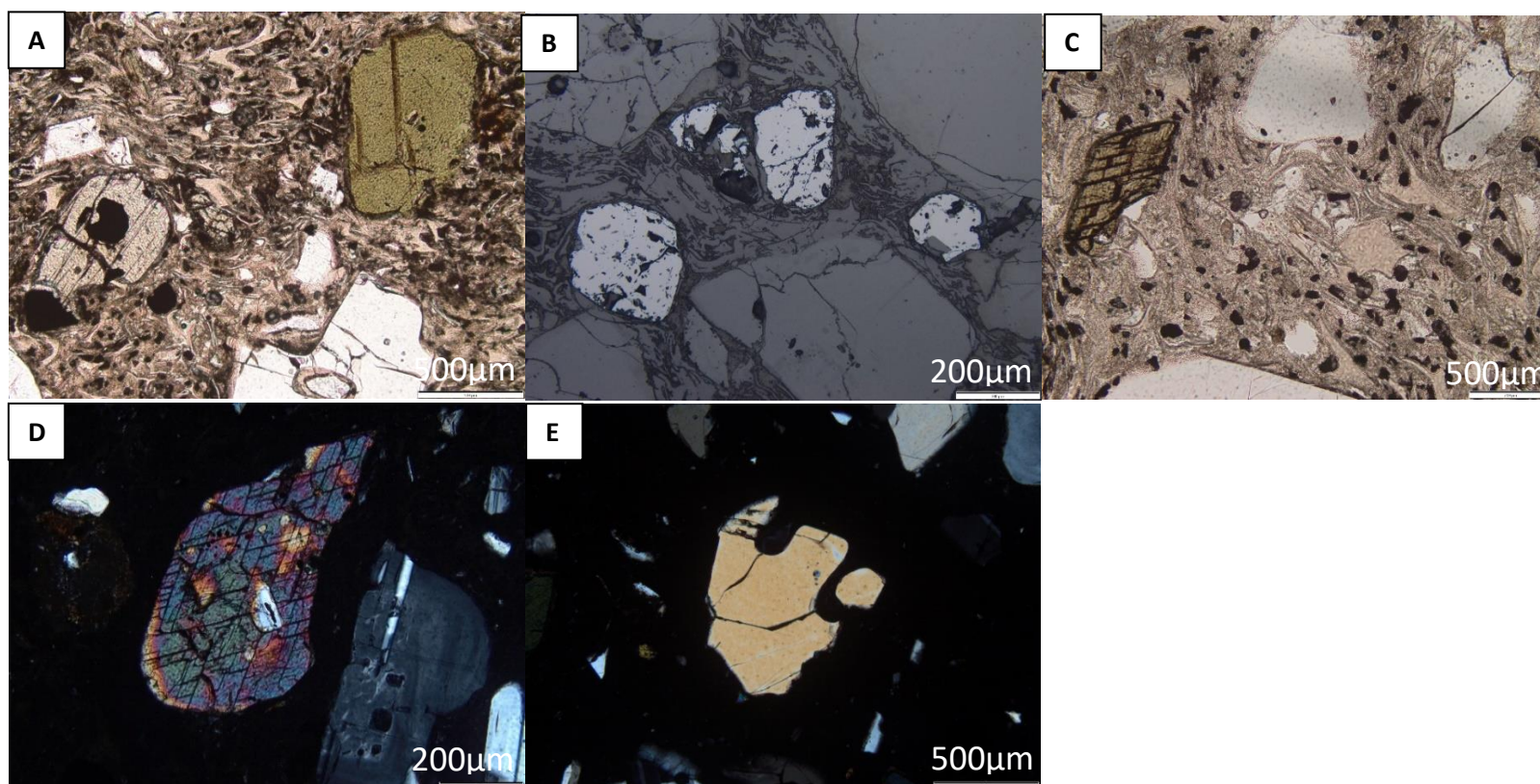
| Sample 220621-1, Andesite in the town of Shinkawa |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|---------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Mineralogy                                        | Texture                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Pl 50%<br>Cpx 15%<br>Opx 10%<br>Mag trace -5%     | The groundmass contains lighter and darker areas where both are very fine grained. The lighter area at a high magnification (50x) look like it contains more lighter minerals. The darker areas at high magnification (50x) contain darker minerals. The darker areas are spotty in the groundmass. The groundmass contains microlites in a minor amount. Various textures in Pl are present, including several grains with either growth zoning, unsieved or sieved with overgrowth. A few Pl grains have an almost completely melted core with overgrowth. Sample is crystal rich (>80vol.%). Mag either occurs disseminated in the groundmass, as phenocrysts and inclusions in Cpx and Opx. Several mag grains have exsolution towards the rim. Cpx, Opx, Pl and Mag form aggregates. |



**Figure A3.2-5:** Sample 220621-1, A) Fine grained groundmass with lighter and darker areas, B) Euhedral Opx and Cpx, C) Mag with exsolution towards the rim, D) Lighter groundmass at high magnification (50x), E) Darker groundmass at high magnification (50x)

| Sample 220621-4, Shishimano dacite                                       |                                                                                                                                                                                                                                                                                                      |
|--------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Mineralogy                                                               | Texture                                                                                                                                                                                                                                                                                              |
| Pl ~10%<br>Qtz ~ 15%<br>Cpx ~5%<br>Opx ~5%<br>Amp ~10%<br>Mag trace - 5% | Pl is euhedral and commonly exhibits growth zoning, no sieve textures are present. Groundmass is very glassy. Mag is euhedral and only occurs as phenocrysts or as inclusions in Cpx, and Opx. Mag is euhedral and typically has a homogenous internal texture. Several Qtz phenocrysts are embayed. |

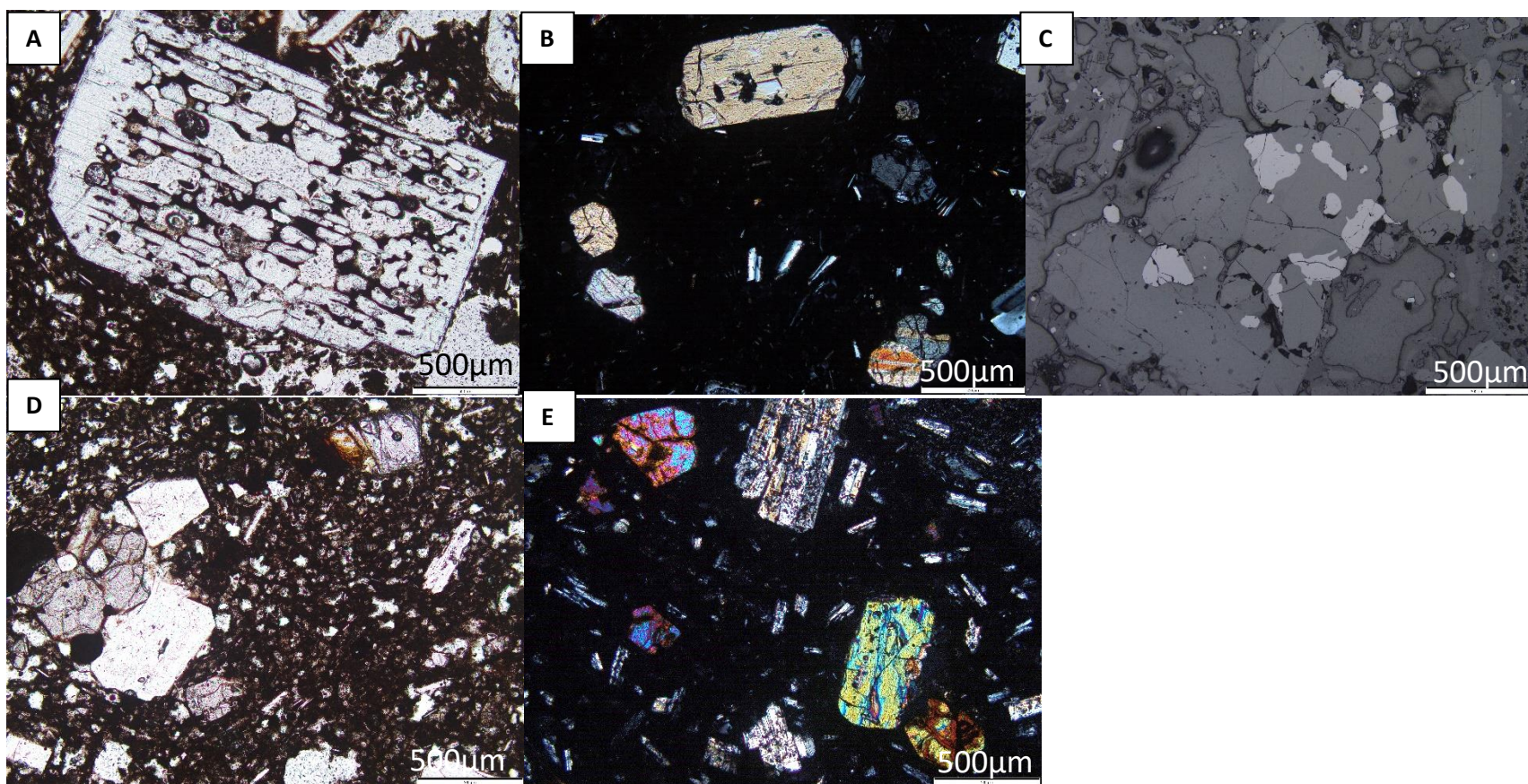




**Figure A3.2-6:** Sample 220621-4, A) Opx (pale beige) and Amp (green) B) Euhedral Mag phenocrysts with homogeneous internal texture, C) Glassy groundmass, Amp and Qz phenocrysts, D) Amp, E) Qz phenocryst with embayment

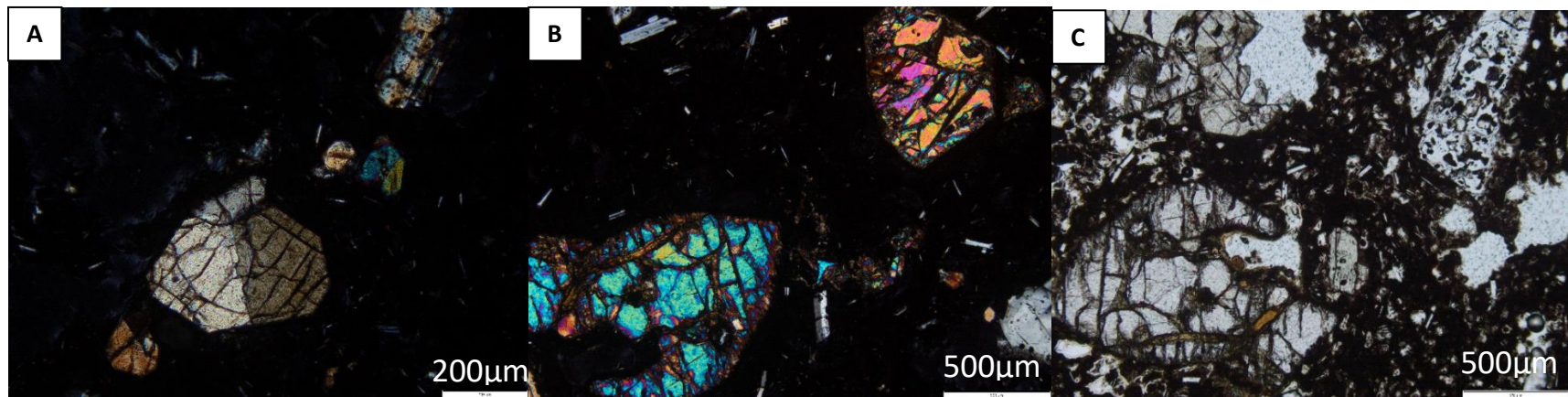
| Sample 220621-5 (1/2 Thin sections), Pyroclastic Olivine Andesite |                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|-------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Mineralogy                                                        | Texture                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| Pl 20%<br>Cpx ~10%<br>Opx ~10%<br>Ol 5-10%<br>Mag Trace-5%        | Groundmass is very dark and vesicular and contains some microlites. Pl is euhedral and is commonly sieved with overgrowth. Several Pl grains are sieved with no overgrowth. Several Pl grains also exhibit growth zoning. Ol is colourless in XPL and commonly has an orange-brown stain. Opx and Cpx are euhedral. Mag only occurs as either phenocrysts or inclusions in Opx and Cpx. The internal texture of Mag is homogenous. Opx, Cpx and Pl form aggregates. |





**Figure A3.2-7:** Sample 220621-5, A) Sieved Pl with overgrowth, B) Euhedral Opx, C) Mag with homogenous internal texture, D) Ol with brown stain, E) Cpx, Pl and Ol

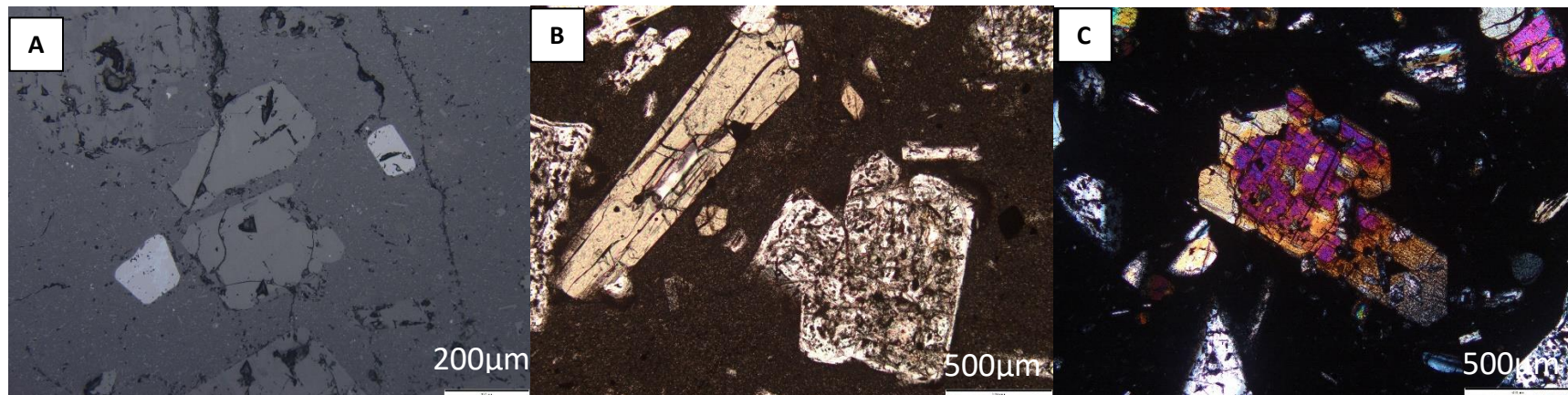
| Sample 220621-5 (2/2 Thin Section), Pyroclastic Olivine Andesite |                                                                                                                                                                                                                                                                                                                                                                                                           |
|------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Mineralogy                                                       | Texture                                                                                                                                                                                                                                                                                                                                                                                                   |
| Pl 25%<br>Opx 5-10%<br>Cpx 5-9%<br>Ol 5-8%<br>Mag trace          | groundmass is dark brownish black and very fine grained, vesicular. Ol is euhedral and colourless in PPI and typically fractured. Ol commonly has a brown stain filling in fractures. Pl varies in texture. Many grains are unsieved or exhibit euhedral growth zoning. Many Pl grains are heavily sieved, some with overgrowth. Opx and Cpx form aggregates. Mag occurs as phenocrysts in trace amounts. |



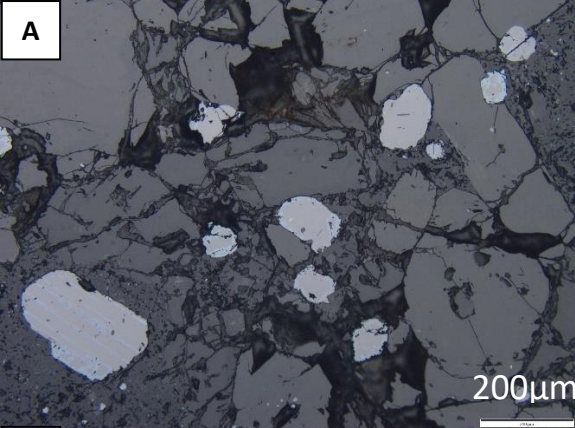
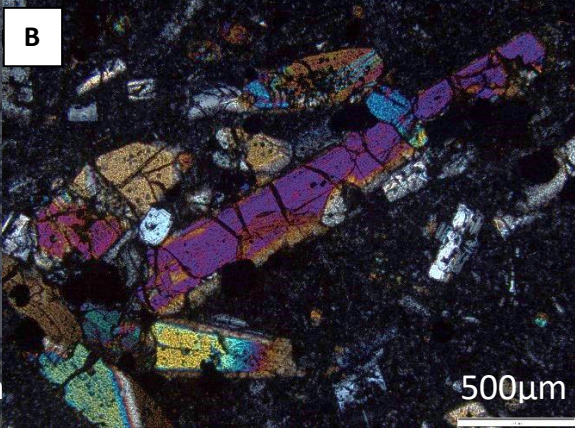
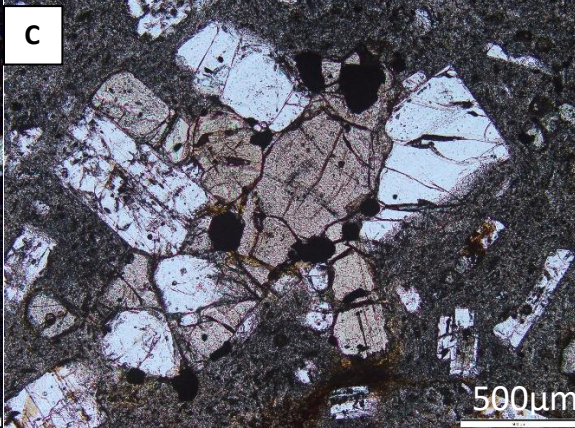
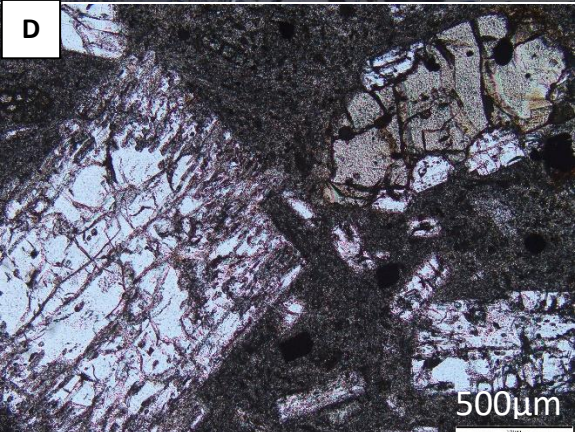
**Figure A3.2-8:** Sample 220621-5, A) Opx and Cpx, B) Ol, C) Ol (bottom left), Cpx (top left), and sieved Pl (top right)



| Sample 220621-6 Andesite on the southern part of Kusumoto Southern Hill |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|-------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Mineralogy                                                              | Texture                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Pl 25-30%<br>Cpx ~20<br>Opx 10-15%<br>Mag ~10%                          | The groundmass is dark and very fine grained containing microlites. Pl is euhedral and sieve textures are common, but not all are sieved. The degree of melting varies in Pl. Several grains of Pl are completely melted with overgrowth and others are sieved with overgrowth. Several Pl grains are sieved but have no overgrowth. Mag occurs disseminated in groundmass and as inclusions in Cpx and Opx. Mag also exhibits exsolution towards its rim. A few Cpx grains exhibit compositional zoning, but most do not. Cpx, Opx, Pl, and Mag form aggregates. |



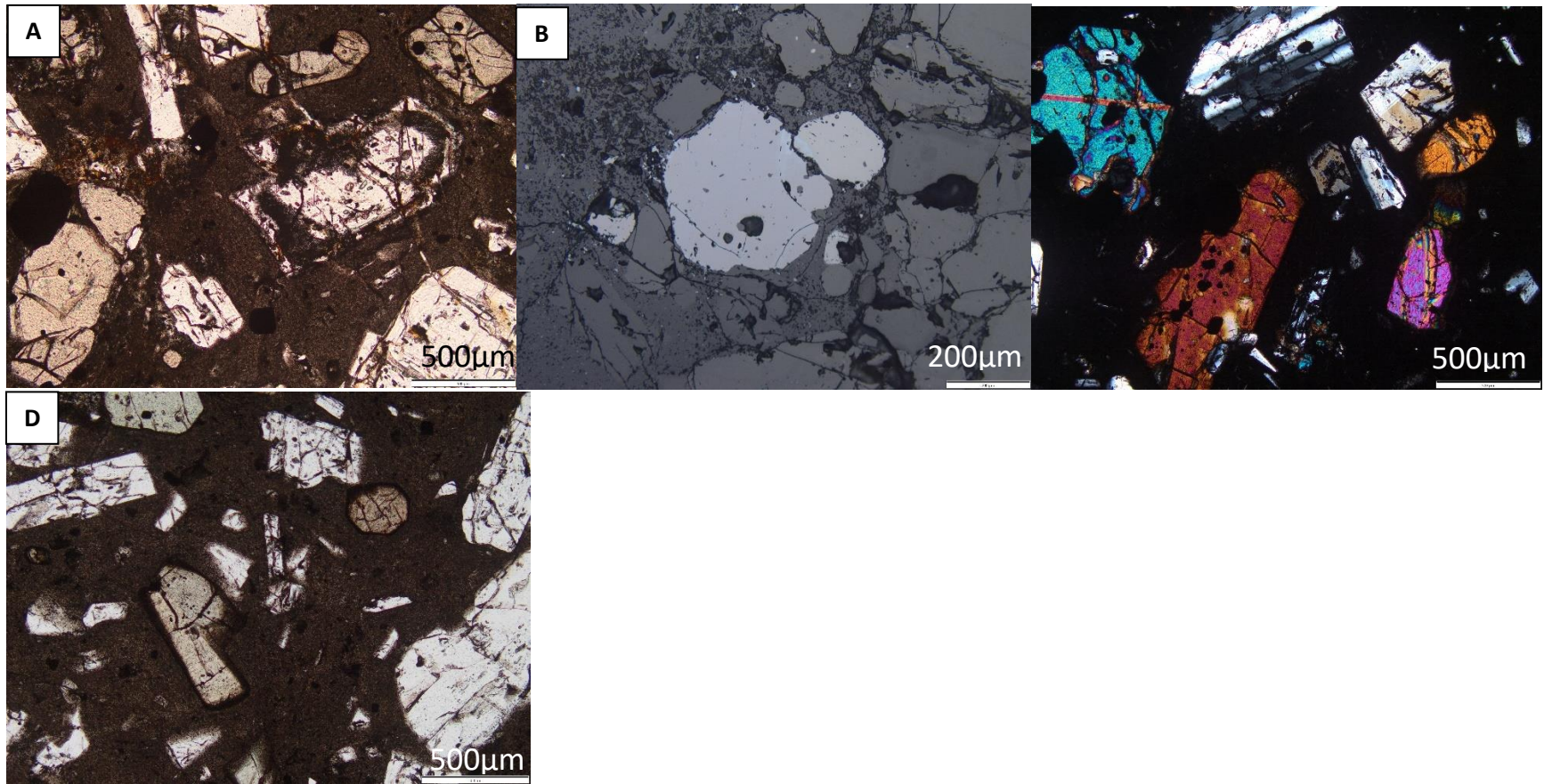
**Figure A3.2-9:** Sample 220621-6, A) Euhedral Mag with exsolution towards the rim, B) Cpx and sieved Pl with overgrowth, C) Compositionally zoned euhedral Cpx

| Sample 220621-7, “Kusumoto andesite, in the southern Kusumoto Hill                                                                                                                                                                                                                                                                                                                                           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Mineralogy                                                                                                                                                                                                                                                                                                                                                                                                   | Texture                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| Pl 30%<br>Cpx 15-20%<br>Opx 10-15%<br>Mag ~10%<br>Ilm Trace – 5%                                                                                                                                                                                                                                                                                                                                             | Pl is euhedral and varies in texture. Most Pl is unsieved. several Pl grains have a sieved core with Pl overgrowth. Additionally, several Pl grains are sieved towards the rim. Most Cpx is euhedral. Pl, Cpx, Opx, Mag and Ilm form aggregates. The groundmass is very fine grained. Mag and Ilm are disseminated throughout the sample. Mag inclusions occur in Cpx, Opx and not Pl. Ilm commonly has exsolution lamellae, while Mag typically has exsolution towards the rim or grid like exsolution |
| <div> <div>  </div> <div>  </div> <div>  </div> <div>  </div> </div> |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |

**Figure A3.2-10:** Sample 220621-7, A) Mag with exsolution towards rim and Ilm with exsolution lamellae, B) Cpx and Opx, C) Cpx, Opx and Pl aggregate, D) Pl sieved towards rim and Opx

| Sample 220621-8 Banded lava of so-called “Kusumoto andesite” |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|--------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Mineralogy                                                   | Texture                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| Pl 30%<br>Opx ~18%<br>Cpx ~12%<br>Mag 5-10%<br>Ilm trace     | Groundmass is dark and very fine grained and contains coarse grained microlites. Pl is euhedral where several grains exhibit growth zoning. Pl commonly contains melt inclusions. A few Pl grains were observed to have a sieved core or are sieved towards the rim with Pl overgrowth. Pl, Cpx, Opx and Mag form aggregates. Mag and Ilm mainly occur as phenocrysts and near each other. The internal texture of Mag and Ilm are typically homogenous; however, a few Mag and Ilm grains have exsolution towards their rim. Mag also occurs as inclusions in Opx and Cpx. Several Opx and Cpx grains are coated with either a thin rim of opacite or a mixture of fine grained minerals. |

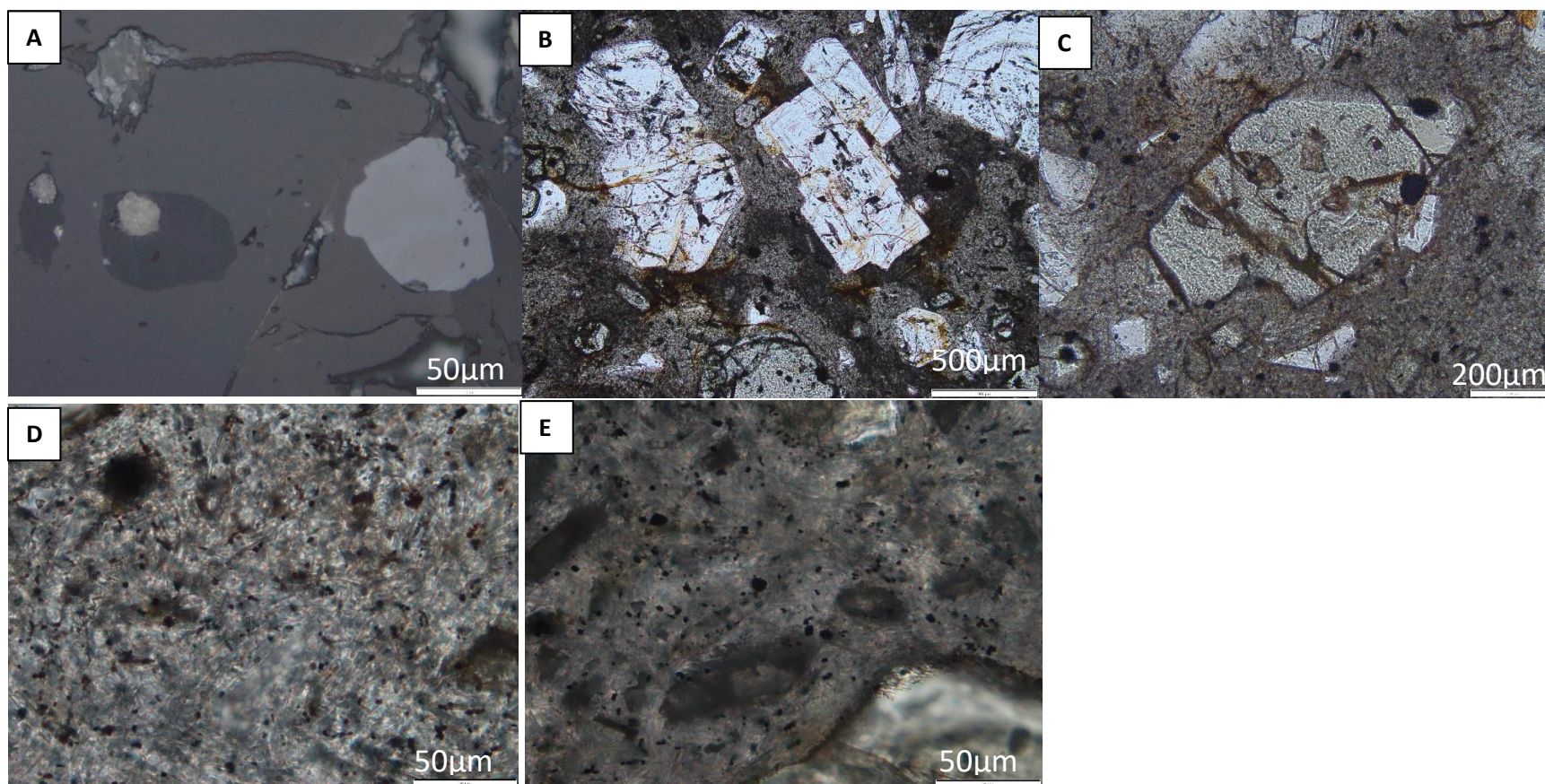




**Figure A3.2-11:** Sample 220621-8, A) Opx, Cpx and various textures in Pl, including Pl that is melted towards the rim with overgrowth, B) Mag (left) and Ilm (right) grains with internal homogenous texture, C) Cpx, Opx and Pl phenocrysts, D) Cpx (left) and Opx (right) coated in a mixture of fine grained minerals

| Sample 220621-9A, So-called “Kusumoto andesite” at the bottom of Kusumoto hill |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|--------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Mineralogy                                                                     | Texture                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| Pl 40%<br>Cpx ~20%<br>Opx ~15%<br>Mag 10%                                      | <p>Several Opx, Cpx and Pl phenocrysts have a reddish-brown stain. The groundmass includes darker and lighter areas. The darker areas appear spotty throughout the groundmass. The darker and lighter areas are both very fine grained. At a high magnification (50µm), the lighter groundmass appears to have more lighter minerals such as Pl. The darker areas observed at a high magnification (50µm) have less lighter mineral mineral. Pl is euhedral and has euhedral growth zoning. Many Pl grains have a sieved core with Pl overgrowth. Mag occurs disseminated and as phenocrysts in the groundmass. Mag inclusions are common in Cpx and Opx and several Pl include mag inclusions. Mag grains exhibit exsolution towards the rim. Several Mag grains exhibit grid like exsolution.</p> |

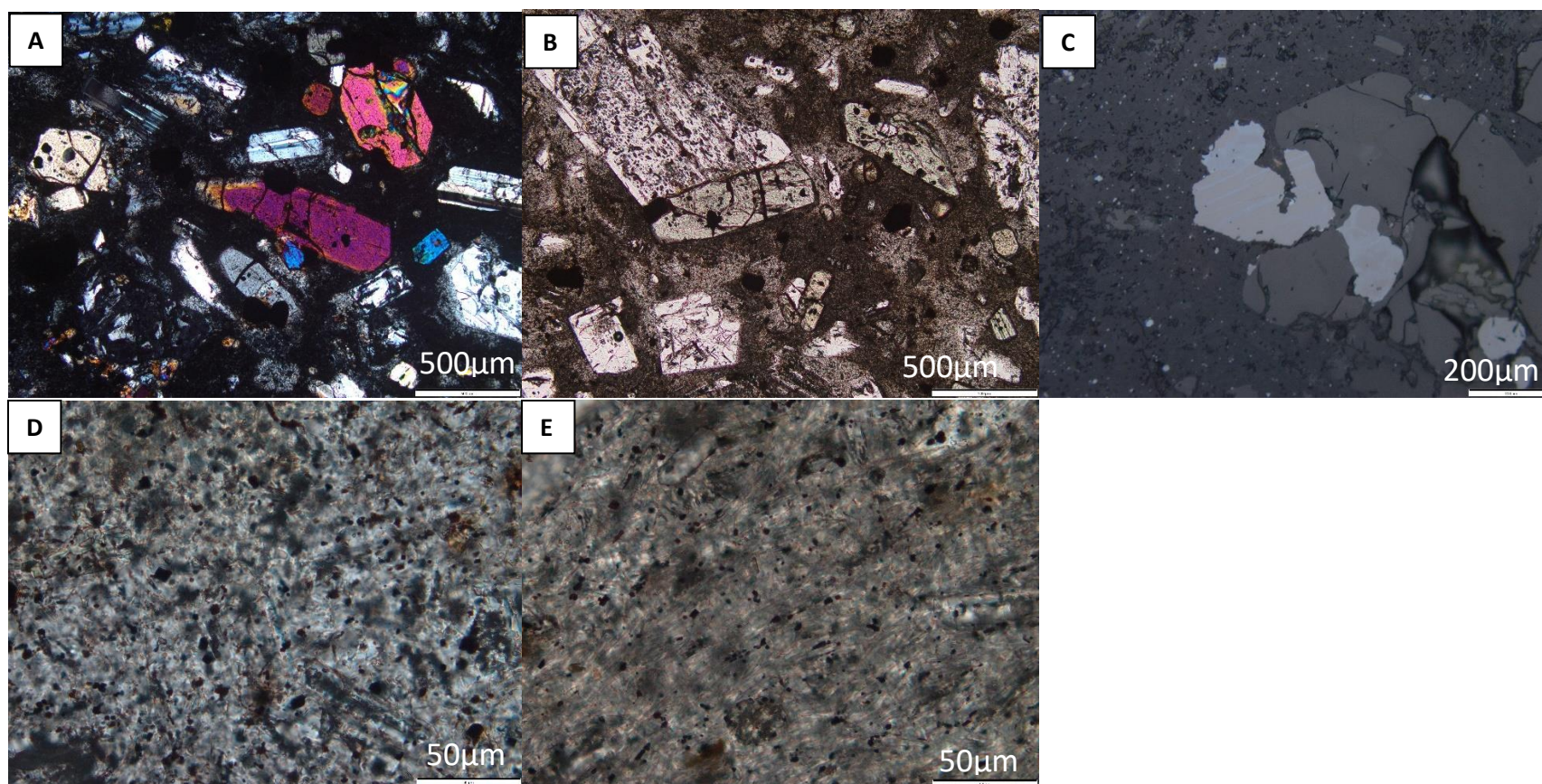




**Figure A3.2-12:** Sample 220621-9A, A) Mag inclusion (right) with exsolution towards rim, B) Euhedral Pl with growth zoning, where the fine grained groundmass shows lighter and darker areas, C) Cpx, D) Lighter groundmass at high magnification (50x), E) Darker groundmass at high magnification (50x)

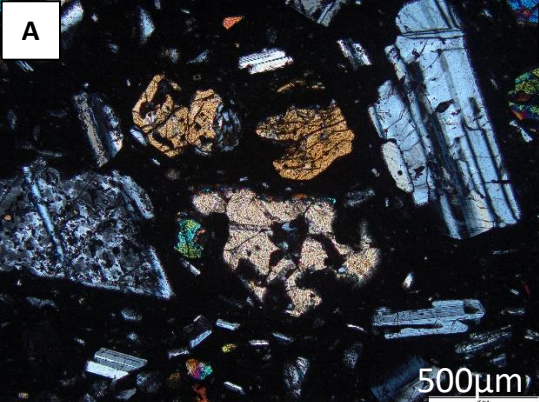
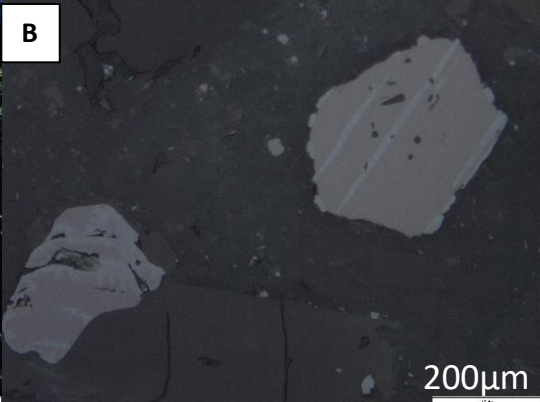
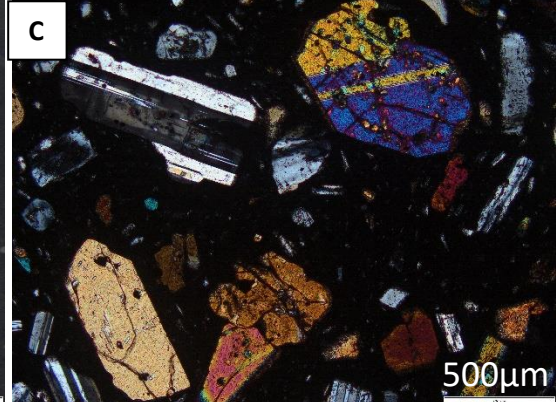
| Sample 220621-9B, Andesite on the Kusumoto Southern hill |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|----------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Mineralogy                                               | Texture                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| Pl ~30%<br>Cpx 15-20%<br>Opx ~10-15%<br>Mag Trace – 10%  | Groundmass contains lighter and darker areas; both are very fine grained. The dark groundmass is spotty throughout the sample. Observed at a high magnification (50x), the lighter groundmass contains more lighter minerals than the darker groundmass. The groundmass also contains some microlites. Pl is euhedral and varies in texture exhibiting unsieved, sieved textures and growth zoning textures. Several Pl grains are sieved with overgrowth. Cpx and Opx is euhedral. Mag occurs disseminated and as phenocrysts in Cpx and Opx. Mag also exhibits exsolutions towards the rims. Ilm only occurs as phenocrysts and exhibits exsolution lamellae. Cpx, Opx, Pl and Mag form aggregates. |





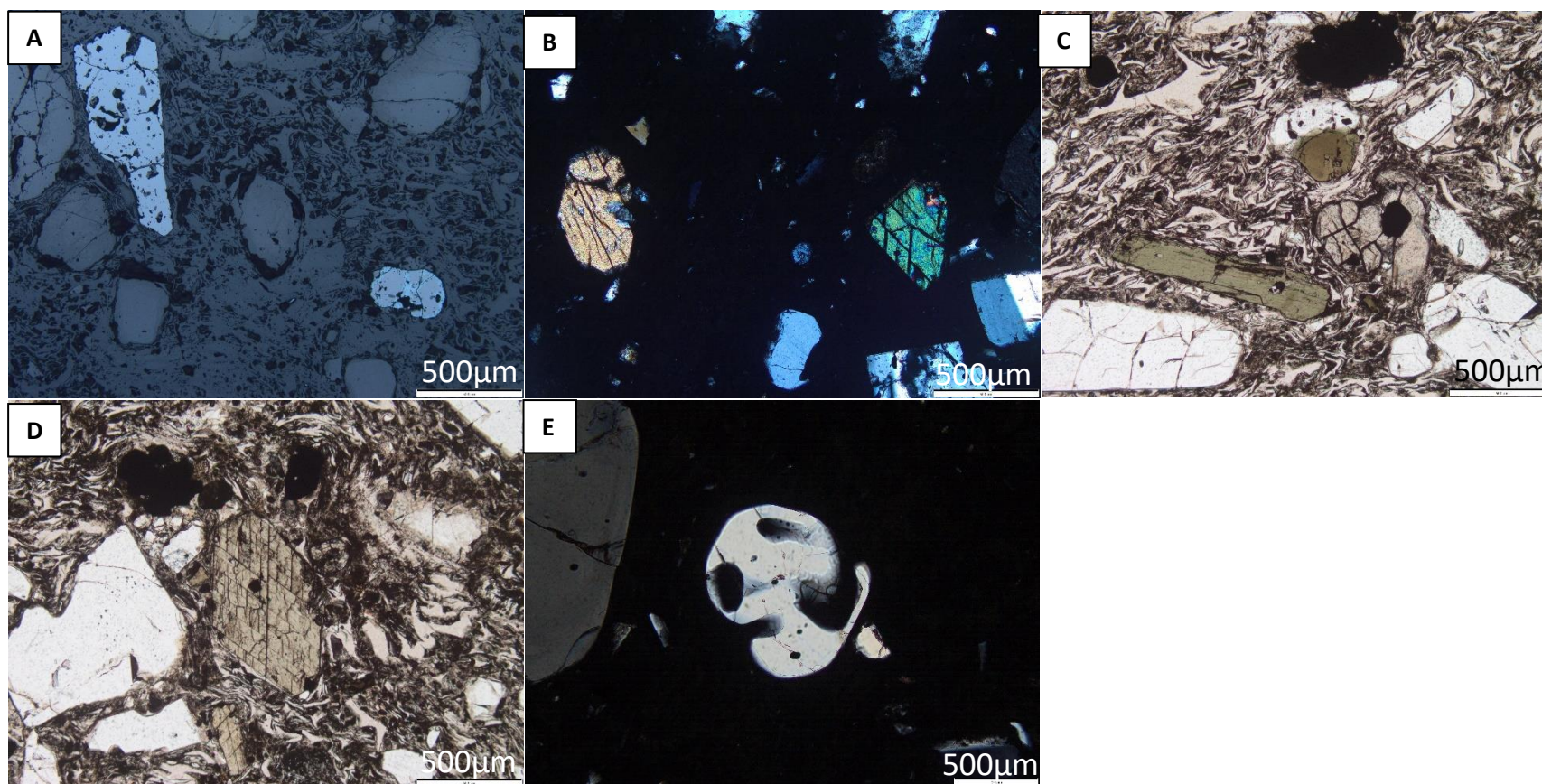
**Figure A3.2-13:** 220621-9b, A) Opx, Cpx and Pl, B) Various textures in Pl including sieved Pl with overgrowth. The groundmass contains lighter and darker areas, both fine grained. C) Ilm with exsolution lamellae (left) and Mag (right) with grid like exsolution,



| Sample 220622-1, “Kurosanson andesite”, south of a pig farm.                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Mineralogy                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | Texture                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| Pl 40%<br>Cpx 15-20%<br>Opx 10-14%<br>Mag trace -4%<br>Ilm trace                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Groundmass is dark and very fine grained and includes microlites. Pl is euhedral and varies in texture. Several grains exhibit euhedral growth zoning, many unsieved, and several that are sieved and have overgrowth. A few grains have an unsieved core and sieved rim. Mag and Ilm mainly occur as phenocrysts where mag typically has exsolution towards the rims and Ilm typically has exsolution lamellae. Mag and Ilm occur near each other. Mag also occurs as inclusions in Cpx and Opx. Opx and Cpx is euhedral. |
| <div style="display: flex; justify-content: space-around; align-items: flex-end;"> <div style="text-align: center;">  <p><b>A</b></p> </div> <div style="text-align: center;">  <p><b>B</b></p> </div> <div style="text-align: center;">  <p><b>C</b></p> </div> </div> |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |

**Figure A3.2-14:** Sample 220622-1, A) Opx and various textures in Pl, B) Mag with exsolution towards rim (left) and Ilm with exsolution lamellae (right), C) Opx and Cpx

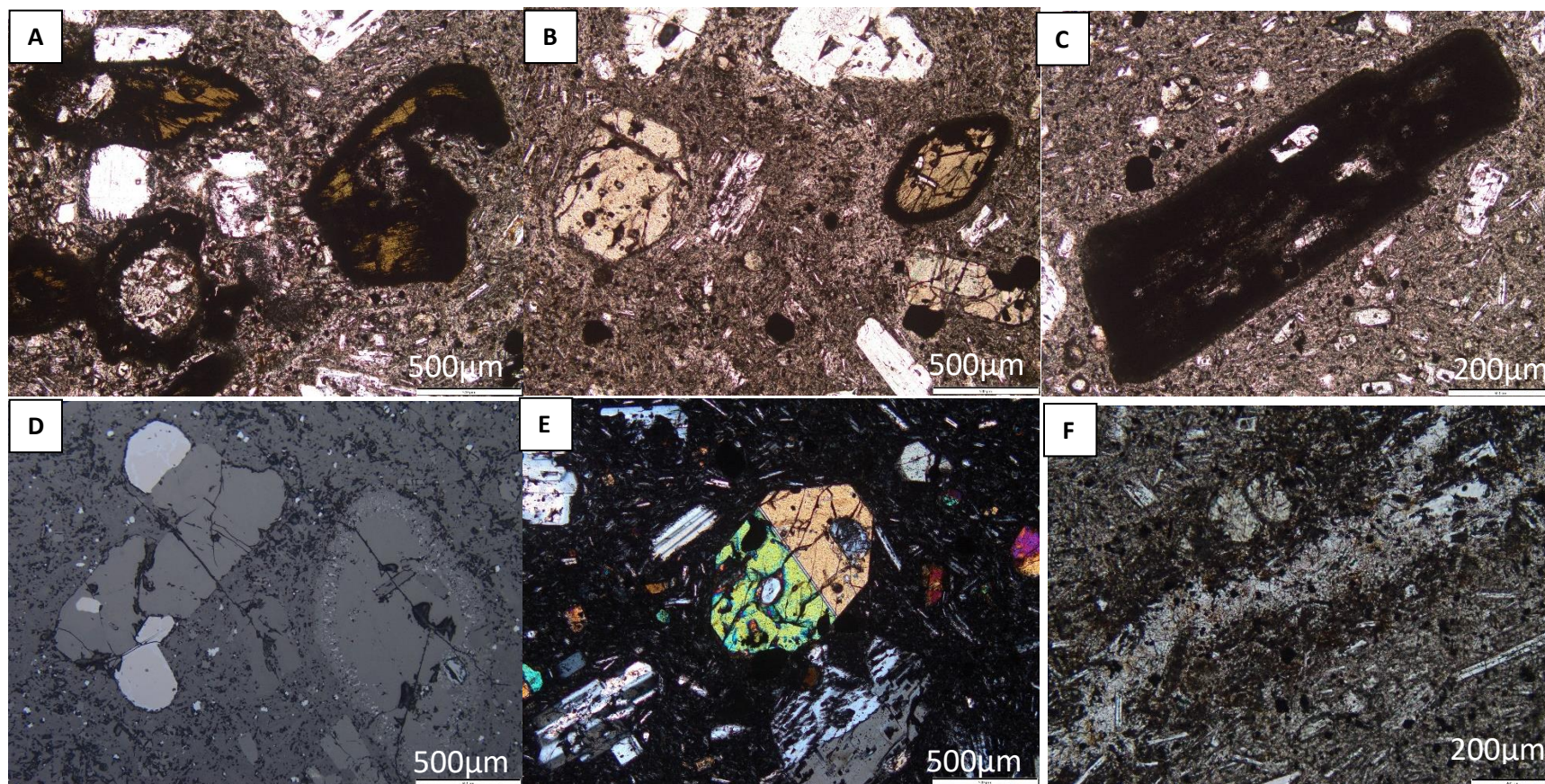
| Sample 220622-2B, dacite, north of Uono                                |                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Mineralogy                                                             | Texture                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| Amp 5-10%<br>Qz~15-20%<br>Pl ~10-15%<br>Cpx 5-10%<br>Opx 10%<br>Mag 5% | Groundmass is welded and glassy. Pl is euhedral where growth zoning is common, no sieve textures are present. Several Opx grains are skeletal or have been invaded by the groundmass. Most mag grains have exsolution towards the rim, but some mag grains have a homogenous internal texture. Mag only occurs as either phenocrysts or inclusions in Amp, Cpx and Opx. The groundmass has invaded several Qz grains creating an embayment texture. |



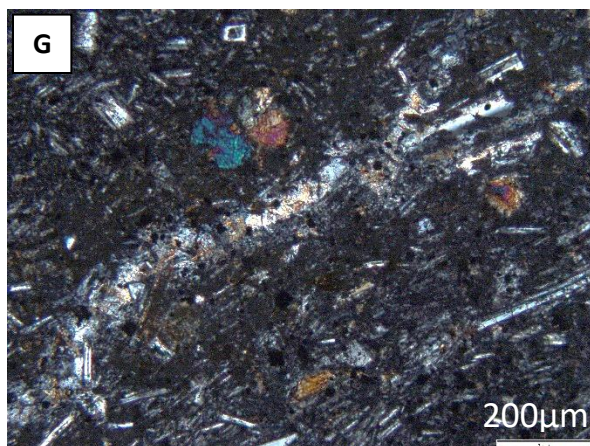
**Figure A3.2-15:** Sample 220622-2B, A) Mag with homogenous internal texture (left) and Mag with exsolution towards the rim (right), B) Opx and Amp, C) Glassy groundmass and phenocrysts of Cpx, Opx, Mag and Qz, D) Amp with prominent cleavage, E) Embayed Qz phenocryst

| Sample 220622-4, so-called Kurosanson andesite, north of Uono |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|---------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Mineralogy                                                    | Texture                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Pl 30%<br>Opx 15%<br>Cpx 20%<br>Amp 10%<br>Mag 10%            | <p>The groundmass contains microlites., Amp grains are commonly coated with a thick band (50µm) of opacite. Several Opx grains are also coated in opacite. Several unknown grains have been almost completely pseudomorphically replaced by a mixture of fine-grained minerals. Several Cpx grains contain Pl inclusions. Pl is euhedral and varies in texture containing both sieved and unsieved grains. Several Pl grains have a melted core or are melted towards the rim with Pl overgrowth. Several Pl grains also include fluid inclusions. Mag, Opx, Cpx and Pl form aggregates. Phenocrysts that form aggregates are not coated in opacite. Mag occurs disseminated within the groundmass as well as phenocrysts and inclusions in Cpx, Opx and in some Pl grains. Mag commonly exhibits exsolution towards the rims. Several narrow quartz veins/precipitation are present in the groundmass.</p> |



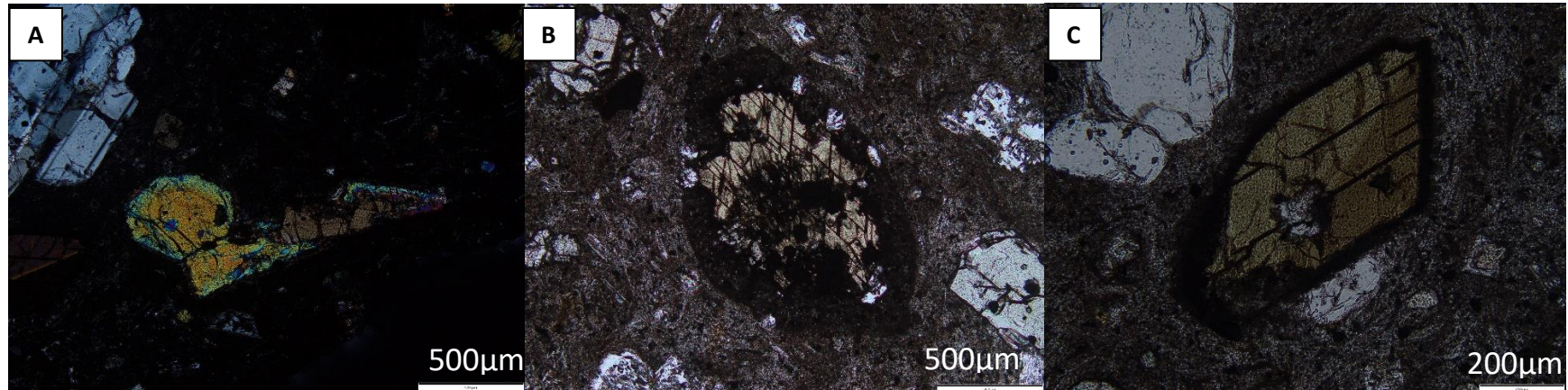






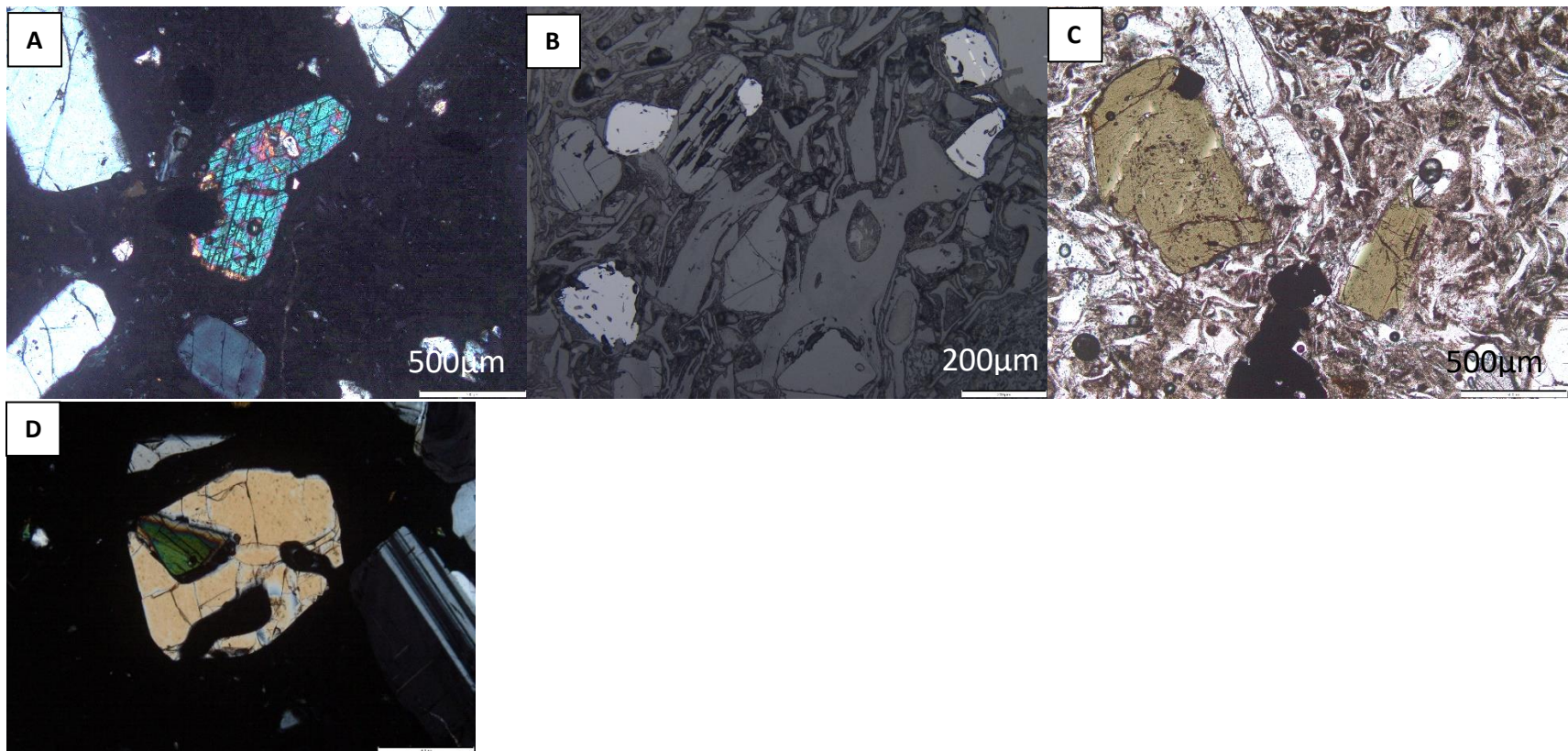
**Figure A3.2-16:** Sample 220622-4: A) Opx (bottom left) and Amp coated with thick opacite rim, B) Opx (left) and opacite coated Amp (right), C) Unknown grain that has been pseudomorphically replaced by a mixture of fine-grained minerals, D) Mag with exsolution towards the rim, E) Cpx, F and G) Qz vein

| Sample 220622-5, “Kurosanson andesite”, north of Unono                                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|---------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Mineralogy                                                                                  | Texture                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Pl 25-30%<br>Cpx 15-20%<br>Opx 10-15%<br>Amp 10-15%<br>Mag 10%<br>Ilm Trace -4%<br>Ap Trace | Pl is euhedral and varies in texture where most are unsieved. Several Pl crystals include melted cores or are melted towards the rim and have Pl overgrowth. Many Cpx exhibits compositional zoning from rim to core.<br>All Amp grains are either fully or partially coated with opacite, typically 20 $\mu$ m in thickness. Several Amp grains are coated with a thicker (100 $\mu$ m) rim of a mixture of fine-grained minerals. Groundmass is fine grained containing microlites. Microlites wrap around phenocrysts including opacite coated phenocrysts.<br>Mag and Ilm phenocrysts form clusters. Mag typically has exsolution towards the rim and/or grid like exsolution. Ilm is in trace amounts and typically has exsolution lamellae. |



**Figure A3.2-17:** Sample 220622-5, A) Cpx with compositional zoning, B) amp with thick very fine-grained rim, C) Amp with opacite rim

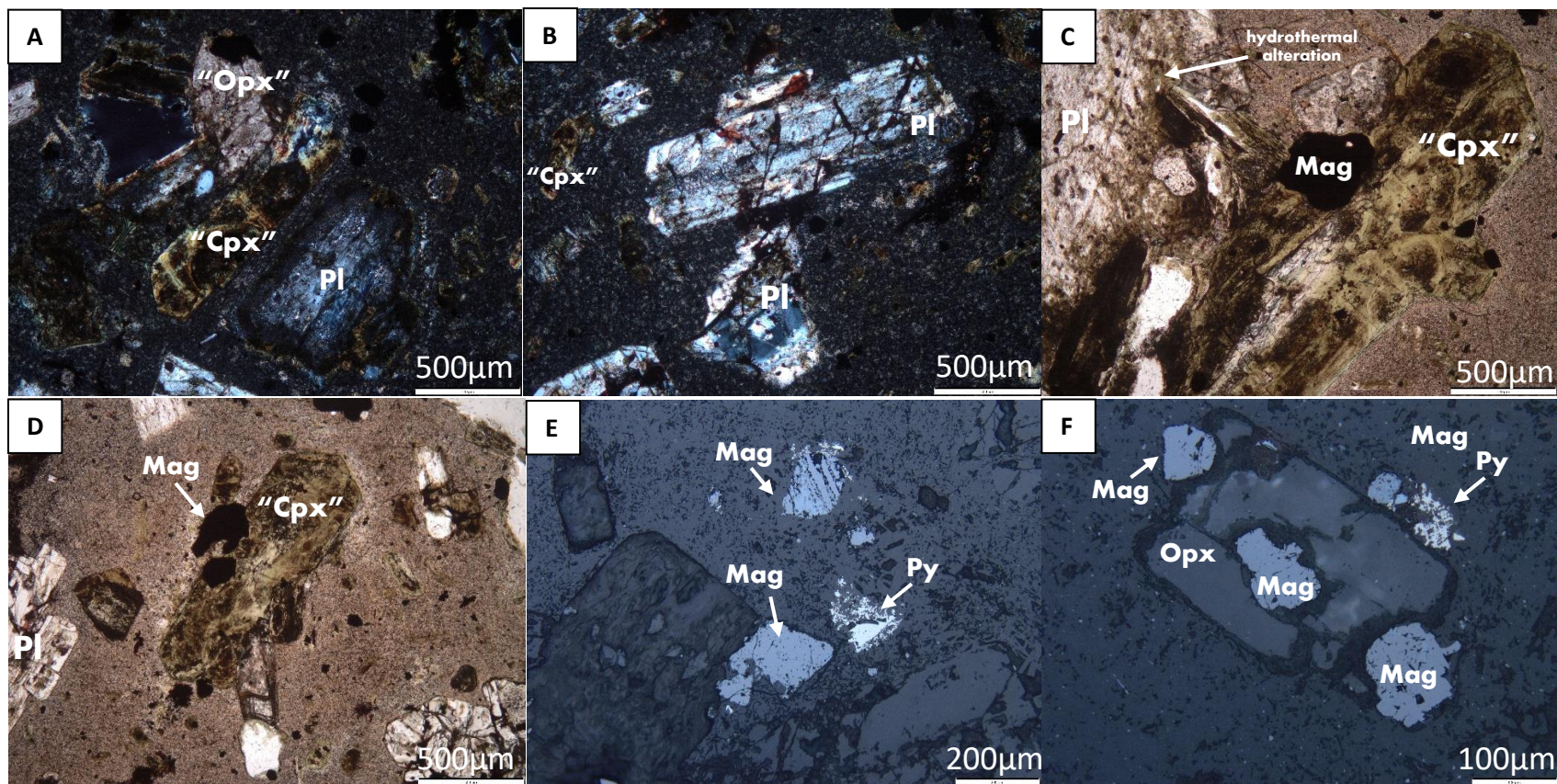
| Sample 220622-6, Andesite on the western slope of Kusumoto North hill |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|-----------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Mineralogy                                                            | Texture                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| Pl 25%<br>Qz 15%<br>Amp 10%<br>Cpx 10%<br>Mag ~5%                     | Groundmass is very glassy. Pl is euhedral and commonly exhibits twinning or oscillatory zoning, and several Pl grains have skeletal texture, no sieve textures. Mag only occurs as phenocrysts or as inclusions where very few Cpx grains include Mag phenocrysts. Cpx is green in PPl. Amp is beige to brown in PPl and exhibit high birefringence in XPL. A few fine grained foreign fragments also occur in this thin section. The groundmass has invaded a few Qz grains, creating an embayment texture. |



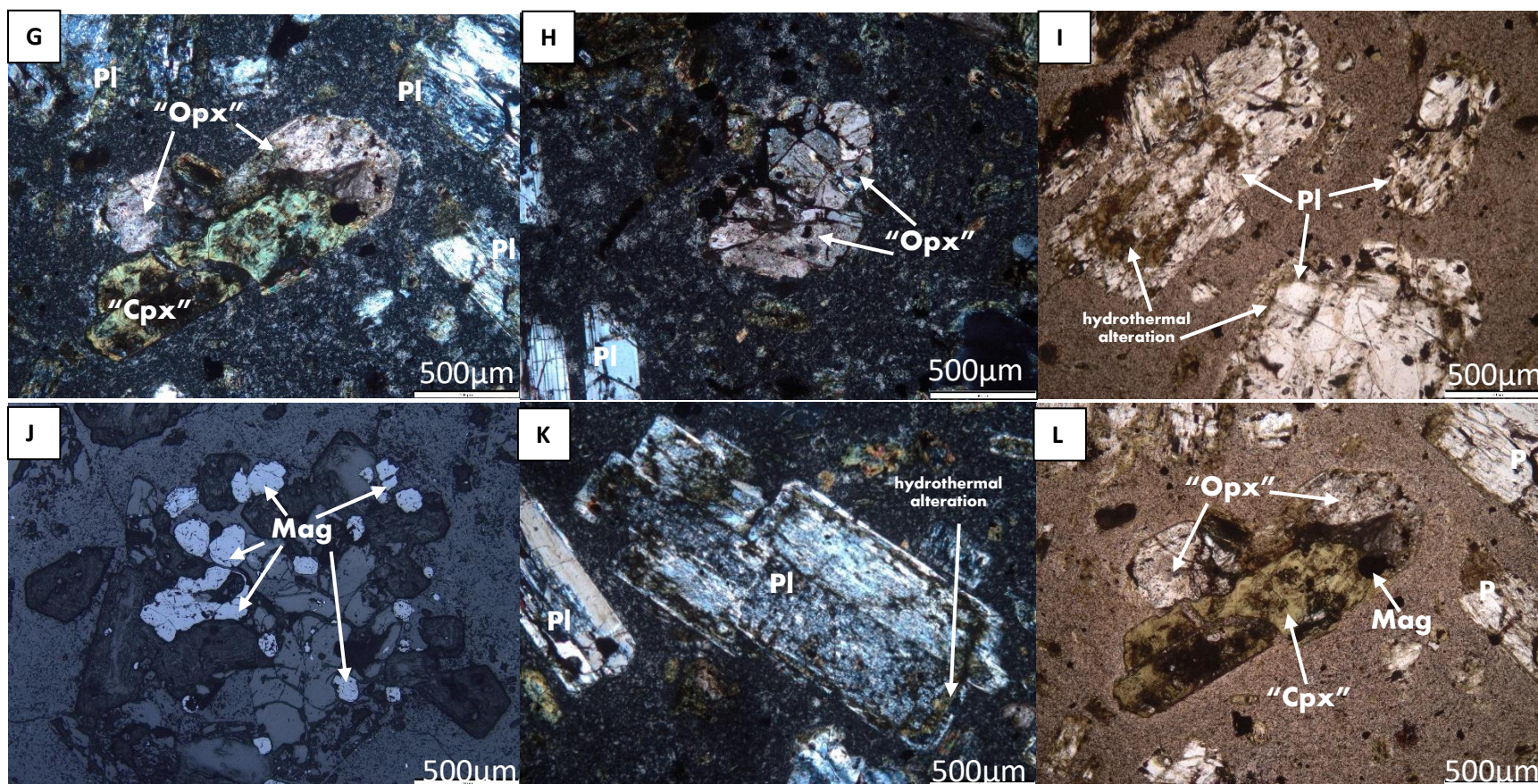
**Figure A3.2-18:** Sample 220622-6, A) Amp with good cleavages, B) Mag phenocrysts, C) Glassy groundmass wrapping around Amp and Pl phenocrysts, D) Groundmass invading Qz grain creating embayment texture and Amp (green)

| Sample 220623-3 (Yamadagawa sample given from Hishikari Mine Office)   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Mineralogy                                                             | Texture                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Opx (10-15%)<br>Cpx (15%)<br>Pl (35-40%)<br>Mag (10%)<br>Py (Trace-4%) | <p>Almost all Pl, Opx and Cpx grains are hydrothermally altered. Alteration is green in pyroxene and is a mixture of clay minerals and chlorite or possibly smectite. Most “Cpx” grains have been partially or pseudomorphically replaced, some with mottled texture. The shape and is similar to Cpx where the original mineral is most likely Cpx. “Opx” is intensely altered, making it difficult to determine the original igneous mineral. Again, the shape is similar to Opx, where the original mineral could have been Opx. Pl is also hydrothermally altered where a brown clay mixture has filled in fractures. Py is disseminated in several areas, commonly forming clusters, but occurs in trace amounts. Mag crystals are rounded. They occur as inclusions in Pl, Cpx and Opx and within the groundmass or in aggregates with Pl, Opx and Cpx. Most Pl is very fractured and euhedral but igneous textures include sieve texture and zoning. Groundmass is very fine grained.</p> |





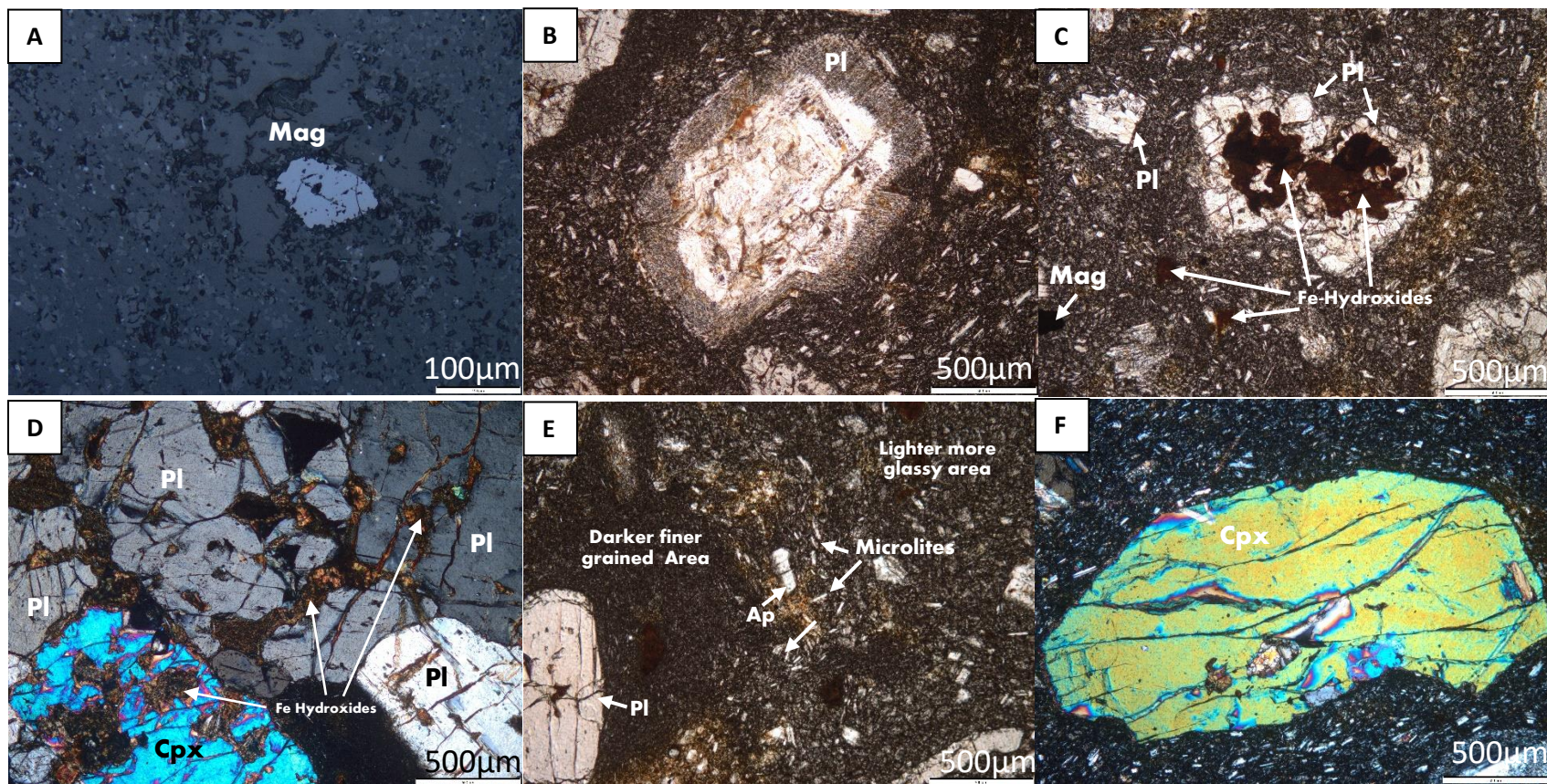




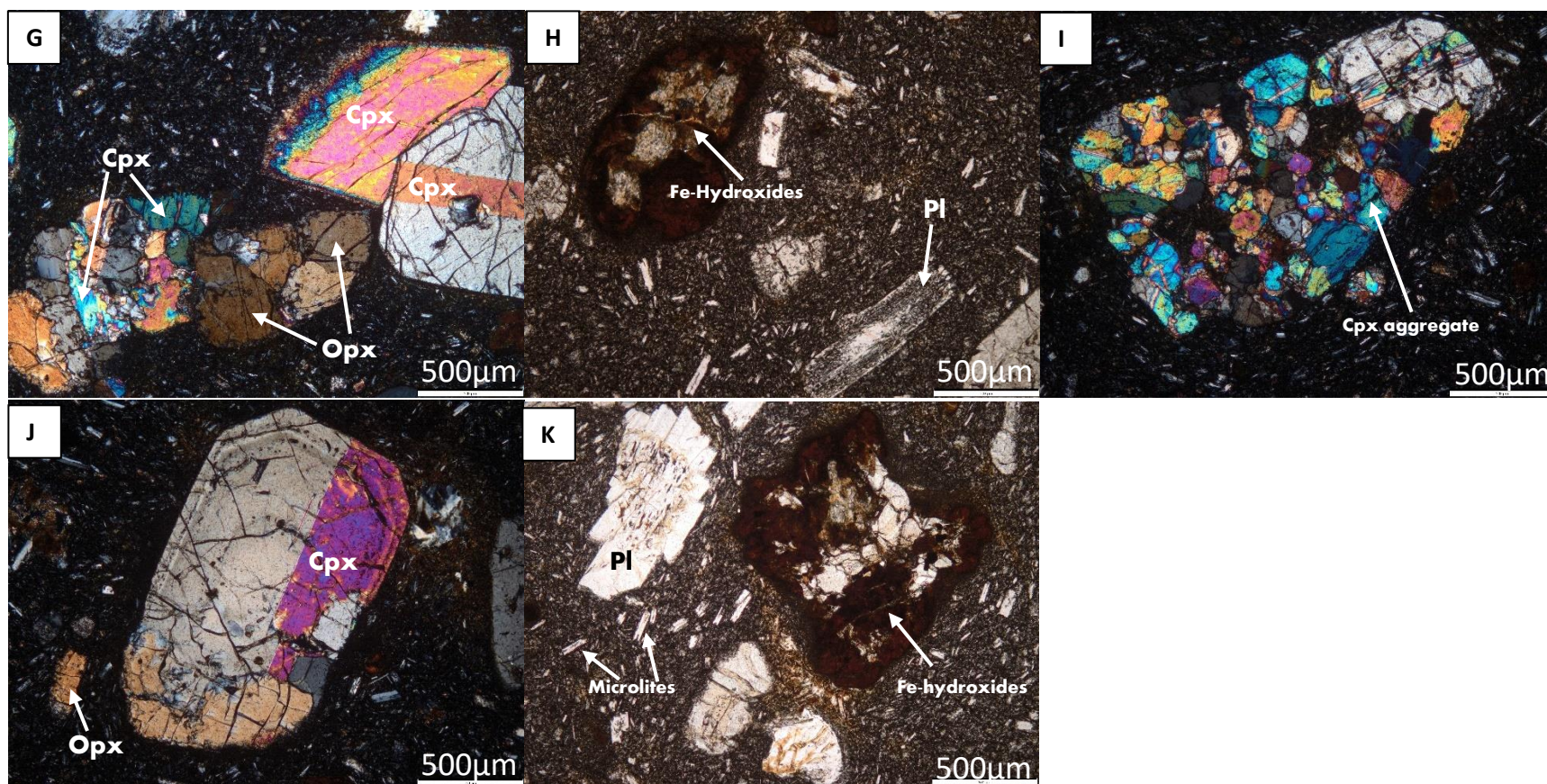
**Figure A3.2-19:** Yamadagawa Andesite: “Opx” is denoted as an altered mineral that is most likely opx, “Cpx” is denoted as an altered mineral that has been pseudomorphically replaced and the original mineral is most likely Cpx. A) “Opx”, “Cpx” and hydrothermally altered Pl with sieved rim, B) Pl, C and D) “Cpx” with mottled texture, E) Mag and Py in groundmass, F) Opx containing Mag inclusion, G) “Opx”, “Cpx” and Pl with hydrothermal alteration, H) “Opx”, I) Several hydrothermally altered Pl; the brown alteration on Pl is most likely a mixture of clay minerals and possibly chlorite or smectite, J) Mag forming aggregate, K) Hydrothermally altered Pl, L) “Opx” and “Cpx” with a mag inclusion.

| Sample 220623-1 (DDH17MAHY-8A)                                              |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|-----------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Mineralogy                                                                  | Texture                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| Cpx (~20%)<br>Opx (~10%)<br>Pl (30%)<br>Mag (Trace - 5%)<br>Ap (Trace - 5%) | <p>Groundmass is very glassy with many microlites. Microlites wrap around phenocrysts and mineral aggregates. These mineral aggregates are composed of Pl, Cpx and Opx. The groundmass is not homogeneous in color where there are lighter and darker areas. The darker areas contain finer grained microlites and the lighter areas are more glassy and contain coarser grained microlites. Pl is commonly sieved where many are sieved closer to the rims and showing overgrowth in the outermost rims. Mag is rare and mainly disseminated in groundmass with rare inclusions Pl, Cpx and Opx. Many Pl, Opx and Cpx grains are weathered and contain a reddish brown material that could possibly be Fe-hydroxides. The possible Fe-hydroxides also occur in the groundmass and filling in fractures of Pl, Opx, and Cpx. Many Cpx shows compositional zoning or growth zoning. Pl exhibits euhedral growth zoning.</p> |





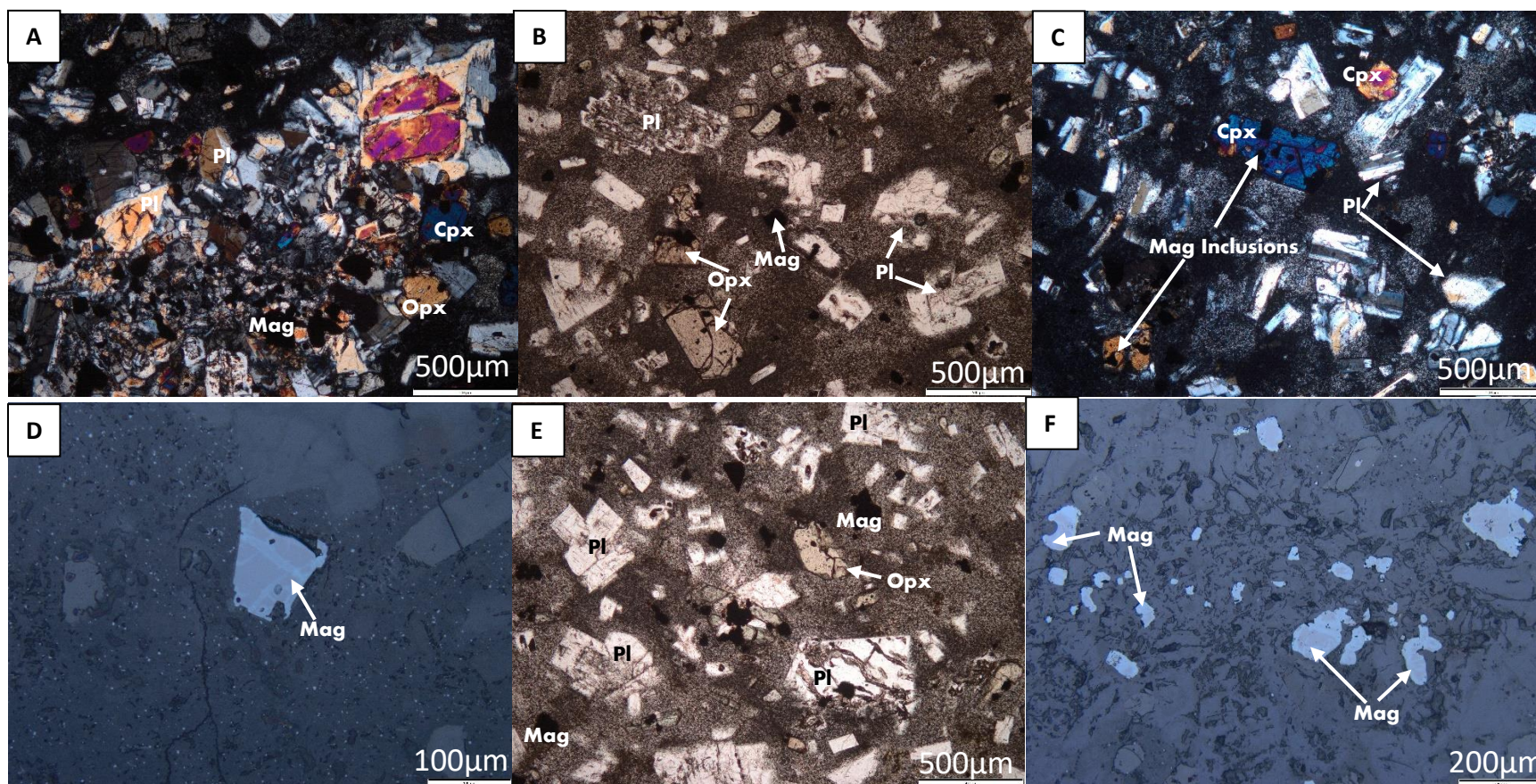




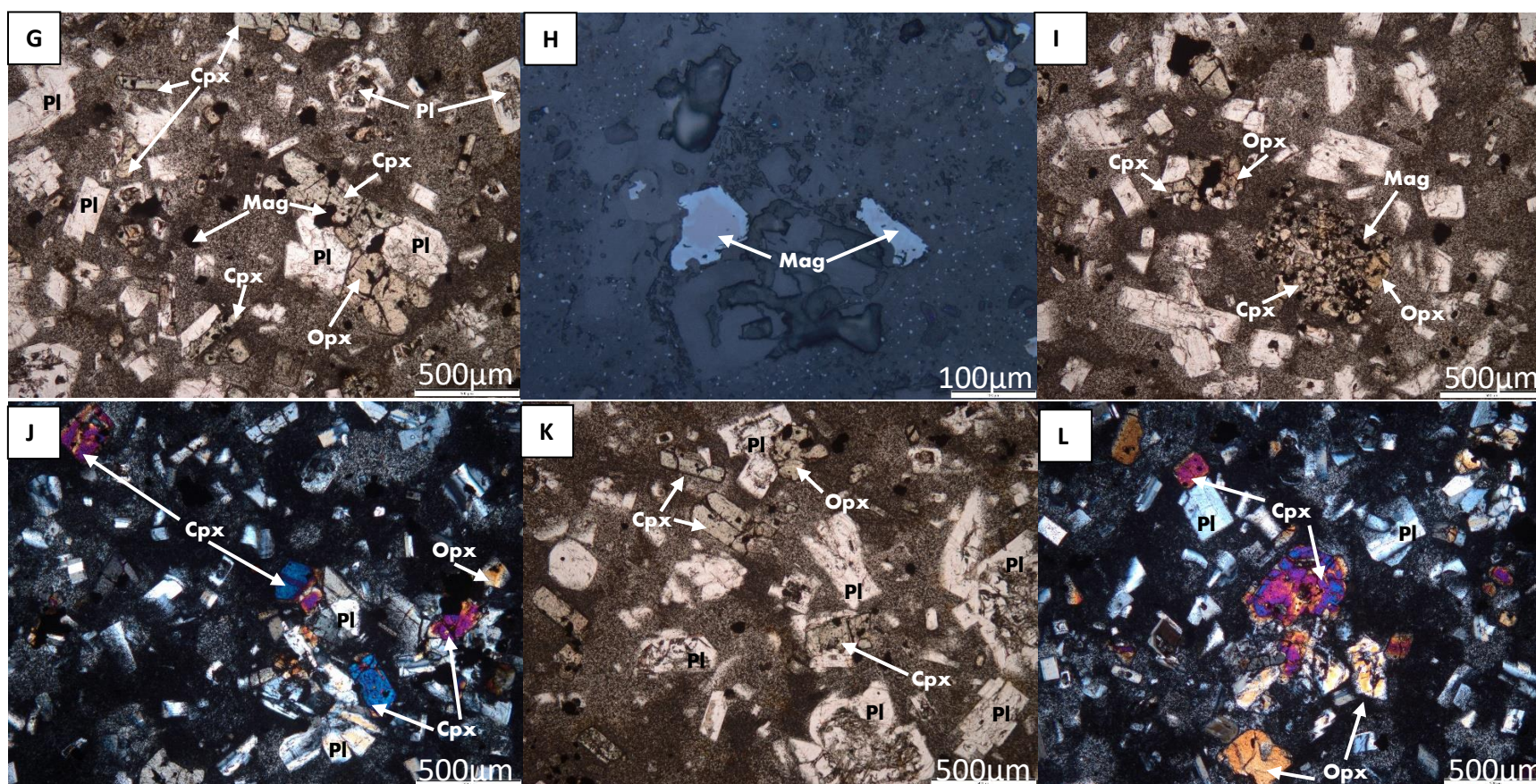
**Figure A3.2-20:** DDH17MAHY-8A: A) Mag crystal, B) Pl with sieved rim and euhedral growth zoning, C) Weathered Pl, D) Possible Fe-hydroxides filling in fractures of Cpx and Pl, E) Groundmass with darker and lighter areas due to microlite grain difference, F) Microlites wrapping around large Cpx grain with compositional zoning, G) Cpx and Opx aggregates, H) Weathered “Cpx”, of which the original mineral is most likely Cpx, and Pl with sieved rim and Pl overgrowth, I) Microlites wrapping around Cpx aggregate, J) Cpx exhibiting growth zoning, K) Weathered “Cpx”, of which the original mineral is most likely Cpx in the core.

| Sample 220623-2 (DDH17MAHY-8B)                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|---------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Mineralogy                                        | Texture                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| Pl (~50%)<br>Opx (15%)<br>Cpx (10%)<br>Mag (~10%) | Pl, Cpx and Opx grains are mostly ~1.5 mm. Pl is commonly blocky-euhedral and twinned. Some Pl grains exhibit zoning. Several Pl crystals have a sieved core with an unsieved overgrowth. Fluid inclusions are uncommon in Pl. Sample is crystal rich (>85%) and Pl is over 50% of crystals. Several Opx, Cpx, Mag, and Pl crystal are aggregated together. Mag is disseminated in groundmass and occurs as inclusions in Pl, Opx and Cpx. Mag commonly exhibits grid like exsolution or exsolution on the outer rims. The groundmass includes darker and lighter areas which could be due to physical mingling of melt with different composition. The darker and lighter areas are both very fine grained. |





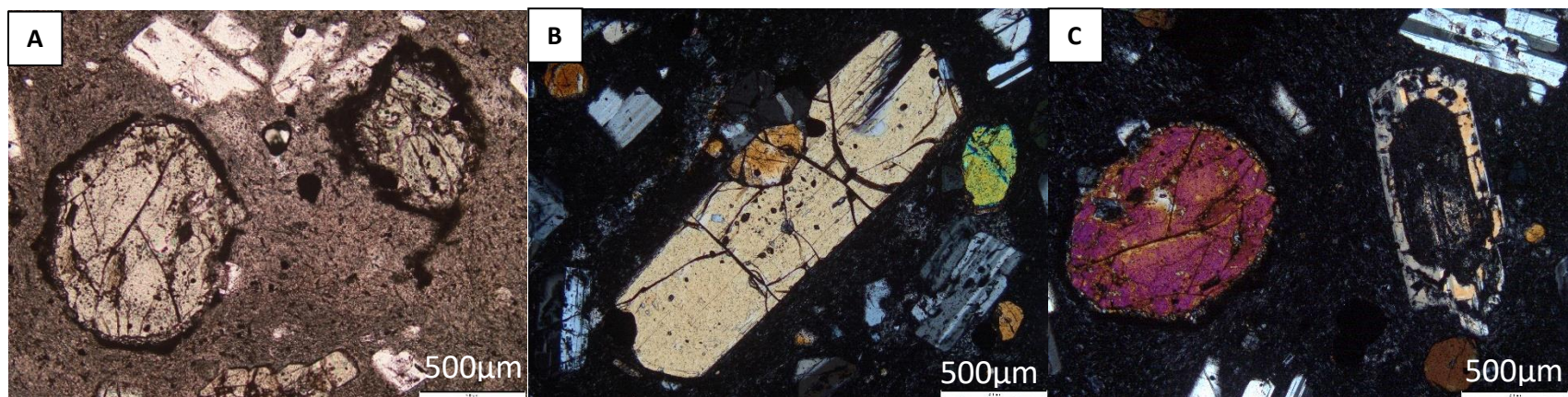




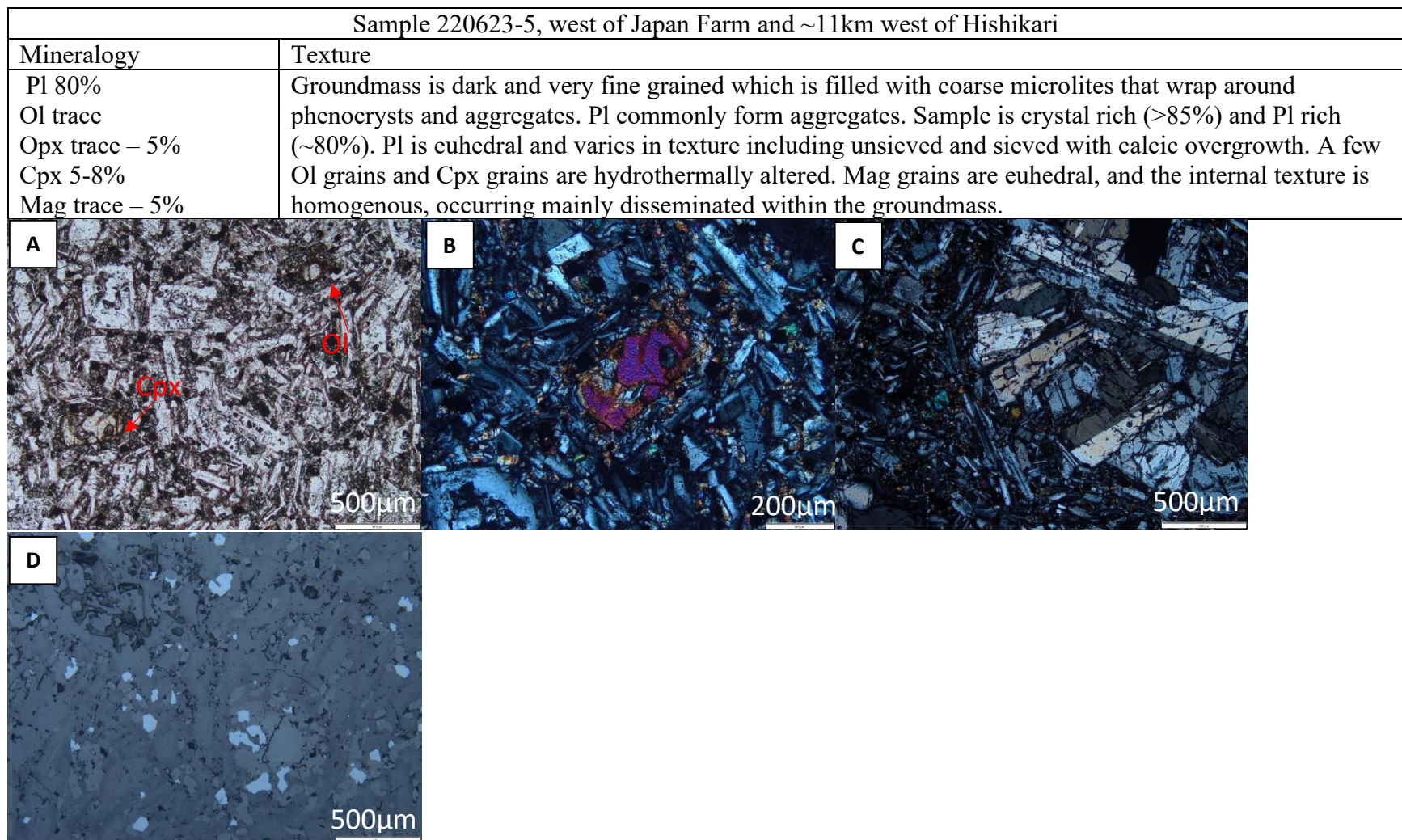
**Figure A3.2-21:** DDH17MAHY-8: A) Aggregate of Opx, Cpx and Pl, B) Groundmass with lighter and darker areas and variation of Pl textures including sieved cores, C) Mag inclusions in Opx and Cpx, D) Mag with exsolution, E) Euhedral Pl, F) Disseminated Mag, G) Aggregate of Pl, Opx, Cpx and Mag, H) Mag with exsolution on rims, I and J) Fine grained aggregate of Pl, Mag, Cpx and Opx, K) Variation of texture in Pl including sieved core with Pl overgrowth, L) Cpx, Opx and Pl phenocrysts.



| Sample 220623-4, Andesite along Yamadag river close to the mine (possible yamadagawa andesite) |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Mineralogy                                                                                     | Texture                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Pl 30%<br>Cpx 15-20%<br>Opx 10-15<br>Mag ~5%                                                   | Groundmass includes darker and lighter areas; both are very fine grained. Pl is euhedral where some grained exhibit euhedral growth zoning. Several Pl grains are sieved and have overgrowth. A few Pl grains have a completely melted core with overgrowth. Melt inclusions are common in Pl. Pl, Cpx, Opx and Mag form large aggregates. There is hydrothermal alteration within the groundmass and also fill fractures of Pl, Opx and Cpx. Several Opx and Cpx grains are partially coated with a thin rim of opacite. 1 grain of Cpx was observed to have concentric zoning. |



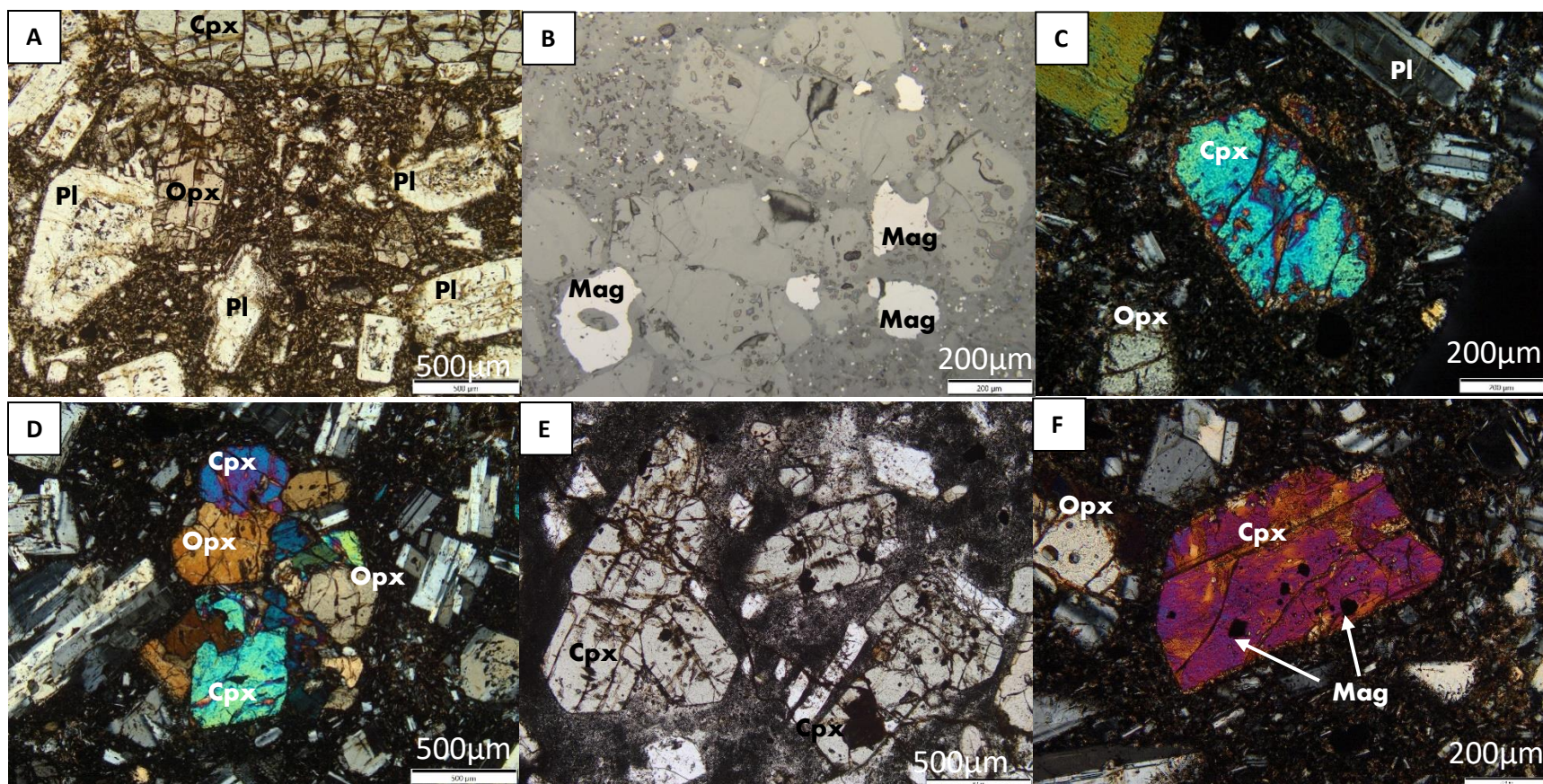
**Figure A3.2-22:** Sample 220623-4, A) Opx and Cpx with partially coating opacite, B) Euhedral Opx (left) and Cpx (right), C) Cpx (left) and Pl with sieved core and overgrowth



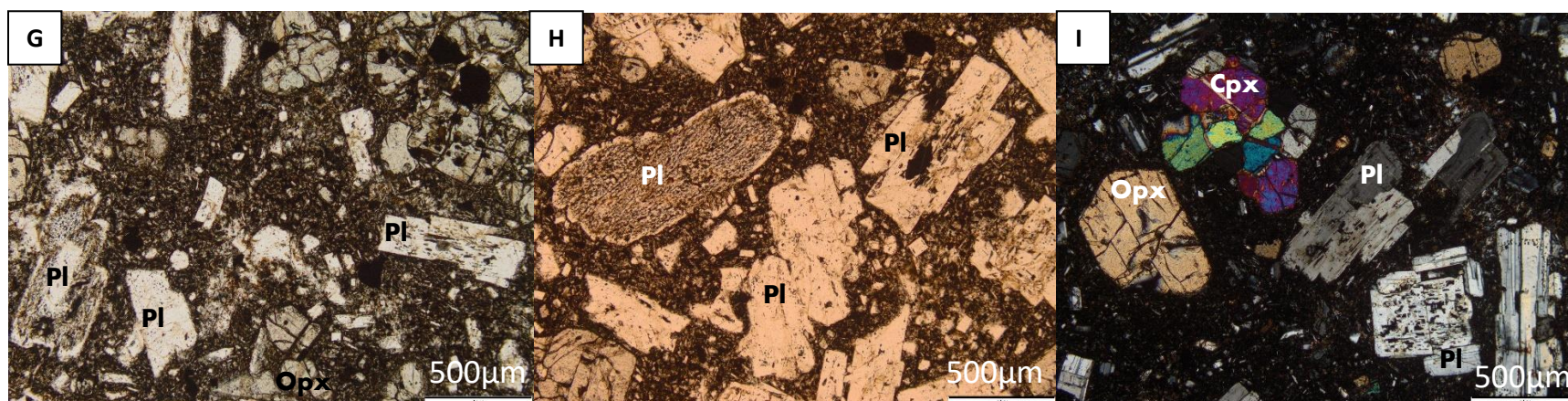
**Figure A3.2-23:** Sample 23-5, A) Cpx and Ol in Pl rich sample, B) Cpx, C) Coarse microlites wrapping around Pl aggregate, D) Mag disseminated in groundmass with homogenous internal texture

| Sample YAM001                             |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|-------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Mineralogy                                | Texture                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| Pl 25-30%<br>Cpx 15%<br>Opx 10%<br>Mag~5% | The groundmass is glassy and contains microlites. Pl, Cpx, Opx and Mag phenocrysts are euhedral and well formed. Mag mainly occurs disseminated within the groundmass and as phenocrysts in Cpx, Opx and Pl. The internal texture of Mag is homogenous. The texture of Pl varies. Many Pl grains are un-sieved and exhibit euhedral growth zoning and a few containing overgrowths. Several Pl grains are sieved at varying degrees. Several Pl grains contain a sieved core or are sieved towards the rim with overgrowth. Opx, Cpx, Pl and Mag phenocrysts form aggregates |







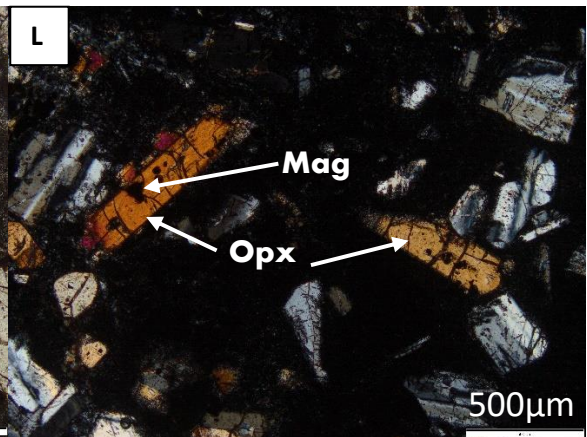
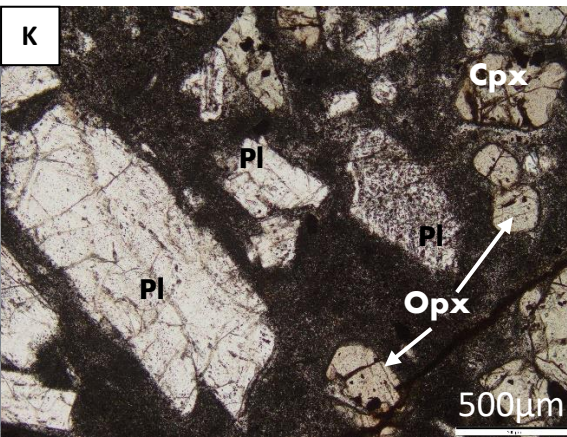
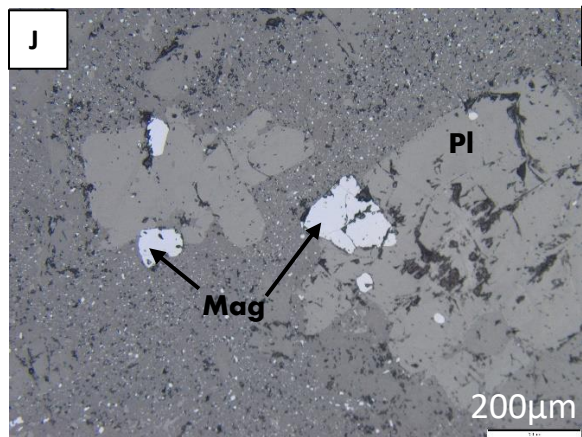
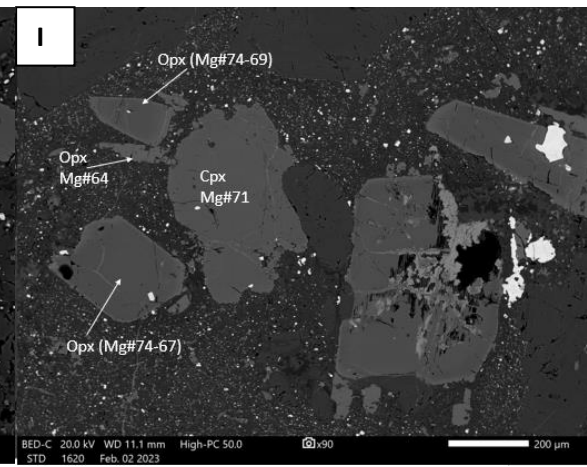
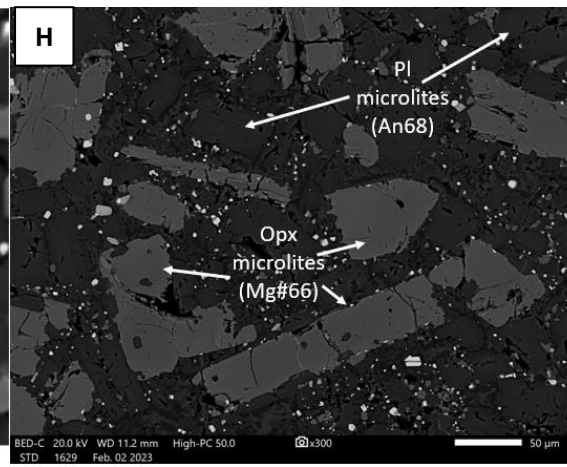
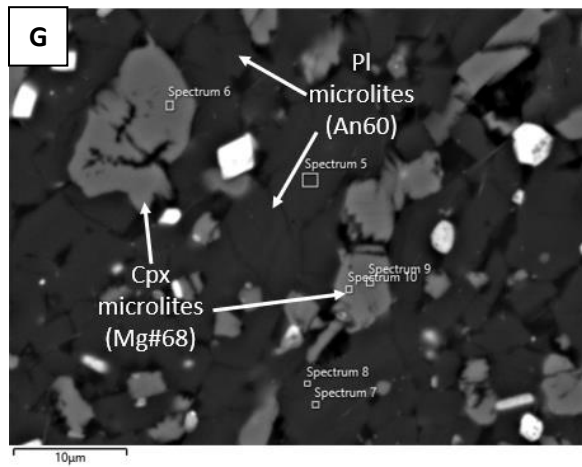


**Figure A3.2-24:** Sample YAM001, A) Sieved Pl grains with overgrowth and Opx and Cpx, B) Mag phenocrysts under incident light, C) Cpx, D) Opx and Cpx aggregate, E) Several Cpx grains in PPL, F) Euhedral Cpx with Mag inclusions, G) Groundmass containing microlites, H) Sieved Pl with overgrowth (left) and euhedral Pl (right), I) Opx and Cpx aggregate and euhedral Opx and Pl.

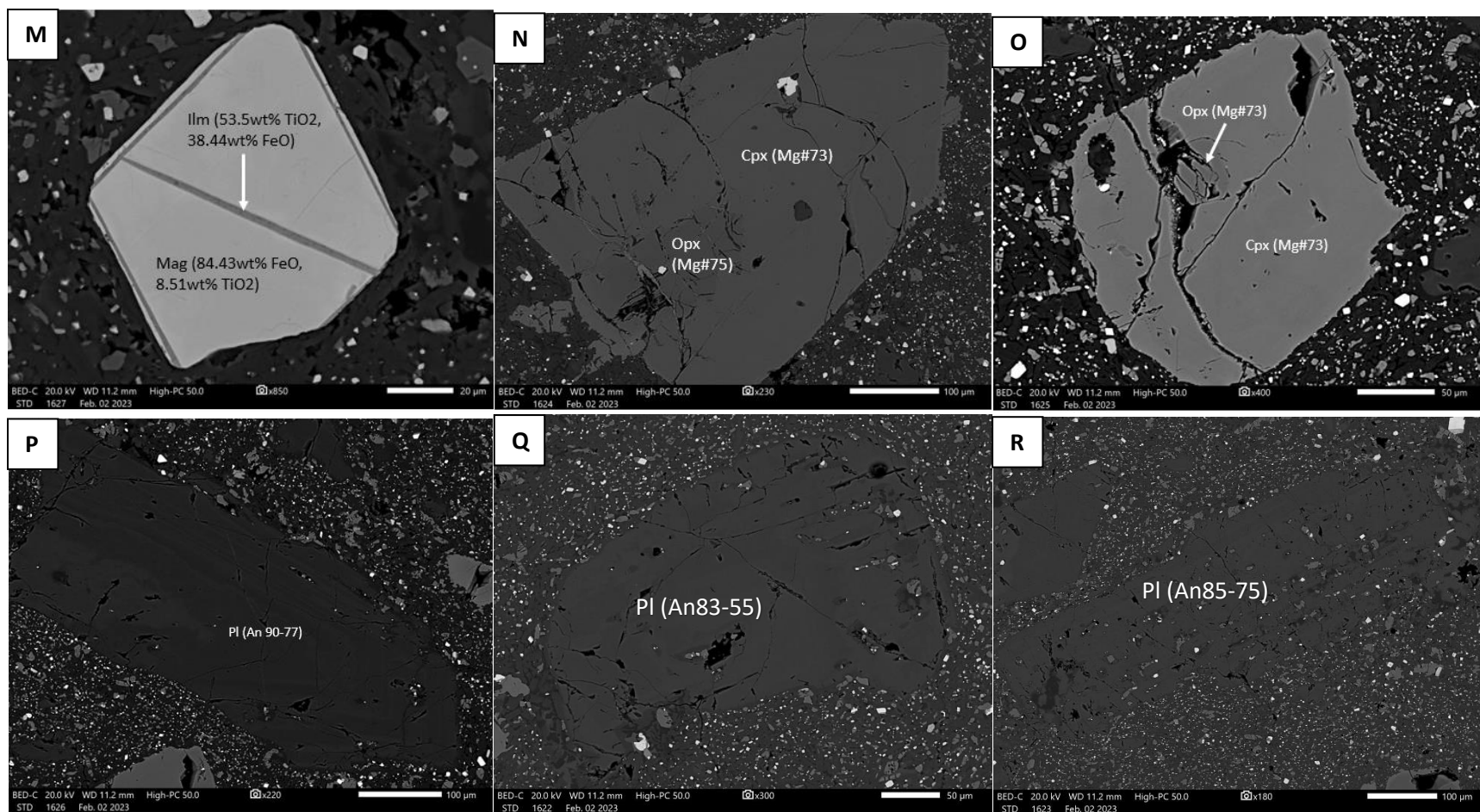


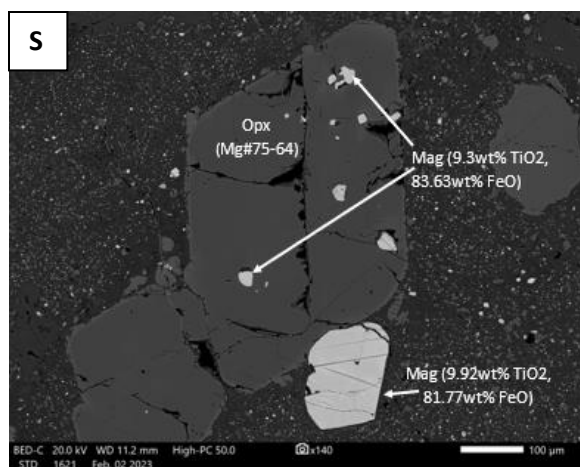
| Sample YAM002                                                                                                                                               |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Mineralogy                                                                                                                                                  | Texture                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Pl 25%<br>Cpx 15%<br>Opx 10%<br>Mag ~5-10%<br>Ilm trace                                                                                                     | Groundmass contains lighter and darker areas. The lighter groundmass contains Opx (Mg#66) and Pl (An68) microlites. The darker groundmass contains Cpx (Mg#68) and Pl (An60) microlites. Pl is euhedral and commonly exhibits albite twinning where the majority is unsieved. Several Pl grains are lightly sieved, and a few are completely destabilized. Several Pl grains exhibit oscillatory zoning. Opx grains are commonly normally zoned (core: Mg#~74, rim: Mg#~67) and have Mag inclusions. Several Cpx (Mg#~73) grains contain Opx inclusions (Mg#~75). Cpx commonly also includes Mag inclusions. Opx, Mag, Cpx and Pl form aggregates. Mag occurs disseminated throughout the groundmass and as microphenocrysts. SEM-EDS analysis did not find olivine. Cpx are augite and Opx phenocrysts are hypersthene. |
| <div> <div>A</div> </div> <div> <div>B</div> </div> <div> <div>C</div> </div> <div> <div>D</div> </div> <div> <div>E</div> </div> <div> <div>F</div> </div> |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |







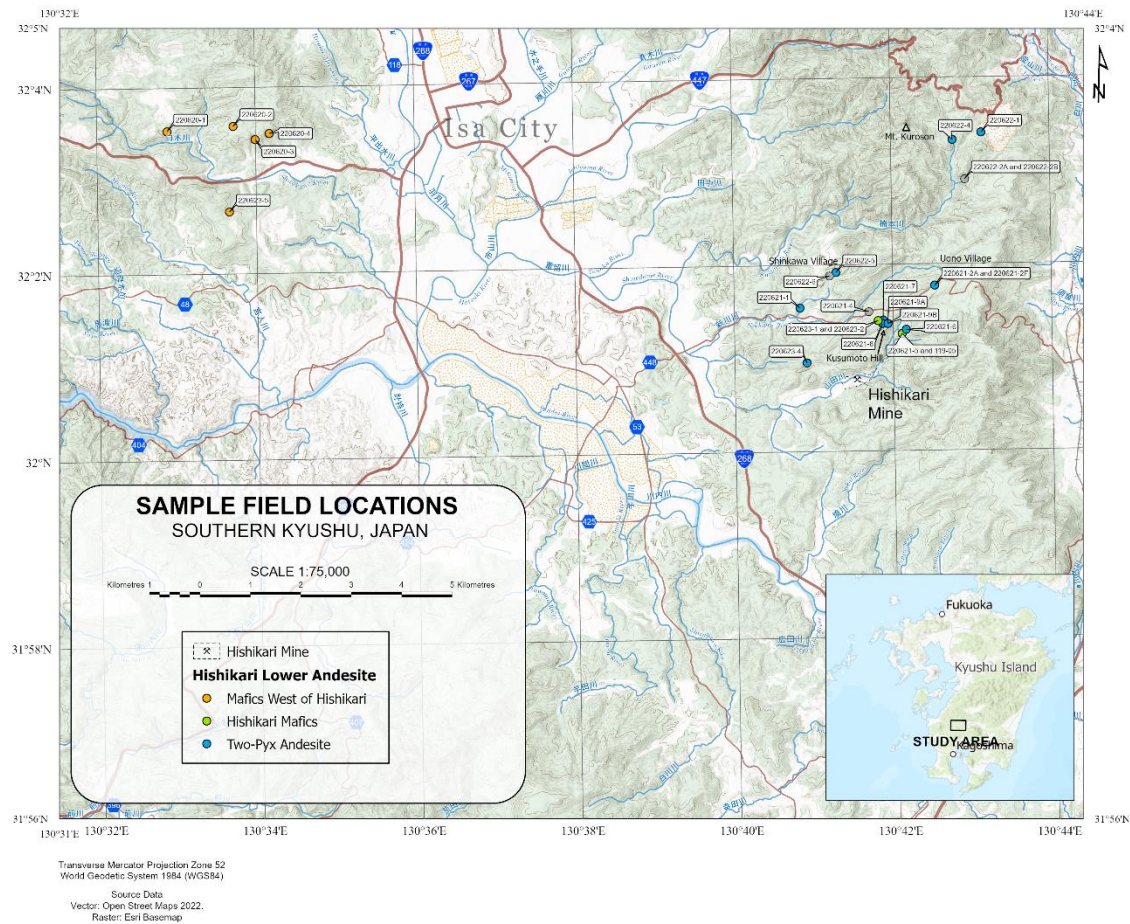




**Figure A3.2-25:** Sample YAM002, A) Cpx exhibiting twinning, B) Cpx with Mag inclusions, C) Opx and Cpx aggregate with Mag inclusions, D) Opx, Cpx, Pl and Mag aggregate, E) Mag phenocrysts and Ilm inclusions in Opx (REFL), F) Lighter groundmass (left) and darker groundmass (right), G) Microlites in dark groundmass, H) Microlites in light groundmass, I) Normally zoned Opx and Cpx, J) Mag phenocrysts (REFL), K) Varying textures in Pl, euhedral growth zoning (left), sieved (right), L) Euhedral Opx containing Mag inclusions, M) Mag grain with exsolution like Ilm, N and O) Cpx with Opx core, P, Q and R) Oscillatory Pl with alternating CaO composition from core to rim, S) Normally zoned Opx with mag inclusions and Mag grain.

## **APPENDIX 3.3. Field Work Report**

**Objective of the field work:** To collect various volcanic rocks focusing on andesite to characterize the nature of the Hishikari Lower Andesite.



**Figure A3.3-1:** Sample locations. Sample 220623-3 (Yamadagawa andesite) is not shown on the map but is located underground in the Yamada ore zone within the Hishikari mine. Sample coordinates are in appendix 4.2.

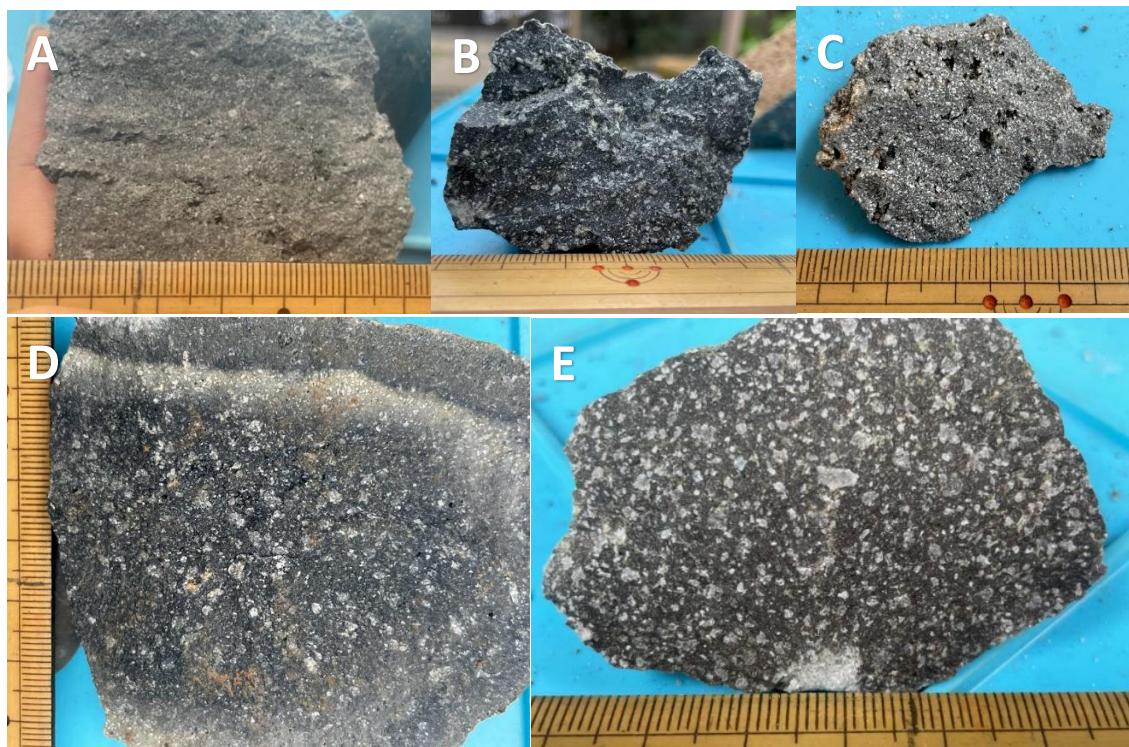
### **Samples ~11km west of Hishikari**

5 samples (220620-1, 220620-2, 220620-3, 220620-4, and 220623-5) of Basalt/basaltic andesite were collected Near the Japan Pig farm located along road 447, west of Isa city. Samples 220620-1, 220620-2, 220620-3, and 220620-4 were collected north of the pig farm on the north side of road 447. Sample 220623-5 was collected south of the pig farm on the south of road 447. All samples were collected along the sides of roads and are similar in texture and mineralogy.



Sample 220620-1 (fig.1.A) is a fine grained, compact, porphyritic lava with Pl and Mag phenocrysts and contains some elongated vesicles. It also contains 1 quartz clast (1.7mm) that is speculated to either be hydrothermal quartz or a xenolith. Sample 220620-2 (Fig.1.B) is darker in colour and is a fine-grained porphyritic lava with Pl, Pyx and Mag phenocrysts. Pl phenocrysts are homogeneous in size and are typically rounded to subrounded giving the rock a “spotted” texture. Sample 220620-3 (fig.1.C) is a fine grained porphyritic lava with Pl, Mag and Pyx phenocrysts. The outcrop is slightly weathered, and the sample is lighter and less dense than the other basaltic andesites. It is crystal rich (>75 vol%) and vesicular. The vesicles are irregularly shaped and up to 8mm in diameter. Pl is typically rounded, giving the rock a “spotted” appearance. Mag is rounded and sometimes forms aggregates. Sample 220620-4 (fig.1.D) is a very fine grained porphyritic lava containing Pl, Pyx and Mag phenocrysts. The outcrop is quite weathered, and it was difficult to find an area that was not weathered. As a result, the sample is weathered on the outside which is prominent by white weathered Pl on the outer portion of the sample. The sample is crystal poor (40-45 vol%) and Pl is subrounded to blocky

Sample 220623-5 is a fine grained porphyritic lava with phenocrysts of Pl, Mag and Pyx. The out crop is slightly weathered and differs slightly compared to the basaltic andesite samples collected on the North side of the pig farm as it has a brownish tint, coarser Pl and crystal rich (>70 vol%). Pl phenocrysts are typically subrounded to rounded giving the rock a distinct “spotted” look. Sample number.



**Figure A3.3-2:** West of Hishikari Hand Samples: A) 220620-1, B) 220620-2, C) 220620-3, D) 220620-4, E) 220623-5





**Figure A3.3-3:** West of Hishikari Outcrops: A) 220620-1, B) 220620-2, C) 220620-3, D) 220620-4



**Figure A3.3-4:** Outcrop South of Pig Farm: A) 220623-5 sample, B) 220623-5 outcrop, C) bottom of hill where sample 220623-5 was collected, D) Sample 220623-5 was collected on the left side of this road, E) Side of the road where sample 220623-5 was collected



Shinkawa Andesite (Shinkawa Village, near Shinkawa river)

1 sample (220621-1) of Shinkawa andesite was collected on the north side of road 448, east of Isa city in Shinkawa village. Shinkawa village is south of the town of Goshiki. Sample 220621-1 is a fine grained porphyritic basaltic andesite lava containing phenocrysts Mag, Pyx and coarse Pl. It is crystal rich ( $>70$  vol%), Pl rich ( $>50$  vol%), and dense. Mag also forms small aggregates, and Pl is subrounded to blocky. Weathered areas of the outcrop are oxidized; however, the sample was taken from a non weathered portion. This sample is very similar to the basaltic andesite samples collected to the northwest and could be part of the same unit.



**Figure A3.3-5:** Sample 220621-1



**Figure A3.3-6:** Outcrop of sample 220621-1

### Andesites in Uono Village

Two samples (220621-2A and 220621-2F) were collected along the side of road 448 in Uono Village. These samples are most likely be Upper Andesite but could also be Yamashita andesite according to field notes by Watanabe. Only the northern side of the road has outcrop where sample 220621-2A was collected. Sample 220621-2A is a fine grained porphyritic basaltic andesite lava with phenocrysts of Pl, Pyx and Mag. Mag is not visible with the naked eye, but sample attract magnet at less than 1 cm. The rock is dense and contains the occasional yellow mineral that was suggested to be oxidized Pl and does not resemble olivine. Sample 220621-2F is a float, collected less than 100m SW down the road. It is unaltered and contained coarser phenocrysts than sample 220621-2A. Sample 220621-2F is a very fine grained porphyritic basaltic andesite lava containing phenocrysts of Pl, Mag and Pyx. The phenocrysts are well formed and all visible with the naked eye. Pl is fresh and glassy. Mag is rounded and disseminated, sometimes forming clumps 2mm in diameter.



**Figure A3.3-7:** Upper Andesite Samples: A) 220621-2A, B) 220621-2F



**Figure A3.3-8:** Upper Andesite Sample Outcrops: A) 220621-2A outcrop, B) 220621-2F outcrop



### Shishimano Dacite

1 sample (220621-4) of Shishimano dacite was collected along road 448 in Uono. Sample 220621-4 is a dacite containing the phenocrysts of Qz, Mag, Pl, and Pyx. The matrix wrapping around phenocrysts seen with a hand lens and Bt is aligned with the alignment observed in the matrix. Qz is coarse (<2mm) and the outcrop is slightly weathered.



**Figure A3.3-9:** Sample 220621-4

### Volcanic Breccia (Town of Goshiki)

1 volcanic breccia (sample 220621-6) was found along a local road that intersects road 448 towards the south. At this location we parked the car at road 448 and walked down the local road (which seemed more like a well-kept trail) southward. Walking north to south we saw various textures in andesite which are believed to be Goshiki andesite as well as a volcanic breccia. Starting from road 448 at the parked car we walked for about 650-700m until we hit an intersection. 150m west of this intersection, down in elevation, was olivine andesite. The observations are as follows from north to south (and down in elevation) along the local road:

- N  
650m  
↓  
S
- 1) Fine grained porphyritic basaltic andesite with phenocrysts of Pyx and coarse Pl
  - 2) Fined grained banded basaltic andesite
  - 3) Very fine grained compact basaltic andesite. The sample is too fine grained to see any mineral but has disseminated pyrite.
  - 4) Fine grained porphyritic basaltic andesite with phenocrysts of Pyx and coarse Pl
  - 5) In a ditch, brecciated basaltic andesite (volcanic breccia sample 220621-6)

Sample 220621-6 is volcanic breccia with subangular clasts up to 5mm in an intermediate matrix. Visible minerals are coarse Pl and Mag.



**Figure A3.3-10:** Sample 220621-6



**Figure A3.3-11:** local road where various Goshiki Andesite and volcanic breccia was seen (facing north)

### Olivine Andesite

As mentioned in the previous section, an outcrop of olivine andesite was found 150m west of the intersection down in elevation. The outcrop is pyroclastic and is along the north side of the road and extends in the road we well (Fig. 11). The outcrop extended no further than about 50m west along the road but could be larger. Samples (220621-5) were collected in the road. Sample 220621-5 is a fine grained pyroclastic basaltic andesite that is vesicular and porphyritic containing phenocrysts of Ol, Pl, Mag and Pyx. Olivine crystals yellow green and <2mm, ~10 vol%. The groundmass shows lighter and darker areas which could indicate physical mixing if the compositions are different. Sample 119-05 which was given by Watanabe was also collected in this area.



**Figure A3.3-12:** Sample 220621-5



**Figure A3.3-13:** Sample 220621-5 outcrop locations: along the north side of local road (left), in the road (right)

### Kusumoto Andesite (Near Kusumoto Hill)

4 samples (220621-7, 220621-8, 220621-9A, 220621-9B) were collected along a trail southward from the road 448. Southward, for about 800m, sample 220621-7 was collected along the side of the trail. Sample 220621-7 came from a large boulder (fig. 14) about 3ft tall. The boulder was banded and slightly oxidized. Sample 220621-7 is a fine grained porphyritic flow banded andesite with coarse phenocrysts of Pl and Pyx. Further south on the trail we sample 220621-8 was collected along the side of the trail in the wooded area (Fig. 13C). Sample 220621-8 is a fine grained porphyritic andesite with Mag and very coarse Pl (<6mm) phenocrysts. Around the same area ~50m along the trail another outcrop was finer grained and vesicular containing a large Qz clast which could either be a xenocryst, accidental fragment, etc. It was difficult to tell if samples 220621-7 and 220621-8 were Kusumoto andesite due to the various textures. These samples were also found at the foothill of Kusumoto hill.

Off trail, trekking up a hill southward in the wooded area, two variations of Kusumoto Andesite were found on a cliff of a tall hill: crystal poor (<30 vol%, sample 220621-9A) and crystal rich (>70vol%, sample 220621-9B). Sample 220621-9A is a fine grained porphyritic basaltic andesite with phenocrysts of Pl, Pyx and mag and is Pyx rich and weathered on the outside. Sample 220621-9B is lighter in colour due to the abundance of Pl. It is a fine grained porphyritic andesite with Pl and Mag phenocrysts. The outcrop looks like a lava flow as the crystals are aligned in the same direction and the texture almost looks flow banded.





**Figure A3.3-14:** Kusumoto andesite outcrop locations: A) part of 220621-7 float/boulder where sample was taken, B) 220621-7 flow banded boulder, C) entrance to wooded area where sample 220621-8 was found further in, D) Yonezu-san and student standing in narrow trail in wooded area used to access samples 220621-9A and 220621-9B which is further up behind them, E) Dr. Hattori pointing at outcrop 220621-9A at the bottom of cliff, F) Kazuki-san standing next to 220621-9B outcrop top of cliff.

### Kurasonsan Andesite (Near Mt. Kuroson)

6 samples (220622-1, 220622-2A, 220622-2B, 220622-4, 220622-5, 220622-6) of Kurosonsan Andesite were collected in both south and north of the study area. 4 samples (220622-1, 220622-2A, 220622-2B, 220622-4) were collected south of road 447 where there is a pig farm. Samples were collected along a well-kept narrow trail southward from the pig farm. After walking for about 500m we collected our first sample, 220622-1, which is a fine grained porphyritic basaltic andesite with phenocrysts of Pyx, Pl and Mag. The rock is Pyx rich, Pl poor and contains bronze, yellow minerals (< 5vol%) that are subrounded and corroded which could either be olivine or an oxidized/weathered mineral. The trail turned westward and continued along a river. Sample 220622-4 was collected along this river. Sample 220622-4 is a fine grained porphyritic andesite with phenocrysts of Pl, Pyx and Mag. It is Pl rich (>50vol%) and has thin banding by crystal abundance. Along the trail, the unconformity between the Shimanto Basement and the Lower andesite was exposed along the river. Polymictic matrix supported conglomerate with gravel to pebble subrounded clasts was observed directly overlying the basement. Further along this river the trail turned into a paved road where we continued and crossed the river by a bridge. We sampled at the bottom of the Kurosonsan hill along the paved road. Sample 220622-2A and 220622-2B was collected ~10m apart from each other where 220622-2B is farther south down the trail. They come from the same large outcrop and are both fine grained porphyritic andesites with phenocrysts of Pl, Pyx, Qz, and Mag. There are small amounts of Qz (~10vol%) and more Pl (~50vol%). Crystals in both samples are aligned, resembling flow banding.

Samples 220622-5 and 220622-6 were collected north of road 448 after trekking a narrow trail into the western edge of Kusumoto hill. These samples could also possibly be Kusumoto Andesite because the samples are similar to Kusumoto Andesite samples 220621-8, 220621-9A, and 220621-9B). These samples (220622-5 and 220622-6) are the same which are fine grained porphyritic andesites with phenocrysts of Pl, Pyx and Mag where sample 220622-6 is more Pl rich. The sample sites are separated by a tall grass field.









**Figure A3.3-15:** Kurosonsan Andesite outcrop locations: A) 220622-1, B) 220622-2A, C) 220622-2B, D) 220622-4, E) River leading to Kurosonsan andesite locality which exposes the unconformity between Lower Andesite and Shimanto Basement, F) Conglomerate overlying Shimanto Basement at unconformity, G) 220622-6, H) Road 448, samples 220622-5 and 220622-6 were collected in the forest shown behind road.

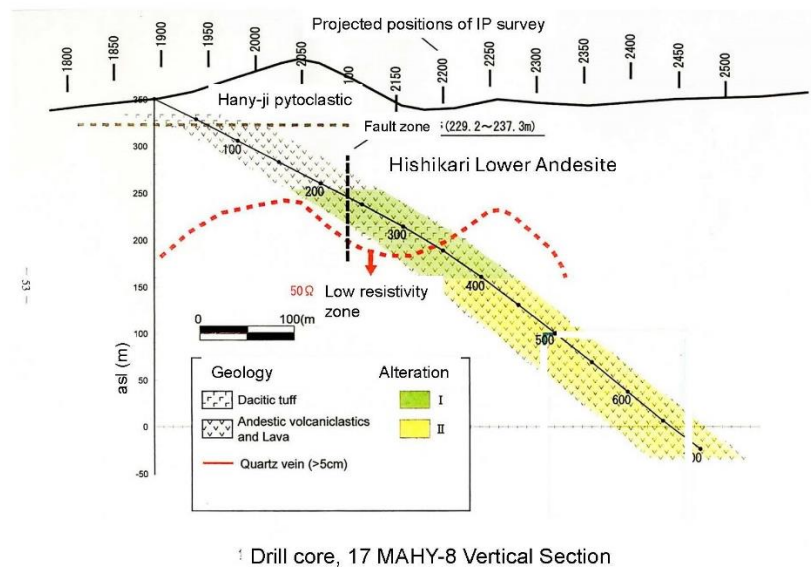


## Drill cores

2 Drill cores were provided by the Hishikari mine office. The total length of the drill core is 700.7m (inclination 25d). The first drill core (sample 220623-1 aka DDH17MAHY-8A) has a depth of 695m is said to be near the bottom of the hole intersecting olivine andesite. This sample is a fine grained porphyritic basaltic andesite containing phenocrysts of Pl, Pyx and Mag. The drill core is also crystal poor (~30vol%). The second drill core (sample 220623-2 aka DDH17MAHY-8B) has a depth of 106m. This sample is a fine to medium grained porphyritic andesite containing Pl, Mag and Pyx. The texture is homogenous throughout the sample.



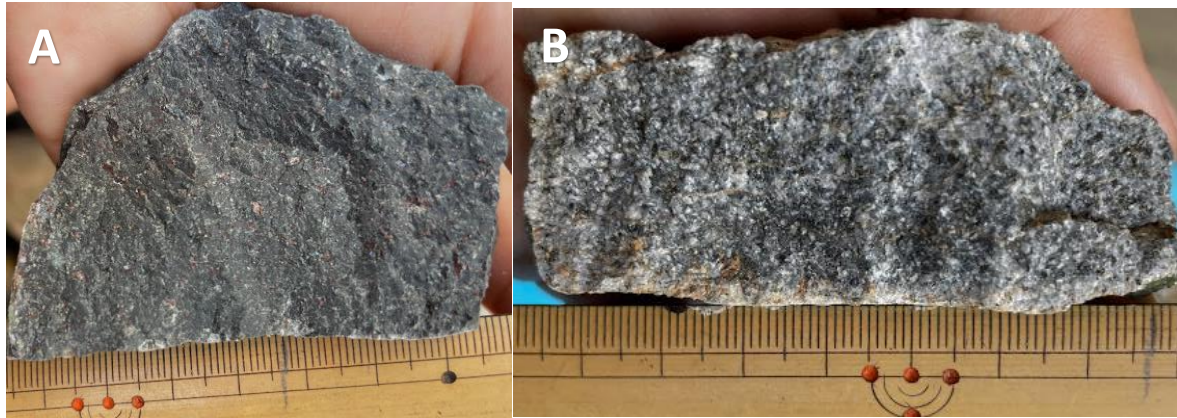
**Figure A3.3-16:** A) sample 220623-1, B) sample 220623-2



**Figure A3.3-17:** Vertical Section of DDH17MAHY-8

Yamadagawa Andesite (Below the surface in Yamada Ore zone)

Sample 220623-3 of Yamadagawa andesite were given by the Hishikari mine. Sample 220623-3 came from the Yamada Ore zone ~100m below the surface, West 138 crosscut. The samples are red due to oxidation. Sample 220623-3 is a fine grained porphyritic basaltic andesite with phenocrysts of Mag, Pl, and coarse Pyx. Py (<5 vol%) is disseminated throughout. We collected another sample of Yamadagawa andesite located about 1km north of the Hishikari mine office from the side of steep hill. This sample (220623-4) is a fine grained porphyritic andesite containing phenocrysts of Pl, Mag and Pyx. This is more crystal rich (75vol%) and Pl rich (>55vol%) than the sample given by the mine.



**Figure A3.3-18:** Yamadagawa Andesite samples: A) 220623-3, B) 220623-4

## **APPENDIX 4. Supplementary Data for Chapter 5**

### **APPENDIX 4.1 Tholeiitic Index Calculation**

#### **The Tholeiitic Index (THI)**

The Tholeiitic Index (THI) is denoted below by Zimmer et al. (2010):

$$\text{THI} = \text{Fe}_{4.0}/\text{Fe}_{8.0}$$

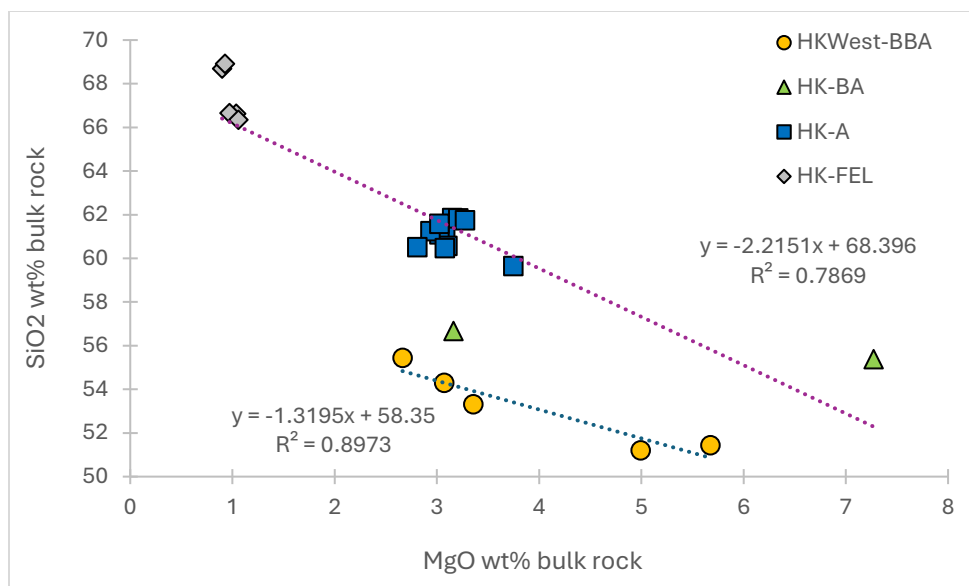
*Where  $\text{Fe}_{4.0}$  is the average  $\text{FeO}^*$  concentration of samples at  $4 \pm 1$  wt% MgO and  $\text{Fe}_{8.0}$  is the average  $\text{FeO}^*$  concentration at  $8 \pm 1$  wt% MgO along a given line of descent. The THI represents the enrichment or depletion of  $\text{FeO}^*$  at parental compositions at 8% MgO to more fractionated compositions at 4% MgO (Zimmer et al., 2010).  $\text{FeO}^*$  = total Fe expressed as FeO. Error is  $\pm 10\%$ .*

Due to insufficient data, the values for  $\text{Fe}_{4.0}$  and  $\text{Fe}_{8.0}$  were extrapolated based on MgO-SiO<sub>2</sub> and  $\text{FeO}^*$ -SiO<sub>2</sub> relationships. SiO<sub>2</sub> at 8wt% MgO and 4wt% MgO was extrapolated using the linear equations from Fig. A5.1-1. Then, the  $\text{FeO}^*$  at each given SiO<sub>2</sub> at 4 and 8 wt% MgO was extrapolated using the linear equations from Fig. A5.1-2. The values are listed in Table A5.1-1.

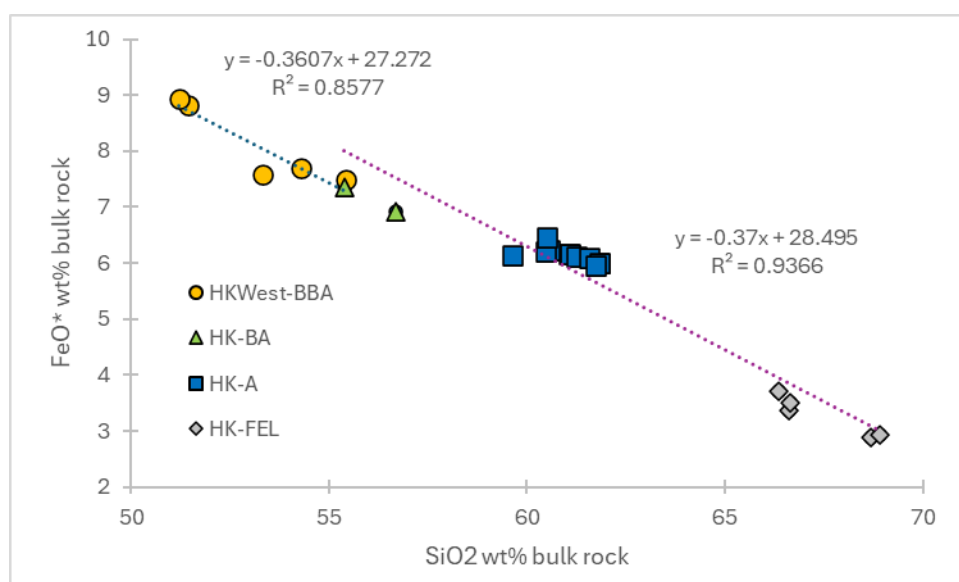
The samples collected west of Hishikari mine (HKWest-BBA) have a higher THI value (0.81) compared to rocks from the Hishikari mine area (0.66) indicating that HKWest-BBA has a stronger tholeiitic character than rocks in the Hishikari mine area.

| Group                                                         | SiO <sub>2</sub><br>(wt%) at<br>8wt%<br>MgO | FeO* (wt%)<br>at<br>SiO <sub>2</sub> 8wt%MgO | SiO <sub>2</sub><br>(wt%) at<br>4wt%<br>MgO | FeO* (wt%)<br>at<br>SiO <sub>2</sub> 4wt%MgO | Fe <sub>8.0</sub><br>(wt%) | Fe <sub>4.0</sub><br>(wt%) | THI         |
|---------------------------------------------------------------|---------------------------------------------|----------------------------------------------|---------------------------------------------|----------------------------------------------|----------------------------|----------------------------|-------------|
| HKWest-BBA (n=5)                                              | 47.79                                       | 10.03                                        | 53.07                                       | 8.13                                         | 10.03                      | 8.13                       | <b>0.81</b> |
| Hishikari<br>mine rocks<br>(HK-BA,<br>HK-A, HK-<br>FEL, n=18) | 50.68                                       | 9.75                                         | 59.54                                       | 6.47                                         | 9.75                       | 6.47                       | <b>0.66</b> |

**Table A4.1-1.** Values of SiO<sub>2</sub> at 8wt% MgO and 4wt% MgO and  $\text{FeO}^*$  at each given SiO<sub>2</sub> at 4 and 8 wt% MgO using the linear equations from Fig. A5.1-1 and A5.1-2. The THI value was calculated using the equation above.



**Figure A4.1-1.** SiO<sub>2</sub> vs. MgO bulk rock for HKWest-BBA (orange circles) and Hishikari mine rocks (green triangles, blue squares and grey diamonds). Lines represent a linear trend with their corresponding linear equation.



**Figure A4.1-2.** FeO\* vs. MgO bulk rock for HKWest-BBA (orange circles) and Hishikari mine rocks (green triangles, blue squares and grey diamonds). Lines represent a linear trend with their corresponding linear equation.

## REFERENCES

Zimmer, M. M., Plank, T., Hauri, E. H., Yogodzinski, G. M., Stelling, P., Larsen, J., & Nye, C. J. (2010). The role of water in generating the calc-alkaline trend: new volatile data for Aleutian magmas and a new tholeiitic index. *Journal of Petrology*, 51(12), 2411-2444.



## **APPENDIX 4.2. Bulk-rock Trace Element Composition.**

nd = not determined

| Analyte Symbol  | Li     | Cd     | V     | Cr    | Mn    | Hf    | Ni     | Er    | Be    | Ho    | Ag     | Cs    | Co     | Eu    |
|-----------------|--------|--------|-------|-------|-------|-------|--------|-------|-------|-------|--------|-------|--------|-------|
| Unit            | ppm    | ppm    | ppm   | ppm   | ppm   | ppm   | ppm    | ppm   | ppm   | ppm   | ppm    | ppm   | ppm    | ppm   |
| Detection Limit | 1      | 0.3    | 1     | 1     | 1     | 0.1   | 1      | 0.1   | 0.1   | 0.1   | 0.3    | 0.05  | 1      | 0.05  |
| Analysis Method | TD-ICP | TD-ICP | TD-MS | TD-MS | TD-MS | TD-MS | TD-ICP | TD-MS | TD-MS | TD-MS | TD-ICP | TD-MS | TD-ICP | TD-MS |
| 220620-1        | 10     | < 0.3  | 227   | 65    | 1240  | 2.5   | 26     | 2.6   | 1     | 0.9   | < 0.3  | 1.39  | 28     | 1.39  |
| 220620-2        | 14     | < 0.3  | 109   | 8     | 930   | 2.4   | 6      | 3.9   | 1.6   | 1.4   | 0.4    | 1.84  | 17     | 2.34  |
| 220620-3        | 11     | < 0.3  | 98    | 34    | 1180  | 2.2   | 25     | 2.8   | 1.3   | 0.9   | 0.3    | 1.37  | 27     | 1.58  |
| 220620-4        | 13     | < 0.3  | 209   | 15    | 1060  | 2.6   | 12     | 2.3   | 1     | 0.7   | < 0.3  | 1.17  | 21     | 1.11  |
| 220621-1        | 19     | < 0.3  | 90    | 33    | 791   | 3.2   | 10     | 3     | 1.2   | 1     | < 0.3  | 4.29  | 15     | 1.26  |
| 220621-2A       | 19     | < 0.3  | 110   | 44    | 791   | 3.6   | 9      | 3.2   | 1.3   | 1     | 0.5    | 4.47  | 15     | 1.33  |
| 220621-2F       | 17     | < 0.3  | 60    | 23    | 746   | 2.3   | 9      | 3.1   | 1.2   | 1.1   | < 0.3  | 4.74  | 15     | 1.39  |
| 220621-4        | 21     | < 0.3  | 41    | 7     | 729   | 2.5   | 2      | 2.6   | 1.4   | 0.8   | < 0.3  | 4.5   | 5      | 1.13  |
| 220621-5        | 12     | < 0.3  | 170   | 25    | 971   | 2.6   | 13     | 2.1   | 1     | 0.7   | < 0.3  | 3.17  | 21     | 0.97  |
| 220621-6        | 19     | < 0.3  | 150   | 35    | 938   | 3.7   | 16     | 2.6   | 1.2   | 0.9   | 0.4    | 4.77  | 19     | 0.99  |
| 220621-7        | 18     | < 0.3  | 67    | 27    | 859   | 2.5   | 10     | 2.8   | 1.2   | 0.9   | < 0.3  | 2.76  | 17     | 1.15  |
| 220621-8        | 17     | < 0.3  | 93    | 18    | 1050  | 2.6   | 9      | 3.2   | 1.2   | 1     | < 0.3  | 3.31  | 17     | 1.09  |
| 220621-9A       | 21     | < 0.3  | 162   | 34    | 714   | 3.9   | 9      | 3.1   | 1.3   | 1.1   | 0.5    | 3.75  | 16     | 1.29  |
| 220621-9B       | 19     | < 0.3  | 65    | 30    | 826   | 2.9   | 10     | 2.9   | 1.2   | 0.9   | 0.3    | 2.95  | 16     | 1.09  |
| 220622-2A       | 19     | < 0.3  | 20    | 7     | 588   | 2     | 3      | 2.4   | 1.4   | 0.7   | < 0.3  | 7.81  | 4      | 0.84  |
| 220622-2B       | 19     | < 0.3  | 30    | 5     | 583   | 2.2   | 2      | 3.3   | 1.5   | 1.1   | < 0.3  | 5.64  | 4      | 1.27  |
| 220622-4        | 15     | < 0.3  | 59    | 26    | 787   | 2.2   | 11     | 2.9   | 1.2   | 1     | < 0.3  | 2.84  | 17     | 1.09  |
| 220622-5        | 16     | < 0.3  | 141   | 30    | 760   | 3.5   | 9      | 3.3   | 1.2   | 1.1   | 0.4    | 3.39  | 16     | 1.18  |
| 220622-6        | 19     | < 0.3  | 20    | 6     | 635   | 1.5   | 1      | 2.6   | 1.3   | 0.9   | < 0.3  | 4.69  | 4      | 1.19  |
| 220622-7        | 20     | < 0.3  | 21    | 6     | 686   | 1.6   | 2      | 1.8   | 1.3   | 0.6   | < 0.3  | 8.35  | 5      | 0.83  |
| 220623-1        | 9      | < 0.3  | 95    | 149   | 1290  | 1.2   | 62     | 1.6   | 1     | 0.6   | 0.3    | 1.36  | 29     | 0.95  |
| 220623-2        | 22     | < 0.3  | 66    | 9     | 693   | 3.6   | 3      | 2.9   | 1.4   | 0.9   | 0.4    | 4.04  | 5      | 1.26  |
| 220623-3        | 57     | < 0.3  | 135   | 29    | 1610  | 3.5   | 12     | 2.8   | 1.2   | 0.9   | 0.3    | 19.1  | 15     | 1.04  |
| 220623-4        | 18     | < 0.3  | 67    | 31    | 828   | 2.9   | 14     | 2.5   | 1.2   | 0.8   | < 0.3  | 2.72  | 18     | 0.97  |
| 220623-5        | 15     | < 0.3  | 141   | 10    | 1070  | 2.5   | 12     | 2.5   | 1.2   | 0.9   | < 0.3  | 0.83  | 22     | 1.39  |
| YAM001          | 10     | < 0.3  | 192   | 97    | 1300  | 2.4   | 28     | 2.4   | 0.8   | 0.8   | < 0.3  | 1.78  | 23     | 1.02  |

|        |   |       |     |    |      |     |    |     |     |     |     |      |    |      |
|--------|---|-------|-----|----|------|-----|----|-----|-----|-----|-----|------|----|------|
| YAM002 | 7 | < 0.3 | 167 | 41 | 1190 | 2.4 | 13 | 2.7 | 0.9 | 0.9 | 0.3 | 4.16 | 19 | 1.14 |
|--------|---|-------|-----|----|------|-----|----|-----|-----|-----|-----|------|----|------|

| Analyte Symbol  | Bi     | Se    | Zn     | Ga    | As    | Rb    | Y     | Sr    | Zr    | Nb       | Mo     | In    | Sn    | Sb    |
|-----------------|--------|-------|--------|-------|-------|-------|-------|-------|-------|----------|--------|-------|-------|-------|
| Unit            | ppm    | ppm   | ppm    | ppm   | ppm   | ppm   | ppm   | ppm   | ppm   | ppm      | ppm    | ppm   | ppm   | ppm   |
| Detection Limit | 0.02   | 0.1   | 1      | 0.1   | 0.1   | 0.2   | 0.1   | 0.2   | 1     | 0.1      | 1      | 0.1   | 1     | 0.1   |
| Analysis Method | TD-MS  | TD-MS | TD-ICP | TD-MS | TD-MS | TD-MS | TD-MS | TD-MS | TD-MS | LA-ICPMS | TD-ICP | TD-MS | TD-MS | TD-MS |
| 220620-1        | 0.04   | 0.3   | 83     | 20.4  | 0.7   | 20.6  | 22.1  | 547   | 84    | 4.59     | < 1    | < 0.1 | < 1   | < 0.1 |
| 220620-2        | 0.05   | 0.2   | 82     | 19.4  | 2.2   | 37.5  | 32.7  | 511   | 81    | 3.08     | < 1    | < 0.1 | < 1   | < 0.1 |
| 220620-3        | 0.04   | 0.3   | 126    | 20.5  | 0.8   | 16.1  | 23.6  | 629   | 74    | nd       | < 1    | < 0.1 | < 1   | < 0.1 |
| 220620-4        | 0.04   | 0.3   | 80     | 22    | 1     | 13.2  | 17.8  | 609   | 84    | 5.85     | < 1    | < 0.1 | < 1   | < 0.1 |
| 220621-1        | 0.03   | < 0.1 | 67     | 17.5  | 1.9   | 77.8  | 25.4  | 353   | 105   | 4.59     | < 1    | < 0.1 | < 1   | < 0.1 |
| 220621-2A       | 0.03   | 0.3   | 67     | 17.4  | 2.1   | 82.3  | 25.8  | 358   | 115   | 4.04     | < 1    | < 0.1 | < 1   | < 0.1 |
| 220621-2F       | 0.06   | 0.2   | 68     | 18    | 2.3   | 75.2  | 27.9  | 395   | 76    | 2.56     | < 1    | < 0.1 | < 1   | < 0.1 |
| 220621-4        | < 0.02 | 0.3   | 63     | 16.7  | 2.7   | 67.4  | 19.4  | 264   | 72    | 5.46     | < 1    | < 0.1 | < 1   | < 0.1 |
| 220621-5        | 0.02   | 0.4   | 65     | 18.7  | 1.6   | 46.6  | 17.1  | 496   | 80    | 5.01     | < 1    | < 0.1 | < 1   | < 0.1 |
| 220621-6        | 0.08   | 0.3   | 62     | 17.4  | 2.3   | 77.7  | 21.3  | 323   | 119   | 4.08     | < 1    | < 0.1 | < 1   | < 0.1 |
| 220621-7        | 0.08   | < 0.1 | 76     | 17.4  | 0.9   | 77.5  | 23.4  | 336   | 79    | 3.00     | < 1    | < 0.1 | < 1   | < 0.1 |
| 220621-8        | 0.03   | 0.3   | 64     | 17.2  | 1.8   | 77.9  | 31.2  | 318   | 81    | 6.06     | < 1    | < 0.1 | < 1   | < 0.1 |
| 220621-9A       | 0.05   | 0.2   | 69     | 18.4  | 2.3   | 78.8  | 28.4  | 333   | 128   | 5.10     | < 1    | < 0.1 | < 1   | < 0.1 |
| 220621-9B       | 0.06   | 0.5   | 70     | 17.9  | 2     | 74.6  | 26.3  | 356   | 91    | 6.71     | < 1    | < 0.1 | < 1   | < 0.1 |
| 220622-2A       | < 0.02 | 0.3   | 55     | 15.9  | 3     | 86    | 18.7  | 243   | 58    | 4.08     | < 1    | < 0.1 | < 1   | < 0.1 |
| 220622-2B       | < 0.02 | 0.3   | 57     | 15.3  | 3.7   | 77.6  | 26.8  | 233   | 64    | nd       | < 1    | < 0.1 | < 1   | < 0.1 |
| 220622-4        | 0.06   | 0.1   | 69     | 17.2  | 1.5   | 71.6  | 25.5  | 335   | 69    | nd       | < 1    | < 0.1 | < 1   | < 0.1 |
| 220622-5        | 0.08   | 0.5   | 70     | 18.9  | 2.3   | 78.4  | 27.9  | 331   | 111   | 4.73     | < 1    | < 0.1 | < 1   | < 0.1 |
| 220622-6        | < 0.02 | 0.3   | 57     | 16.3  | 2.1   | 65.2  | 21.9  | 281   | 45    | 6.10     | < 1    | < 0.1 | < 1   | < 0.1 |
| 220622-7        | < 0.02 | 0.4   | 58     | 18.9  | 2.6   | 74.1  | 14.6  | 278   | 46    | 4.05     | < 1    | < 0.1 | < 1   | < 0.1 |
| 220623-1        | 0.03   | 0.2   | 68     | 17.7  | 0.6   | 32.1  | 14.2  | 544   | 40    | 3.67     | < 1    | < 0.1 | < 1   | < 0.1 |
| 220623-2        | 0.06   | 0.1   | 82     | 19.6  | 1.3   | 73.9  | 24.6  | 411   | 124   | 5.58     | < 1    | < 0.1 | < 1   | < 0.1 |
| 220623-3        | 0.05   | 0.4   | 66     | 19.7  | 16.8  | 340   | 23.5  | 284   | 116   | 5.11     | < 1    | < 0.1 | < 1   | 2     |
| 220623-4        | 0.29   | 0.2   | 64     | 17.5  | 1.6   | 85.5  | 20.5  | 314   | 95    | 3.89     | < 1    | < 0.1 | < 1   | < 0.1 |
| 220623-5        | 0.02   | 0.4   | 80     | 21.2  | 1.3   | 35.2  | 22.3  | 602   | 82    | 6.10     | < 1    | < 0.1 | < 1   | < 0.1 |
| YAM001          | 0.04   | 0.4   | 82     | 17.5  | 2.3   | 17.8  | 20.7  | 411   | 78    | 6.82     | < 1    | < 0.1 | < 1   | 0.2   |
| YAM002          | < 0.02 | 0.2   | 93     | 19    | 0.9   | 26.9  | 22.3  | 447   | 86    | 6.09     | < 1    | < 0.1 | < 1   | < 0.1 |

| Analyte Symbol  | Te    | Ba    | La    | Ce    | Pr    | Nd    | Sm    | Gd    | Tb    | Dy    | Cu     | Ge    | Tm    |
|-----------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|--------|-------|-------|
| Unit            | ppm   | ppm   | ppm   | ppm   | ppm   | ppm   | ppm   | ppm   | ppm   | ppm   | ppm    | ppm   | ppm   |
| Detection Limit | 0.1   | 1     | 0.1   | 0.1   | 0.1   | 0.1   | 0.1   | 0.1   | 0.1   | 0.1   | 1      | 0.1   | 0.1   |
| Analysis Method | TD-MS | TD-MS | TD-MS | TD-MS | TD-MS | TD-MS | TD-MS | TD-MS | TD-MS | TD-MS | TD-ICP | TD-MS | TD-MS |
| 220620-1        | < 0.1 | 273   | 16.5  | 31.9  | 4.7   | 20.2  | 4.4   | 4.8   | 0.7   | 4.4   | 45     | 0.1   | 0.4   |
| 220620-2        | < 0.1 | 356   | 28.4  | 42.1  | 8.7   | 35.9  | 9.2   | 8.1   | 1.3   | 7     | 18     | < 0.1 | 0.5   |
| 220620-3        | < 0.1 | 394   | 22.4  | 45.8  | 6.4   | 26.1  | 6.7   | 5.5   | 0.8   | 4.6   | 45     | 0.1   | 0.4   |
| 220620-4        | < 0.1 | 321   | 11.5  | 26.4  | 3.5   | 14.8  | 4.3   | 4.1   | 0.6   | 3.7   | 63     | 0.4   | 0.3   |
| 220621-1        | < 0.1 | 370   | 23.1  | 38.7  | 6.2   | 24.7  | 5.5   | 5.4   | 0.9   | 5     | 21     | 0.3   | 0.4   |
| 220621-2A       | < 0.1 | 379   | 24.5  | 41.4  | 6.5   | 25.7  | 6     | 5.5   | 0.9   | 5.3   | 21     | 0.3   | 0.4   |
| 220621-2F       | < 0.1 | 373   | 25.5  | 36.3  | 6.3   | 25.6  | 6.1   | 5.8   | 0.9   | 5     | 33     | 0.1   | 0.4   |
| 220621-4        | < 0.1 | 365   | 27    | 55.4  | 6.8   | 25    | 4.7   | 4.5   | 0.7   | 4.4   | 3      | 0.1   | 0.4   |
| 220621-5        | < 0.1 | 294   | 13.8  | 28.6  | 3.6   | 14.5  | 3.6   | 3.4   | 0.6   | 3.2   | 71     | 0.3   | 0.3   |
| 220621-6        | < 0.1 | 385   | 18.2  | 36.2  | 4.8   | 20.1  | 4.6   | 4.2   | 0.7   | 4     | 65     | 0.3   | 0.4   |
| 220621-7        | < 0.1 | 399   | 19.8  | 36.2  | 5.2   | 21.5  | 5.1   | 4.9   | 0.8   | 4.7   | 21     | 0.2   | 0.4   |
| 220621-8        | < 0.1 | 412   | 21.3  | 38.3  | 5.4   | 20.7  | 5     | 5     | 0.8   | 4.9   | 21     | 0.2   | 0.4   |
| 220621-9A       | < 0.1 | 398   | 22    | 38.1  | 5.6   | 22.6  | 5.6   | 5.5   | 0.8   | 5.1   | 13     | < 0.1 | 0.4   |
| 220621-9B       | < 0.1 | 383   | 22.3  | 38.5  | 5.6   | 21.4  | 5.2   | 4.6   | 0.7   | 4.5   | 19     | 0.2   | 0.4   |
| 220622-2A       | < 0.1 | 437   | 19.6  | 39.1  | 4.7   | 17.1  | 3.6   | 3.5   | 0.6   | 3.6   | 3      | 0.2   | 0.3   |
| 220622-2B       | < 0.1 | 402   | 38    | 52.2  | 8.7   | 30.5  | 6.6   | 5.7   | 0.9   | 5.5   | 2      | < 0.1 | 0.5   |
| 220622-4        | < 0.1 | 340   | 18.4  | 35    | 5     | 18.9  | 4.3   | 4.5   | 0.7   | 4.6   | 30     | 0.1   | 0.4   |
| 220622-5        | < 0.1 | 455   | 24.1  | 47    | 6.4   | 25.3  | 5.8   | 5.3   | 0.9   | 5     | 27     | 0.3   | 0.4   |
| 220622-6        | < 0.1 | 355   | 31.7  | 33.7  | 7.2   | 25.8  | 5.3   | 4.6   | 0.7   | 4.5   | 3      | 0.2   | 0.4   |
| 220622-7        | < 0.1 | 361   | 14.5  | 26.2  | 3.2   | 12.1  | 2.9   | 2.6   | 0.4   | 2.8   | 2      | 0.2   | 0.3   |
| 220623-1        | < 0.1 | 264   | 12.1  | 25.6  | 3.4   | 14.1  | 3.7   | 3.3   | 0.5   | 2.9   | 81     | 0.2   | 0.2   |
| 220623-2        | < 0.1 | 399   | 22.8  | 43.9  | 5.5   | 21.9  | 5.2   | 4.8   | 0.8   | 4.7   | 2      | < 0.1 | 0.4   |
| 220623-3        | < 0.1 | 426   | 21.5  | 42.9  | 5.4   | 20.5  | 4.5   | 4.4   | 0.7   | 4.3   | 26     | 0.3   | 0.4   |
| 220623-4        | < 0.1 | 396   | 18.1  | 38.6  | 4.8   | 18.9  | 4.6   | 4.2   | 0.7   | 4     | 50     | 0.2   | 0.3   |
| 220623-5        | < 0.1 | 383   | 16.6  | 33.4  | 4.7   | 19.9  | 4.5   | 4.7   | 0.7   | 4.4   | 28     | 0.1   | 0.3   |
| YAM001          | < 0.1 | 252   | 11.3  | 23.6  | 3.2   | 13.2  | 3.4   | 3.6   | 0.6   | 3.7   | 26     | 0.1   | 0.3   |
| YAM002          | < 0.1 | 276   | 14.3  | 30.2  | 4     | 16.8  | 4.1   | 4     | 0.7   | 4.2   | 20     | 0.1   | 0.3   |

| Analyte Symbol  | Yb    | Lu    | Ta    | W     | Re    | Tl    | Pb     | Sc     | Th    | U     | Ti     | P      | S      |
|-----------------|-------|-------|-------|-------|-------|-------|--------|--------|-------|-------|--------|--------|--------|
| Unit            | ppm   | ppm   | ppm   | ppm   | ppm   | ppm   | ppm    | ppm    | ppm   | ppm   | %      | %      | %      |
| Detection Limit | 0.1   | 0.1   | 0.1   | 0.1   | 0.001 | 0.05  | 3      | 1      | 0.1   | 0.1   | 0.0005 | 0.001  | 0.01   |
| Analysis Method | TD-MS | TD-MS | TD-MS | TD-MS | TD-MS | TD-MS | TD-ICP | TD-ICP | TD-MS | TD-MS | TD-ICP | TD-ICP | TD-ICP |
| 220620-1        | 2.5   | 0.4   | < 0.1 | < 0.1 | 0.004 | 0.1   | < 3    | 29     | 3     | 0.6   | 0.39   | 0.077  | < 0.01 |
| 220620-2        | 3.7   | 0.5   | < 0.1 | 0.6   | 0.004 | 0.19  | 6      | 23     | 4.3   | 0.9   | 0.159  | 0.079  | < 0.01 |
| 220620-3        | 2.6   | 0.4   | < 0.1 | < 0.1 | 0.004 | 0.15  | 14     | 29     | 6.9   | 1.2   | 0.186  | 0.104  | < 0.01 |
| 220620-4        | 2.3   | 0.3   | < 0.1 | 0.1   | 0.003 | 0.08  | 5      | 21     | 2.1   | 0.6   | 0.428  | 0.078  | < 0.01 |
| 220621-1        | 2.9   | 0.4   | < 0.1 | < 0.1 | 0.004 | 0.3   | 8      | 21     | 7.7   | 1.7   | 0.203  | 0.048  | < 0.01 |
| 220621-2A       | 3     | 0.5   | < 0.1 | < 0.1 | 0.004 | 0.3   | 9      | 22     | 7.7   | 1.7   | 0.239  | 0.049  | < 0.01 |
| 220621-2F       | 2.9   | 0.4   | < 0.1 | < 0.1 | 0.004 | 0.37  | 8      | 21     | 7.6   | 1.8   | 0.112  | 0.048  | < 0.01 |
| 220621-4        | 2.7   | 0.4   | < 0.1 | < 0.1 | 0.004 | 0.37  | 12     | 10     | 6.9   | 1.6   | 0.174  | 0.033  | < 0.01 |
| 220621-5        | 2.1   | 0.3   | < 0.1 | < 0.1 | 0.004 | 0.24  | 3      | 25     | 5.1   | 1.2   | 0.275  | 0.053  | < 0.01 |
| 220621-6        | 2.6   | 0.4   | < 0.1 | 0.6   | 0.004 | 0.4   | 9      | 23     | 8.5   | 1.9   | 0.269  | 0.051  | < 0.01 |
| 220621-7        | 2.8   | 0.4   | < 0.1 | < 0.1 | 0.004 | 0.41  | 11     | 22     | 8     | 1.7   | 0.132  | 0.048  | < 0.01 |
| 220621-8        | 2.9   | 0.5   | < 0.1 | < 0.1 | 0.004 | 0.33  | 8      | 20     | 7.9   | 1.7   | 0.192  | 0.042  | < 0.01 |
| 220621-9A       | 3     | 0.5   | < 0.1 | 0.1   | 0.004 | 0.34  | 9      | 22     | 7.7   | 1.7   | 0.337  | 0.051  | < 0.01 |
| 220621-9B       | 2.8   | 0.4   | < 0.1 | 0.1   | 0.004 | 0.33  | 11     | 21     | 8     | 1.7   | 0.141  | 0.048  | < 0.01 |
| 220622-2A       | 2.5   | 0.4   | < 0.1 | < 0.1 | 0.004 | 0.44  | 15     | 9      | 7.3   | 1.6   | 0.096  | 0.038  | < 0.01 |
| 220622-2B       | 3.5   | 0.5   | < 0.1 | < 0.1 | 0.004 | 0.5   | 13     | 9      | 7     | 1.5   | 0.128  | 0.041  | < 0.01 |
| 220622-4        | 2.9   | 0.4   | < 0.1 | < 0.1 | 0.004 | 0.32  | 6      | 23     | 7.6   | 1.7   | 0.123  | 0.046  | < 0.01 |
| 220622-5        | 3.1   | 0.5   | < 0.1 | 0.1   | 0.005 | 0.36  | 9      | 22     | 7.9   | 1.7   | 0.305  | 0.054  | < 0.01 |
| 220622-6        | 2.7   | 0.4   | < 0.1 | < 0.1 | 0.004 | 0.39  | 11     | 10     | 6     | 1.4   | 0.0834 | 0.034  | < 0.01 |
| 220622-7        | 1.9   | 0.3   | < 0.1 | < 0.1 | 0.004 | 0.41  | 12     | 10     | 5.8   | 1.2   | 0.105  | 0.013  | < 0.01 |
| 220623-1        | 1.6   | 0.2   | < 0.1 | < 0.1 | 0.004 | 0.12  | 8      | 30     | 3.5   | 0.9   | 0.115  | 0.049  | < 0.01 |
| 220623-2        | 2.8   | 0.4   | < 0.1 | 0.3   | 0.004 | 0.31  | 10     | 14     | 6.7   | 1.5   | 0.268  | 0.072  | < 0.01 |
| 220623-3        | 2.7   | 0.4   | < 0.1 | < 0.1 | 0.004 | 2.71  | 9      | 19     | 9.5   | 2.2   | 0.238  | 0.051  | 0.07   |
| 220623-4        | 2.5   | 0.4   | < 0.1 | < 0.1 | 0.004 | 0.39  | 11     | 21     | 8.8   | 1.9   | 0.141  | 0.045  | < 0.01 |
| 220623-5        | 2.6   | 0.4   | < 0.1 | < 0.1 | 0.004 | 0.09  | 4      | 20     | 3.4   | 0.8   | 0.245  | 0.085  | < 0.01 |
| YAM001          | 2.3   | 0.4   | < 0.1 | 0.1   | 0.003 | 0.07  | 6      | 27     | 2.5   | 0.6   | 0.286  | 0.062  | < 0.01 |
| YAM002          | 2.5   | 0.4   | < 0.1 | < 0.1 | 0.003 | 0.07  | < 3    | 26     | 3.2   | 0.7   | 0.281  | 0.082  | < 0.01 |



## **APPENDIX 4.3 Major element composition of olivine, pyroxene, and magnetite determined by EPMA (wt%)**

**a** = Total Fe expressed as FeO

**b** = Ferrous and ferric Fe contents, calculated based on stoichiometry

**bdl** = below detection limit

**n** = # of analysis points used to determine average core or rim composition of zoned grains

**Table A4.3-1. Major element composition of olivine determined by EPMA**

| SAMPLE ID                      | comment           | Analysis point ID | SiO2        | TiO2        | Al2O3       | Cr2O3       | FeO (T) <sup>a</sup> | MnO         | MgO         | NiO         | CaO         | V2O3        | Na2O        | K2O         | TOTAL  | Mg#  |
|--------------------------------|-------------------|-------------------|-------------|-------------|-------------|-------------|----------------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|--------|------|
| <b>Detection limit</b>         |                   |                   | <b>0.01</b> | <b>0.01</b> | <b>0.01</b> | <b>0.02</b> | <b>0.02</b>          | <b>0.02</b> | <b>0.01</b> | <b>0.01</b> | <b>0.01</b> | <b>0.01</b> | <b>0.02</b> | <b>0.01</b> |        |      |
| 220620-1 circle a olivine core | dark part in BSE  | 328               | 37.91       | 0.03        | bdl         | bdl         | 24.58                | 0.44        | 36.69       | 0.05        | 0.19        | 0.02        | bdl         | 0.02        | 99.90  | 0.73 |
| 220620-1 circle a olivine core | dark part in BSE  | 329               | 38.09       | 0.01        | bdl         | bdl         | 24.71                | 0.41        | 36.70       | 0.04        | 0.16        | bdl         | bdl         | 0.02        | 100.12 | 0.73 |
| 220620-1 circle a olivine core | light part in BSE | 330               | 36.81       | 0.02        | 0.28        | 0.01        | 28.75                | 0.41        | 28.02       | 0.02        | 0.30        | 0.02        | 0.01        | 0.01        | 94.66  | 0.63 |
| 220620-1 circle a olivine core | dark part in BSE  | 331               | 38.12       | 0.05        | bdl         | bdl         | 24.80                | 0.44        | 36.68       | 0.04        | 0.17        | 0.00        | bdl         | 0.02        | 100.29 | 0.73 |
|                                |                   |                   |             |             |             |             |                      |             |             |             |             |             |             |             |        |      |
| 220620-1 circle a olivine 2    | rim               | 332               | 37.28       | 0.03        | bdl         | bdl         | 27.68                | 0.52        | 34.49       | 0.03        | 0.15        | bdl         | bdl         | 0.02        | 100.16 | 0.69 |
| 220620-1 circle a olivine 2    | core              | 333               | 38.64       | 0.01        | bdl         | bdl         | 20.99                | 0.33        | 40.58       | 0.05        | 0.13        | 0.01        | bdl         | 0.02        | 100.73 | 0.78 |
| 220620-1 circle a olivine 2    | core              | 334               | 38.63       | 0.03        | bdl         | bdl         | 20.64                | 0.38        | 40.79       | 0.05        | 0.12        | bdl         | bdl         | 0.01        | 100.62 | 0.78 |
| 220620-1 circle a olivine 2    | core              | 335               | 38.62       | 0.02        | bdl         | 0.01        | 20.91                | 0.32        | 40.80       | 0.03        | 0.12        | 0.01        | 0.01        | 0.02        | 100.87 | 0.78 |
| 220620-1 circle a olivine 2    | core              | 336               | 38.82       | 0.02        | bdl         | 0.01        | 21.19                | 0.32        | 40.13       | 0.04        | 0.12        | bdl         | bdl         | 0.01        | 100.64 | 0.77 |
|                                | core avg (n=4)    |                   | 38.68       | 0.02        | bdl         | 0.01        | 20.93                | 0.33        | 40.58       | 0.04        | 0.12        | 0.01        | 0.01        | 0.01        | 100.71 | 0.78 |
|                                |                   |                   |             |             |             |             |                      |             |             |             |             |             |             |             |        |      |
| 220620-1 circle c olivine      | core              | 346               | 37.91       | 0.02        | 0.01        | bdl         | 24.90                | 0.45        | 37.06       | 0.04        | 0.18        | bdl         | bdl         | 0.02        | 100.59 | 0.73 |
| 220620-1 circle c olivine      | core              | 347               | 38.41       | 0.03        | bdl         | 0.03        | 24.49                | 0.41        | 37.13       | 0.03        | 0.18        | 0.03        | bdl         | 0.01        | 100.75 | 0.73 |
|                                | core avg (n=2)    |                   | 38.16       | 0.02        | 0.01        | 0.03        | 24.70                | 0.43        | 37.09       | 0.04        | 0.18        | 0.01        | bdl         | 0.02        | 100.67 | 0.73 |
| 220620-1 circle c olivine      | rim               | 348               | 38.10       | 0.03        | bdl         | bdl         | 24.68                | 0.40        | 36.77       | 0.06        | 0.17        | bdl         | 0.01        | 0.01        | 100.22 | 0.73 |
| 220620-1 circle c olivine      | rim               | 349               | 37.69       | 0.03        | 0.01        | bdl         | 25.03                | 0.42        | 36.59       | 0.04        | 0.19        | bdl         | bdl         | 0.02        | 100.01 | 0.72 |
|                                | rim avg (n=2)     |                   | 37.89       | 0.03        | 0.01        | bdl         | 24.85                | 0.41        | 36.68       | 0.05        | 0.18        | bdl         | bdl         | 0.02        | 100.11 | 0.72 |
|                                |                   |                   |             |             |             |             |                      |             |             |             |             |             |             |             |        |      |
| 220620-1 circle d olivine      | rim               | 354               | 36.98       | 0.05        | bdl         | 0.02        | 29.04                | 0.57        | 32.90       | 0.02        | 0.19        | bdl         | 0.02        | 0.01        | 99.79  | 0.67 |
| 220620-1 circle d olivine      | core              | 355               | 38.19       | 0.03        | bdl         | 0.01        | 24.38                | 0.45        | 37.52       | 0.04        | 0.17        | bdl         | bdl         | 0.02        | 100.79 | 0.73 |
| 220620-1 circle d olivine      | core              | 356               | 38.20       | 0.03        | 0.01        | bdl         | 24.53                | 0.44        | 37.12       | 0.04        | 0.18        | bdl         | bdl         | 0.02        | 100.53 | 0.73 |

|                            |                |     |       |      |      |      |       |      |       |      |      |      |      |      |        |      |
|----------------------------|----------------|-----|-------|------|------|------|-------|------|-------|------|------|------|------|------|--------|------|
| 220620-1 circle d olivine  | core           | 357 | 38.00 | 0.02 | bdl  | 0.02 | 24.08 | 0.48 | 37.51 | 0.04 | 0.18 | bdl  | bdl  | 0.01 | 100.34 | 0.74 |
|                            | core avg (n=3) |     | 38.13 | 0.03 | 0.01 | 0.01 | 24.33 | 0.46 | 37.38 | 0.04 | 0.18 | bdl  | bdl  | 0.02 | 100.55 | 0.73 |
|                            |                |     |       |      |      |      |       |      |       |      |      |      |      |      |        |      |
| 220620-4 circle a olivine1 | core           | 424 | 36.46 | 0.01 | bdl  | bdl  | 32.29 | 0.54 | 30.61 | 0.03 | 0.17 | bdl  | bdl  | 0.02 | 100.10 | 0.63 |
| 220620-4 circle a olivine1 | rim            | 425 | 35.26 | 0.04 | bdl  | bdl  | 34.17 | 0.69 | 28.26 | 0.01 | 0.25 | bdl  | bdl  | 0.01 | 98.68  | 0.60 |
| 220620-4 circle a olivine1 | rim            | 426 | 35.72 | 0.03 | bdl  | bdl  | 32.85 | 0.63 | 29.76 | 0.01 | 0.18 | bdl  | 0.01 | 0.04 | 99.21  | 0.62 |
| 220620-4 circle a olivine1 | rim            | 427 | 35.56 | 0.04 | bdl  | bdl  | 33.39 | 0.66 | 28.94 | 0.02 | 0.24 | bdl  | bdl  | 0.02 | 98.85  | 0.61 |
|                            | rim avg (n=3)  |     | 35.51 | 0.04 | bdl  | bdl  | 33.47 | 0.66 | 28.99 | 0.02 | 0.23 | bdl  | 0.01 | 0.02 | 98.91  | 0.61 |
|                            |                |     |       |      |      |      |       |      |       |      |      |      |      |      |        |      |
| 220620-4 circle a olivine2 | core           | 433 | 36.78 | 0.02 | bdl  | bdl  | 26.65 | 0.50 | 34.62 | 0.04 | 0.16 | bdl  | 0.01 | 0.02 | 98.81  | 0.70 |
| 220620-4 circle a olivine2 | rim            | 434 | 36.62 | 0.03 | bdl  | 0.01 | 29.66 | 0.55 | 32.48 | bdl  | 0.18 | bdl  | bdl  | 0.01 | 99.48  | 0.66 |
| 220620-4 circle a olivine2 | core           | 435 | 36.97 | 0.03 | 0.01 | 0.01 | 27.93 | 0.54 | 33.74 | 0.02 | 0.18 | bdl  | bdl  | 0.02 | 99.43  | 0.68 |
| 220620-4 circle a olivine2 | rim            | 436 | 36.27 | 0.04 | bdl  | 0.02 | 32.50 | 0.63 | 30.41 | 0.01 | 0.22 | 0.02 | bdl  | 0.03 | 100.10 | 0.63 |
| 220620-4 circle a olivine2 | rim            | 437 | 36.39 | 0.04 | bdl  | bdl  | 30.18 | 0.55 | 31.80 | 0.02 | 0.18 | 0.01 | bdl  | 0.02 | 99.17  | 0.65 |
|                            | core avg (n=2) |     | 36.87 | 0.02 | 0.01 | 0.01 | 27.29 | 0.52 | 34.18 | 0.03 | 0.17 | bdl  | 0.01 | 0.02 | 99.12  | 0.69 |
|                            | rim avg (n=3)  |     | 36.42 | 0.04 | bdl  | 0.01 | 30.78 | 0.58 | 31.56 | 0.01 | 0.19 | 0.01 | bdl  | 0.02 | 99.58  | 0.65 |
|                            |                |     |       |      |      |      |       |      |       |      |      |      |      |      |        |      |
| 220620-4 circle c olivine1 | rim            | 500 | 36.47 | 0.05 | 0.00 | 0.01 | 32.43 | 0.60 | 29.73 | 0.02 | 0.21 | bdl  | bdl  | 0.03 | 99.53  | 0.62 |
| 220620-4 circle c olivine1 | core           | 501 | 37.34 | 0.02 | bdl  | bdl  | 29.62 | 0.59 | 33.01 | 0.02 | 0.18 | 0.01 | 0.02 | 0.02 | 100.79 | 0.67 |
| 220620-4 circle c olivine1 | core           | 502 | 37.22 | 0.04 | bdl  | bdl  | 29.31 | 0.57 | 32.89 | 0.02 | 0.18 | 0.02 | 0.01 | 0.01 | 100.25 | 0.67 |
| 220620-4 circle c olivine1 | core           | 503 | 37.48 | 0.03 | 0.01 | bdl  | 28.83 | 0.55 | 33.65 | 0.01 | 0.18 | bdl  | bdl  | 0.02 | 100.76 | 0.68 |
| 220620-4 circle c olivine1 | rim            | 504 | 36.33 | 0.05 | bdl  | 0.01 | 33.52 | 0.63 | 29.86 | 0.02 | 0.20 | bdl  | bdl  | 0.02 | 100.65 | 0.61 |
|                            | core avg (n=3) |     | 37.35 | 0.03 | 0.01 | bdl  | 29.25 | 0.57 | 33.18 | 0.02 | 0.18 | 0.01 | 0.01 | 0.02 | 100.60 | 0.67 |
|                            | rim avg (n=2)  |     | 36.40 | 0.05 | bdl  | 0.01 | 32.98 | 0.62 | 29.80 | 0.02 | 0.20 | bdl  | bdl  | 0.03 | 100.09 | 0.62 |
|                            |                |     |       |      |      |      |       |      |       |      |      |      |      |      |        |      |
| 220620-4 circle c olivine2 | core           | 509 | 36.55 | 0.02 | 0.01 | bdl  | 32.25 | 0.60 | 30.98 | 0.01 | 0.19 | 0.01 | bdl  | 0.01 | 100.62 | 0.63 |
| 220620-4 circle c olivine2 | rim            | 510 | 36.42 | 0.02 | bdl  | bdl  | 33.22 | 0.65 | 29.68 | 0.03 | 0.21 | bdl  | bdl  | 0.01 | 100.17 | 0.61 |
| 220620-4 circle c olivine2 | rim            | 511 | 36.56 | 0.02 | bdl  | bdl  | 33.49 | 0.62 | 29.68 | 0.01 | 0.21 | bdl  | 0.01 | 0.02 | 100.62 | 0.61 |
| 220620-4 circle c olivine2 | rim            | 512 | 36.54 | 0.03 | bdl  | bdl  | 32.70 | 0.65 | 29.91 | 0.01 | 0.23 | 0.01 | 0.01 | 0.01 | 100.09 | 0.62 |
|                            | rim avg (n=3)  |     | 36.51 | 0.02 | bdl  | bdl  | 33.14 | 0.64 | 29.76 | 0.02 | 0.21 | 0.01 | 0.01 | 0.01 | 100.29 | 0.62 |
|                            |                |     |       |      |      |      |       |      |       |      |      |      |      |      |        |      |
| 220620-4 circle b olivine1 | core           | 530 | 37.41 | 0.03 | bdl  | bdl  | 28.16 | 0.54 | 34.35 | 0.02 | 0.17 | bdl  | 0.01 | 0.01 | 100.71 | 0.68 |
| 220620-4 circle b olivine1 | rim            | 531 | 36.69 | 0.04 | bdl  | 0.01 | 30.78 | 0.58 | 32.34 | 0.01 | 0.18 | 0.01 | bdl  | 0.02 | 100.65 | 0.65 |
| 220620-4 circle b olivine1 | rim            | 532 | 37.23 | 0.04 | 0.01 | bdl  | 30.57 | 0.57 | 32.55 | 0.02 | 0.15 | bdl  | bdl  | 0.01 | 101.13 | 0.65 |

|                            |                |     |       |      |      |      |       |      |       |      |      |      |      |      |        |      |
|----------------------------|----------------|-----|-------|------|------|------|-------|------|-------|------|------|------|------|------|--------|------|
| 220620-4 circle b olivine1 | core           | 533 | 37.46 | 0.04 | bdl  | bdl  | 27.39 | 0.46 | 34.28 | 0.03 | 0.18 | bdl  | bdl  | 0.03 | 99.85  | 0.69 |
| 220620-4 circle b olivine1 | rim            | 534 | 37.29 | 0.05 | bdl  | bdl  | 29.83 | 0.59 | 32.90 | 0.02 | 0.19 | 0.02 | bdl  | 0.02 | 100.86 | 0.66 |
|                            | core avg (n=2) |     | 37.43 | 0.03 | bdl  | bdl  | 27.78 | 0.50 | 34.31 | 0.03 | 0.17 | bdl  | 0.01 | 0.02 | 100.28 | 0.69 |
|                            | rim avg (n=3)  |     | 37.07 | 0.04 | 0.01 | 0.01 | 30.40 | 0.58 | 32.59 | 0.02 | 0.18 | 0.01 | bdl  | 0.02 | 100.88 | 0.66 |
|                            |                |     |       |      |      |      |       |      |       |      |      |      |      |      |        |      |
| 220620-4 circle b olivine2 | core           | 535 | 37.64 | 0.05 | 0.01 | bdl  | 26.91 | 0.54 | 35.17 | 0.00 | 0.20 | bdl  | 0.01 | 0.01 | 100.53 | 0.70 |
| 220620-4 circle b olivine2 | core           | 536 | 37.65 | 0.04 | 0.01 | 0.01 | 27.39 | 0.50 | 35.14 | 0.02 | 0.17 | bdl  | bdl  | 0.02 | 100.93 | 0.70 |
| 220620-4 circle b olivine2 | core           | 537 | 37.62 | 0.03 | bdl  | bdl  | 27.25 | 0.49 | 35.20 | 0.02 | 0.18 | bdl  | bdl  | 0.01 | 100.79 | 0.70 |
| 220620-4 circle b olivine2 | core           | 538 | 37.64 | 0.06 | bdl  | bdl  | 27.67 | 0.53 | 35.07 | 0.03 | 0.19 | 0.01 | 0.01 | 0.01 | 101.22 | 0.69 |
|                            | core avg (n=3) |     | 37.64 | 0.04 | 0.01 | 0.01 | 27.31 | 0.52 | 35.15 | 0.02 | 0.18 | 0.01 | 0.01 | 0.02 | 100.87 | 0.70 |
|                            |                |     |       |      |      |      |       |      |       |      |      |      |      |      |        |      |
| 220320-3 circle b olivine1 | core           | 592 | 37.43 | 0.06 | bdl  | bdl  | 29.06 | 0.46 | 33.64 | 0.04 | 0.18 | 0.01 | 0.00 | 0.01 | 100.86 | 0.67 |
| 220320-3 circle b olivine1 | rim            | 593 | 36.15 | 0.06 | 0.02 | 0.01 | 34.48 | 0.60 | 28.47 | 0.01 | 0.25 | 0.01 | bdl  | 0.02 | 100.07 | 0.60 |
| 220320-3 circle b olivine1 | core           | 594 | 36.94 | 0.05 | bdl  | 0.02 | 30.07 | 0.50 | 32.42 | 0.02 | 0.18 | 0.01 | bdl  | 0.02 | 100.19 | 0.66 |
| 220320-3 circle b olivine1 | rim            | 595 | 37.36 | 0.03 | bdl  | 0.01 | 32.21 | 0.55 | 31.24 | 0.02 | 0.21 | 0.01 | bdl  | 0.02 | 101.64 | 0.63 |
| 220320-3 circle b olivine1 | core           | 596 | 37.55 | 0.04 | 0.02 | bdl  | 29.89 | 0.53 | 33.23 | 0.02 | 0.18 | bdl  | bdl  | 0.02 | 101.48 | 0.66 |
|                            | core avg (n=3) |     | 37.30 | 0.05 | 0.02 | 0.02 | 29.67 | 0.50 | 33.10 | 0.02 | 0.18 | 0.01 | bdl  | 0.02 | 100.84 | 0.67 |
|                            | rim avg (n=2)  |     | 36.76 | 0.05 | 0.01 | 0.01 | 33.34 | 0.57 | 29.86 | 0.02 | 0.23 | 0.01 | bdl  | 0.02 | 100.85 | 0.61 |
|                            |                |     |       |      |      |      |       |      |       |      |      |      |      |      |        |      |
| 220320-3 circle b olivine2 | core           | 597 | 37.63 | 0.03 | bdl  | 0.03 | 29.55 | 0.50 | 33.07 | 0.01 | 0.19 | bdl  | bdl  | 0.02 | 101.01 | 0.67 |
| 220320-3 circle b olivine2 | core           | 598 | 37.60 | 0.04 | bdl  | 0.01 | 27.20 | 0.42 | 35.11 | 0.04 | 0.18 | bdl  | bdl  | 0.01 | 100.59 | 0.70 |
| 220320-3 circle b olivine2 | rim            | 599 | 36.53 | 0.06 | bdl  | bdl  | 34.45 | 0.64 | 29.22 | 0.03 | 0.24 | 0.01 | bdl  | 0.02 | 101.16 | 0.60 |
| 220320-3 circle b olivine2 | rim            | 600 | 36.61 | 0.05 | bdl  | 0.01 | 32.23 | 0.59 | 30.63 | 0.02 | 0.23 | 0.03 | bdl  | 0.02 | 100.40 | 0.63 |
| 220320-3 circle b olivine2 | core           | 601 | 37.95 | 0.03 | 0.01 | bdl  | 27.95 | 0.48 | 34.63 | 0.03 | 0.19 | bdl  | bdl  | 0.03 | 101.30 | 0.69 |
|                            | core avg (n=3) |     | 37.73 | 0.03 | bdl  | 0.01 | 28.23 | 0.47 | 34.27 | 0.02 | 0.19 | bdl  | bdl  | 0.02 | 100.97 | 0.68 |
|                            | rim avg (n=2)  |     | 36.57 | 0.05 | bdl  | 0.01 | 33.34 | 0.61 | 29.92 | 0.02 | 0.23 | 0.02 | bdl  | 0.02 | 100.78 | 0.62 |
|                            |                |     |       |      |      |      |       |      |       |      |      |      |      |      |        |      |
| 220620-3 circle b olivine3 | rim            | 652 | 36.39 | 0.05 | 0.01 | bdl  | 31.53 | 0.59 | 31.16 | 0.04 | 0.17 | 0.01 | 0.01 | 0.01 | 99.97  | 0.64 |
| 220620-3 circle b olivine3 | core           | 653 | 37.36 | 0.04 | bdl  | 0.02 | 27.26 | 0.44 | 35.99 | 0.04 | 0.17 | 0.02 | 0.01 | 0.03 | 101.37 | 0.70 |
| 220620-3 circle b olivine3 | core           | 654 | 36.78 | 0.05 | bdl  | 0.02 | 30.54 | 0.52 | 32.48 | 0.02 | 0.18 | 0.03 | bdl  | 0.01 | 100.62 | 0.65 |
| 220620-3 circle b olivine3 | rim            | 655 | 36.35 | 0.05 | bdl  | bdl  | 32.33 | 0.57 | 30.70 | 0.02 | 0.22 | 0.03 | 0.01 | 0.02 | 100.29 | 0.63 |
| 220620-3 circle b olivine3 | core           | 656 | 37.28 | 0.03 | bdl  | bdl  | 27.24 | 0.44 | 35.48 | 0.02 | 0.16 | bdl  | bdl  | 0.02 | 100.67 | 0.70 |
|                            | core avg (n=3) |     | 37.14 | 0.04 | bdl  | 0.01 | 28.35 | 0.47 | 34.65 | 0.03 | 0.17 | 0.02 | 0.01 | 0.02 | 100.88 | 0.69 |
|                            | rim avg (n=2)  |     | 36.37 | 0.05 | 0.01 | bdl  | 31.93 | 0.58 | 30.93 | 0.03 | 0.19 | 0.02 | 0.01 | 0.01 | 100.13 | 0.63 |

|                                 |  |     |       |      |         |      |       |      |       |      |      |      |      |      |        |      |
|---------------------------------|--|-----|-------|------|---------|------|-------|------|-------|------|------|------|------|------|--------|------|
|                                 |  |     |       |      |         |      |       |      |       |      |      |      |      |      |        |      |
| 220621-5 circle a olivine       |  | 615 | 38.44 | 0.02 | 0.01    | 0.01 | 22.35 | 0.37 | 39.41 | 0.06 | 0.13 | bdl  | 0.02 | 0.01 | 100.83 | 0.76 |
| 220621-5 circle a olivine       |  | 616 | 38.96 | 0.01 | bdl     | bdl  | 22.21 | 0.36 | 39.30 | 0.04 | 0.13 | 0.01 | bdl  | 0.01 | 101.01 | 0.76 |
| 220621-5 circle a olivine       |  | 617 | 38.53 | 0.04 | bdl     | 0.01 | 22.57 | 0.36 | 39.43 | 0.04 | 0.11 | bdl  | bdl  | 0.01 | 101.08 | 0.76 |
| 220621-5 circle a olivine       |  | 618 | 38.63 | 0.02 | bdl     | 0.01 | 22.61 | 0.33 | 39.33 | 0.05 | 0.13 | 0.01 | 0.02 | 0.01 | 101.14 | 0.76 |
| <i>average</i>                  |  |     | 38.64 | 0.02 | 0.01    | 0.01 | 22.44 | 0.35 | 39.37 | 0.05 | 0.13 | 0.01 | 0.02 | 0.01 | 101.01 | 0.76 |
|                                 |  |     |       |      |         |      |       |      |       |      |      |      |      |      |        |      |
| 119-05 section2 circle1 olivine |  | 395 | 38.14 | 0.01 | bdl bdl | 0.01 | 22.18 | 0.32 | 39.08 | 0.05 | 0.14 | 0.04 | bdl  | 0.02 | 99.97  | 0.76 |
| 119-05 section2 circle1 olivine |  | 396 | 37.94 | bdl  | bdl     | bdl  | 22.27 | 0.34 | 38.68 | 0.06 | 0.14 | bdl  | bdl  | 0.02 | 99.43  | 0.76 |
| 119-05 section2 circle1 olivine |  | 398 | 38.48 | 0.02 | 0.01    | bdl  | 21.97 | 0.35 | 38.62 | 0.04 | 0.14 | 0.01 | bdl  | 0.02 | 99.67  | 0.76 |
| 119-05 section2 circle1 olivine |  | 173 | 38.49 | 0.01 | bdl     | 0.01 | 21.17 | 0.37 | 38.49 | 0.04 | 0.12 | bdl  | bdl  | 0.02 | 98.69  | 0.76 |
| 119-05 section2 circle1 olivine |  | 176 | 38.78 | 0.02 | bdl     | bdl  | 22.94 | 0.36 | 38.19 | 0.05 | 0.13 | bdl  | bdl  | 0.01 | 100.49 | 0.75 |
| 119-05 section2 circle1 olivine |  | 177 | 38.62 | bdl  | bdl     | 0.01 | 22.62 | 0.39 | 38.77 | 0.04 | 0.14 | bdl  | bdl  | 0.02 | 100.57 | 0.75 |
| 119-05 section2 circle1 olivine |  | 178 | 38.92 | bdl  | bdl     | bdl  | 22.12 | 0.32 | 39.06 | 0.06 | 0.13 | 0.01 | bdl  | 0.01 | 100.63 | 0.76 |
| 119-05 section2 circle1 olivine |  | 179 | 38.59 | 0.01 | bdl     | bdl  | 22.85 | 0.35 | 38.54 | 0.06 | 0.14 | 0.01 | bdl  | 0.01 | 100.55 | 0.75 |
| <i>Average</i>                  |  |     | 38.49 | 0.01 | bdl     | 0.01 | 22.26 | 0.35 | 38.68 | 0.05 | 0.14 | 0.02 | bdl  | 0.02 | 100.00 | 0.76 |
|                                 |  |     |       |      |         |      |       |      |       |      |      |      |      |      |        |      |
| 119-05 section2 circle2 olivine |  | 409 | 38.55 | 0.03 | 0.01    | bdl  | 22.17 | 0.33 | 39.19 | 0.03 | 0.13 | bdl  | bdl  | 0.02 | 100.44 | 0.76 |
| 119-05 section2 circle2 olivine |  | 410 | 38.51 | 0.01 | bdl     | bdl  | 21.99 | 0.35 | 39.36 | 0.06 | 0.12 | 0.03 | bdl  | 0.01 | 100.43 | 0.76 |
| 119-05 section2 circle2 olivine |  | 411 | 38.43 | 0.02 | bdl     | bdl  | 22.22 | 0.38 | 39.20 | 0.04 | 0.11 | 0.01 | bdl  | 0.01 | 100.41 | 0.76 |
| 119-05 section2 circle2 olivine |  | 412 | 38.32 | 0.01 | 0.01    | bdl  | 22.05 | 0.36 | 38.98 | 0.04 | 0.12 | bdl  | bdl  | 0.02 | 99.90  | 0.76 |
| 119-05 section2 circle2 olivine |  | 413 | 38.60 | 0.02 | 0.01    | 0.01 | 22.10 | 0.35 | 39.19 | 0.04 | 0.12 | bdl  | bdl  | 0.01 | 100.43 | 0.76 |
| <i>Average</i>                  |  |     | 38.48 | 0.02 | 0.01    | 0.01 | 22.11 | 0.35 | 39.18 | 0.04 | 0.12 | 0.02 | bdl  | 0.01 | 100.32 | 0.76 |
|                                 |  |     |       |      |         |      |       |      |       |      |      |      |      |      |        |      |
| 119-05 section2 circle3 olivine |  | 415 | 38.32 | 0.01 | 0.01    | bdl  | 22.52 | 0.38 | 38.77 | 0.07 | 0.12 | bdl  | bdl  | 0.01 | 100.18 | 0.75 |
| 119-05 section2 circle3 olivine |  | 416 | 38.50 | 0.01 | 0.01    | 0.01 | 22.60 | 0.37 | 39.04 | 0.06 | 0.13 | bdl  | bdl  | 0.02 | 100.73 | 0.75 |
| 119-05 section2 circle3 olivine |  | 417 | 38.27 | 0.01 | 0.01    | bdl  | 22.29 | 0.32 | 38.88 | 0.04 | 0.13 | 0.01 | 0.01 | 0.01 | 99.98  | 0.76 |
| 119-05 section2 circle3 olivine |  | 418 | 38.25 | 0.02 | 0.01    | bdl  | 22.45 | 0.33 | 38.85 | 0.06 | 0.14 | 0.03 | bdl  | 0.02 | 100.13 | 0.76 |
| 119-05 section2 circle3 olivine |  | 419 | 38.29 | bdl  | bdl     | 0.01 | 22.53 | 0.36 | 39.01 | 0.05 | 0.14 | 0.01 | bdl  | 0.01 | 100.39 | 0.76 |
| 119-05 section2 circle3 olivine |  | 420 | 38.44 | 0.03 | 0.01    | bdl  | 22.42 | 0.38 | 38.95 | 0.06 | 0.11 | 0.04 | bdl  | 0.01 | 100.44 | 0.76 |
| 119-05 section2 circle3 olivine |  | 421 | 38.19 | 0.02 | 0.01    | 0.01 | 22.13 | 0.35 | 38.86 | 0.05 | 0.13 | 0.03 | bdl  | 0.03 | 99.78  | 0.76 |
| <i>Average</i>                  |  |     | 38.32 | 0.02 | 0.01    | 0.01 | 22.42 | 0.36 | 38.91 | 0.06 | 0.13 | 0.02 | 0.01 | 0.02 | 100.23 | 0.76 |
|                                 |  |     |       |      |         |      |       |      |       |      |      |      |      |      |        |      |
| 119-05 section2 circle6 olivine |  | 426 | 38.76 | 0.02 | bdl     | bdl  | 19.87 | 0.29 | 40.71 | 0.05 | 0.12 | 0.01 | 0.03 | 0.02 | 99.87  | 0.79 |



|                                 |  |     |       |      |     |      |       |      |       |      |      |      |      |      |        |      |
|---------------------------------|--|-----|-------|------|-----|------|-------|------|-------|------|------|------|------|------|--------|------|
| 119-05 section2 circle6 olivine |  | 427 | 38.88 | 0.02 | bdl | bdl  | 20.21 | 0.33 | 40.50 | 0.05 | 0.16 | bdl  | 0.03 | 0.02 | 100.20 | 0.78 |
| 119-05 section2 circle6 olivine |  | 428 | 38.66 | 0.02 | bdl | bdl  | 20.68 | 0.35 | 39.92 | 0.04 | 0.12 | bdl  | bdl  | 0.01 | 99.80  | 0.77 |
| 119-05 section2 circle6 olivine |  | 429 | 38.74 | bdl  | bdl | bdl  | 20.42 | 0.33 | 40.26 | 0.06 | 0.14 | bdl  | 0.01 | 0.02 | 99.98  | 0.78 |
| 119-05 section2 circle6 olivine |  | 430 | 38.75 | bdl  | bdl | bdl  | 20.79 | 0.32 | 40.02 | 0.06 | 0.13 | 0.05 | bdl  | 0.01 | 100.11 | 0.77 |
| 119-05 section2 circle6 olivine |  | 431 | 38.73 | bdl  | bdl | 0.01 | 21.00 | 0.33 | 39.99 | 0.07 | 0.12 | bdl  | 0.01 | 0.01 | 100.27 | 0.77 |
| 119-05 section2 circle6 olivine |  | 432 | 38.82 | 0.02 | bdl | bdl  | 20.31 | 0.32 | 40.48 | 0.05 | 0.14 | 0.03 | bdl  | 0.02 | 100.16 | 0.78 |
| 119-05 section2 circle6 olivine |  | 433 | 38.87 | 0.01 | bdl | bdl  | 20.63 | 0.35 | 40.28 | 0.06 | 0.11 | bdl  | bdl  | 0.02 | 100.29 | 0.78 |
| Average                         |  |     | 38.78 | 0.02 | bdl | 0.01 | 20.49 | 0.33 | 40.27 | 0.06 | 0.13 | 0.02 | 0.02 | 0.02 | 100.09 | 0.78 |

**Table A4.3-2. Major element composition of pyroxene determined by EPMA**

| SAMPLE ID                                                                      | Analysis point ID (comment) | SiO2  | TiO2 | Al2O3 | FeO  | MnO  | MgO   | CaO   | Na2O | K2O  | Cr2O3 | V2O3 | NiO  | TOTAL  | Mg#   |
|--------------------------------------------------------------------------------|-----------------------------|-------|------|-------|------|------|-------|-------|------|------|-------|------|------|--------|-------|
| Detection limit                                                                |                             | 0.01  | 0.01 | 0.01  | 0.02 | 0.02 | 0.01  | 0.01  | 0.02 | 0.01 | 0.02  | 0.02 | 0.01 |        |       |
| Sample 220620-1                                                                |                             |       |      |       |      |      |       |       |      |      |       |      |      |        |       |
| CPX                                                                            |                             |       |      |       |      |      |       |       |      |      |       |      |      |        |       |
| <u>oscillatory zoned (from rim to core)</u>                                    | -                           |       |      |       |      |      |       |       |      |      |       |      |      |        |       |
| 220620-1 circle c cpx                                                          | 339 (rim stage 4)           | 50.94 | 0.70 | 3.68  | 9.01 | 0.29 | 15.80 | 18.26 | 0.25 | 0.02 | 0.23  | 0.10 | bdl  | 99.26  | 75.76 |
| 220620-1 circle c cpx                                                          | 337 (mantle stage 3)        | 52.09 | 0.47 | 2.29  | 8.77 | 0.29 | 16.62 | 18.37 | 0.26 | 0.01 | 0.23  | 0.07 | bdl  | 99.47  | 77.15 |
| 220620-1 circle c cpx                                                          | 338 (mantle stage 2)        | 52.16 | 0.56 | 2.42  | 9.32 | 0.31 | 16.20 | 17.95 | 0.30 | 0.02 | 0.07  | 0.05 | 0.01 | 99.35  | 75.60 |
| 220620-1 circle c cpx                                                          | 340 (mantle stage 2)        | 52.07 | 0.57 | 2.39  | 9.55 | 0.30 | 16.67 | 17.58 | 0.26 | 0.01 | 0.11  | 0.07 | bdl  | 99.56  | 75.69 |
| mantle stage 2 avg (n=3)                                                       |                             | 52.11 | 0.57 | 2.40  | 9.43 | 0.30 | 16.43 | 17.76 | 0.28 | 0.01 | 0.09  | 0.06 | bdl  | 99.46  | 75.64 |
| 220620-1 circle c cpx                                                          | 341 (core stage 1)          | 51.30 | 0.44 | 3.79  | 7.86 | 0.22 | 16.49 | 18.30 | 0.34 | 0.01 | 0.06  | 0.07 | 0.02 | 98.90  | 78.90 |
|                                                                                |                             |       |      |       |      |      |       |       |      |      |       |      |      |        |       |
| <u>reverse zoned</u>                                                           |                             |       |      |       |      |      |       |       |      |      |       |      |      |        |       |
| 220620-1 circle c cpx2                                                         | 350 (core)                  | 51.42 | 0.63 | 2.73  | 9.36 | 0.28 | 15.90 | 18.26 | 0.33 | 0.01 | 0.06  | 0.07 | bdl  | 99.05  | 75.18 |
| 220620-1 circle c cpx2                                                         | 351 (core)                  | 51.25 | 0.62 | 2.80  | 9.39 | 0.27 | 16.09 | 17.99 | 0.28 | 0.01 | 0.11  | 0.07 | bdl  | 98.88  | 75.34 |
| core Average (n=2)                                                             |                             | 51.33 | 0.62 | 2.77  | 9.38 | 0.27 | 16.00 | 18.13 | 0.31 | 0.01 | 0.08  | 0.07 | bdl  | 98.97  | 75.26 |
| 220620-1 circle c cpx2                                                         | 352 (rim)                   | 52.54 | 0.48 | 2.33  | 8.62 | 0.28 | 16.73 | 18.16 | 0.27 | 0.02 | 0.15  | 0.06 | bdl  | 99.63  | 77.59 |
| 220620-1 circle c cpx2                                                         | 353 (rim)                   | 51.66 | 0.59 | 2.53  | 8.36 | 0.26 | 16.04 | 19.02 | 0.26 | 0.02 | 0.33  | 0.04 | 0.01 | 99.13  | 77.38 |
| rim Average (n=2)                                                              |                             | 52.10 | 0.54 | 2.43  | 8.49 | 0.27 | 16.38 | 18.59 | 0.26 | 0.02 | 0.24  | 0.05 | 0.01 | 99.38  | 77.48 |
|                                                                                |                             |       |      |       |      |      |       |       |      |      |       |      |      |        |       |
| <u>oscillatory zoned (from core to rim) each point is treated individually</u> |                             |       |      |       |      |      |       |       |      |      |       |      |      |        |       |
| 220620-1 circle e cpx                                                          | 358 core (core to rim)      | 52.06 | 0.39 | 3.42  | 6.86 | 0.19 | 16.59 | 20.25 | 0.26 | 0.01 | 0.13  | 0.05 | bdl  | 100.22 | 81.18 |
| 220620-1 circle e cpx                                                          | 359                         | 52.11 | 0.44 | 3.32  | 6.54 | 0.18 | 16.78 | 19.90 | 0.22 | 0.02 | 0.24  | 0.02 | bdl  | 99.77  | 82.06 |

|                        |                                    |             |             |              |             |             |             |             |             |             |              |             |             |              |            |
|------------------------|------------------------------------|-------------|-------------|--------------|-------------|-------------|-------------|-------------|-------------|-------------|--------------|-------------|-------------|--------------|------------|
| 220620-1 circle e cpx  | 360                                | 50.71       | 0.74        | 3.73         | 10.42       | 0.24        | 14.87       | 17.92       | 0.40        | 0.01        | 0.04         | 0.11        | 0.01        | 99.21        | 71.78      |
| 220620-1 circle e cpx  | 361                                | 51.69       | 0.38        | 3.05         | 6.64        | 0.16        | 16.88       | 19.99       | 0.26        | bdl         | 0.15         | 0.04        | 0.01        | 99.27        | 81.91      |
| 220620-1 circle e cpx  | 362                                | 52.16       | 0.64        | 2.49         | 9.30        | 0.21        | 14.47       | 19.61       | 0.29        | 0.01        | 0.07         | 0.20        | bdl         | 99.45        | 73.50      |
| 220620-1 circle e cpx  | 363 rim (core to rim)              | 52.07       | 0.48        | 2.12         | 8.35        | 0.23        | 16.67       | 18.80       | 0.29        | 0.01        | 0.19         | 0.07        | 0.02        | 99.29        | 78.07      |
|                        |                                    |             |             |              |             |             |             |             |             |             |              |             |             |              |            |
| <b>OPX</b>             | <b>Analysis point ID (comment)</b> | <b>SiO2</b> | <b>TiO2</b> | <b>Al2O3</b> | <b>FeO</b>  | <b>MnO</b>  | <b>MgO</b>  | <b>CaO</b>  | <b>Na2O</b> | <b>K2O</b>  | <b>Cr2O3</b> | <b>V2O3</b> | <b>NiO</b>  | <b>TOTAL</b> | <b>Mg#</b> |
| <b>Detection limit</b> |                                    | <b>0.01</b> | <b>0.01</b> | <b>0.01</b>  | <b>0.02</b> | <b>0.02</b> | <b>0.01</b> | <b>0.01</b> | <b>0.02</b> | <b>0.01</b> | <b>0.02</b>  | <b>0.02</b> | <b>0.01</b> |              |            |
| <u>reverse zoned</u>   |                                    |             |             |              |             |             |             |             |             |             |              |             |             |              |            |
| 220620-1 circle a opx  | 324 rim                            | 53.52       | 0.29        | 2.12         | 15.59       | 0.39        | 26.65       | 1.68        | 0.03        | 0.03        | 0.03         | 0.05        | 0.01        | 100.38       | 75.30      |
| 220620-1 circle a opx  | 325 core                           | 53.33       | 0.28        | 1.86         | 16.31       | 0.37        | 25.88       | 1.69        | 0.02        | 0.02        | 0.01         | 0.04        | 0.02        | 99.82        | 73.88      |
| 220620-1 circle a opx  | 326 core                           | 53.79       | 0.33        | 1.82         | 16.15       | 0.42        | 26.18       | 1.74        | 0.01        | 0.01        | 0.05         | 0.03        | 0.02        | 100.56       | 74.29      |
| 220620-1 circle a opx  | 327 core                           | 53.36       | 0.35        | 1.90         | 15.91       | 0.39        | 26.02       | 1.74        | 0.01        | 0.01        | 0.02         | 0.02        | bdl         | 99.74        | 74.46      |
| core Average (n=3)     |                                    | 53.49       | 0.32        | 1.86         | 16.13       | 0.39        | 26.03       | 1.72        | 0.02        | 0.01        | 0.03         | 0.03        | 0.01        | 100.04       | 74.21      |
|                        |                                    |             |             |              |             |             |             |             |             |             |              |             |             |              |            |
| <u>unzoned</u>         |                                    |             |             |              |             |             |             |             |             |             |              |             |             |              |            |
| 220620-1 circle c opx  | 342                                | 54.29       | 0.24        | 1.09         | 15.08       | 0.41        | 26.80       | 1.65        | 0.01        | 0.01        | 0.03         | 0.03        | 0.01        | 99.66        | 76.01      |
| 220620-1 circle c opx  | 343                                | 53.73       | 0.29        | 1.88         | 14.89       | 0.41        | 26.76       | 1.77        | 0.04        | 0.02        | 0.10         | 0.04        | 0.01        | 99.95        | 76.21      |
| 220620-1 circle c opx  | 344                                | 54.05       | 0.28        | 1.61         | 14.73       | 0.40        | 26.96       | 1.72        | 0.02        | 0.01        | 0.08         | 0.01        | 0.01        | 99.89        | 76.54      |
| average                |                                    | 54.03       | 0.27        | 1.52         | 14.90       | 0.41        | 26.84       | 1.71        | 0.02        | 0.02        | 0.07         | 0.03        | 0.01        | 99.83        | 76.25      |

| SAMPLE ID                                                                      | Analysis point ID (comment) | SiO2        | TiO2        | Al2O3       | FeO         | MnO         | MgO         | CaO         | Na2O        | K2O         | Cr2O3       | V2O3        | NiO         | TOTAL  | Mg#   |
|--------------------------------------------------------------------------------|-----------------------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|--------|-------|
| <b>Detection limit</b>                                                         |                             | <b>0.01</b> | <b>0.01</b> | <b>0.01</b> | <b>0.02</b> | <b>0.02</b> | <b>0.01</b> | <b>0.01</b> | <b>0.02</b> | <b>0.01</b> | <b>0.02</b> | <b>0.02</b> | <b>0.01</b> |        |       |
| <b>sample 220620-3</b>                                                         |                             |             |             |             |             |             |             |             |             |             |             |             |             |        |       |
| <b>CPX</b>                                                                     |                             |             |             |             |             |             |             |             |             |             |             |             |             |        |       |
| <u>Oscillatory zoned (from rim to core) each point is treated individually</u> |                             |             |             |             |             |             |             |             |             |             |             |             |             |        |       |
| 220620-3 circle a cpx                                                          | 590 rim (rim to core)       | 51.26       | 0.60        | 3.13        | 9.85        | 0.28        | 15.31       | 18.87       | 0.34        | 0.02        | 0.07        | 0.06        | bdl         | 99.78  | 73.48 |
| 220620-3 circle a cpx                                                          | 589                         | 52.07       | 0.57        | 2.83        | 10.50       | 0.31        | 15.27       | 18.35       | 0.35        | 0.02        | 0.05        | 0.07        | 0.01        | 100.39 | 72.18 |
| 220620-3 circle a cpx                                                          | 588                         | 51.22       | 0.62        | 4.38        | 8.11        | 0.22        | 15.18       | 19.99       | 0.37        | 0.02        | 0.07        | 0.08        | bdl         | 100.26 | 76.94 |
| 220620-3 circle a cpx                                                          | 587                         | 51.13       | 0.52        | 4.99        | 7.69        | 0.20        | 15.71       | 19.50       | 0.36        | 0.03        | 0.08        | 0.04        | 0.01        | 100.25 | 78.44 |
| 220620-3 circle a cpx                                                          | 591 core (rime to core)     | 52.88       | 0.35        | 3.32        | 6.76        | 0.17        | 16.84       | 19.97       | 0.30        | 0.01        | 0.16        | 0.04        | 0.01        | 100.82 | 81.62 |
|                                                                                |                             |             |             |             |             |             |             |             |             |             |             |             |             |        |       |
| <u>Cpx with partial rim of Opx</u>                                             |                             |             |             |             |             |             |             |             |             |             |             |             |             |        |       |
| <u>unzoned opx partial rim</u>                                                 |                             |             |             |             |             |             |             |             |             |             |             |             |             |        |       |

|                        |                                    |             |             |              |             |             |             |             |             |             |              |             |             |              |            |
|------------------------|------------------------------------|-------------|-------------|--------------|-------------|-------------|-------------|-------------|-------------|-------------|--------------|-------------|-------------|--------------|------------|
| 220320-3 circle c cpx  | 602                                | 52.99       | 0.37        | 2.55         | 17.10       | 0.38        | 24.79       | 1.87        | 0.02        | 0.01        | 0.04         | 0.05        | 0.01        | 100.18       | 72.10      |
| 220320-3 circle c cpx  | 603                                | 53.18       | 0.34        | 2.29         | 17.35       | 0.39        | 24.65       | 1.75        | 0.01        | 0.02        | bdl          | 0.03        | bdl         | 100.00       | 71.69      |
| opx average            |                                    | 53.09       | 0.36        | 2.42         | 17.23       | 0.39        | 24.72       | 1.81        | 0.02        | 0.02        | 0.02         | 0.04        | 0.01        | 100.09       | 71.90      |
| <u>unzoned cpx</u>     |                                    |             |             |              |             |             |             |             |             |             |              |             |             |              |            |
| 220320-3 circle c cpx  | 604                                | 52.23       | 0.55        | 2.78         | 9.92        | 0.26        | 15.59       | 18.75       | 0.34        | bdl         | 0.02         | 0.07        | bdl         | 100.51       | 73.70      |
| 220320-3 circle c cpx  | 605                                | 51.45       | 0.69        | 3.19         | 9.57        | 0.21        | 15.18       | 19.08       | 0.30        | 0.02        | 0.14         | 0.08        | bdl         | 99.90        | 73.88      |
| 220320-3 circle c cpx  | 606                                | 52.13       | 0.62        | 2.60         | 10.24       | 0.30        | 15.61       | 18.49       | 0.31        | 0.02        | 0.04         | 0.08        | 0.01        | 100.44       | 73.10      |
| cpx average            |                                    | 51.94       | 0.62        | 2.86         | 9.91        | 0.26        | 15.46       | 18.77       | 0.32        | 0.01        | 0.07         | 0.08        | 0.01        | 100.28       | 73.56      |
|                        |                                    |             |             |              |             |             |             |             |             |             |              |             |             |              |            |
| <b>OPX</b>             | <b>Analysis point ID (comment)</b> | <b>SiO2</b> | <b>TiO2</b> | <b>Al2O3</b> | <b>FeO</b>  | <b>MnO</b>  | <b>MgO</b>  | <b>CaO</b>  | <b>Na2O</b> | <b>K2O</b>  | <b>Cr2O3</b> | <b>V2O3</b> | <b>NiO</b>  | <b>TOTAL</b> | <b>Mg#</b> |
| <b>Detection limit</b> |                                    | <b>0.01</b> | <b>0.01</b> | <b>0.01</b>  | <b>0.02</b> | <b>0.02</b> | <b>0.01</b> | <b>0.01</b> | <b>0.02</b> | <b>0.01</b> | <b>0.02</b>  | <b>0.02</b> | <b>0.01</b> |              |            |
| <u>patchy zoned?</u>   |                                    |             |             |              |             |             |             |             |             |             |              |             |             |              |            |
| 220320-3 circle c opx  | 607 (light area in BSE)            | 52.82       | 0.34        | 2.64         | 17.90       | 0.45        | 24.01       | 1.92        | 0.03        | 0.01        | 0.03         | 0.05        | 0.03        | 100.24       | 70.51      |
| 220320-3 circle c opx  | 608 (light area in BSE)            | 52.76       | 0.34        | 2.57         | 18.25       | 0.42        | 24.30       | 1.78        | 0.04        | 0.02        | 0.02         | 0.05        | 0.01        | 100.57       | 70.35      |
| 220320-3 circle c opx  | 609 (dark area in BSE)             | 54.23       | 0.25        | 1.44         | 16.46       | 0.39        | 25.55       | 1.80        | 0.04        | 0.01        | 0.02         | 0.02        | 0.01        | 100.22       | 73.45      |
| 220320-3 circle c opx  | 610 (dark area in BSE)             | 54.21       | 0.22        | 1.26         | 16.97       | 0.39        | 25.47       | 1.73        | 0.05        | 0.02        | 0.02         | 0.02        | 0.02        | 100.38       | 72.79      |

| SAMPLE ID                                                   | Analysis point ID (comment) | SiO2        | TiO2        | Al2O3       | FeO         | MnO         | MgO         | CaO         | Na2O        | K2O         | Cr2O3       | V2O3        | NiO         | TOTAL  | Mg#   |
|-------------------------------------------------------------|-----------------------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|--------|-------|
| <b>Detection limit</b>                                      |                             | <b>0.01</b> | <b>0.01</b> | <b>0.01</b> | <b>0.02</b> | <b>0.02</b> | <b>0.01</b> | <b>0.01</b> | <b>0.02</b> | <b>0.01</b> | <b>0.02</b> | <b>0.02</b> | <b>0.01</b> |        |       |
| <b>sample 220620-4</b>                                      |                             |             |             |             |             |             |             |             |             |             |             |             |             |        |       |
| <b>CPX</b>                                                  |                             |             |             |             |             |             |             |             |             |             |             |             |             |        |       |
| <u>unzoned</u>                                              |                             |             |             |             |             |             |             |             |             |             |             |             |             |        |       |
| 220620-4 circle a cpx                                       | 446                         | 51.27       | 0.83        | 1.64        | 13.17       | 0.42        | 14.26       | 17.36       | 0.32        | 0.02        | bdl         | 0.08        | bdl         | 99.35  | 65.86 |
| 220620-4 circle a cpx                                       | 447                         | 51.84       | 0.65        | 1.29        | 14.64       | 0.49        | 15.34       | 15.16       | 0.24        | 0.02        | 0.01        | 0.08        | bdl         | 99.74  | 65.13 |
| 220620-4 circle a cpx                                       | 448                         | 51.69       | 0.62        | 1.20        | 15.33       | 0.50        | 15.64       | 14.23       | 0.23        | 0.02        | 0.01        | 0.05        | bdl         | 99.51  | 64.52 |
| 220620-4 circle a cpx                                       | 449                         | 51.40       | 0.68        | 1.44        | 14.62       | 0.47        | 15.49       | 14.93       | 0.23        | 0.01        | bdl         | 0.06        | bdl         | 99.34  | 65.38 |
| 220620-4 circle a cpx                                       | 450                         | 51.39       | 0.75        | 1.43        | 14.64       | 0.47        | 14.94       | 15.62       | 0.24        | 0.02        | bdl         | 0.05        | bdl         | 99.54  | 64.52 |
| average                                                     |                             | 51.52       | 0.71        | 1.40        | 14.48       | 0.47        | 15.13       | 15.46       | 0.25        | 0.02        | 0.01        | 0.06        | bdl         | 99.50  | 65.08 |
|                                                             |                             |             |             |             |             |             |             |             |             |             |             |             |             |        |       |
| <u>oscillatory zoned each point is treated individually</u> |                             |             |             |             |             |             |             |             |             |             |             |             |             |        |       |
| 220620-4 circle c cpx1                                      | 505 (light area in BSE)     | 52.31       | 0.61        | 1.26        | 13.45       | 0.51        | 15.12       | 16.38       | 0.23        | 0.02        | bdl         | 0.07        | bdl         | 99.96  | 66.71 |
| 220620-4 circle c cpx1                                      | 506 (darker area in BSE)    | 51.86       | 0.79        | 2.10        | 12.33       | 0.41        | 14.45       | 17.93       | 0.29        | 0.02        | bdl         | 0.10        | bdl         | 100.26 | 67.62 |
| 220620-4 circle c cpx1                                      | 507 (light area in BSE)     | 51.76       | 0.83        | 1.78        | 13.61       | 0.45        | 14.56       | 16.84       | 0.29        | 0.02        | 0.01        | 0.07        | bdl         | 100.21 | 65.60 |

|                                                             |                                    |             |             |              |             |             |             |             |             |             |              |             |             |              |            |
|-------------------------------------------------------------|------------------------------------|-------------|-------------|--------------|-------------|-------------|-------------|-------------|-------------|-------------|--------------|-------------|-------------|--------------|------------|
| 220620-4 circle c cpx1                                      | 508 (darker area in BSE)           | 51.91       | 0.65        | 1.64         | 12.93       | 0.46        | 15.06       | 16.74       | 0.27        | 0.01        | bdl          | 0.04        | bdl         | 99.70        | 67.48      |
| average                                                     |                                    | 51.96       | 0.72        | 1.69         | 13.08       | 0.46        | 14.80       | 16.97       | 0.27        | 0.02        | 0.01         | 0.07        | bdl         | 100.03       | 66.86      |
|                                                             |                                    |             |             |              |             |             |             |             |             |             |              |             |             |              |            |
| <u>Oscillatory zoned each point is treated individually</u> |                                    |             |             |              |             |             |             |             |             |             |              |             |             |              |            |
| 220620-4 circle c cpx2                                      | 517 (lighter area in BSE)          | 51.81       | 0.80        | 1.82         | 13.57       | 0.43        | 14.56       | 16.69       | 0.30        | 0.02        | 0.02         | 0.07        | bdl         | 100.09       | 65.67      |
| 220620-4 circle c cpx2                                      | 518 (darker area in BSE)           | 52.36       | 0.55        | 1.23         | 13.48       | 0.46        | 15.72       | 15.96       | 0.25        | 0.01        | bdl          | 0.05        | bdl         | 100.04       | 67.53      |
| 220620-4 circle c cpx2                                      | 519 (lighter area in BSE)          | 51.98       | 0.71        | 1.61         | 13.36       | 0.42        | 14.37       | 17.38       | 0.32        | bdl         | bdl          | 0.08        | bdl         | 100.22       | 65.72      |
| 220620-4 circle c cpx2                                      | 520 (lighter area in BSE)          | 51.85       | 0.67        | 1.42         | 13.81       | 0.52        | 15.10       | 15.86       | 0.26        | 0.01        | 0.01         | 0.06        | bdl         | 99.56        | 66.08      |
| 220620-4 circle c cpx2                                      | 521 (lighter area in BSE)          | 52.34       | 0.54        | 1.16         | 14.28       | 0.47        | 15.80       | 14.87       | 0.20        | 0.01        | bdl          | 0.06        | bdl         | 99.71        | 66.35      |
| average                                                     |                                    | 52.07       | 0.65        | 1.45         | 13.70       | 0.46        | 15.11       | 16.15       | 0.27        | 0.01        | 0.01         | 0.06        | bdl         | 99.92        | 66.27      |
|                                                             |                                    |             |             |              |             |             |             |             |             |             |              |             |             |              |            |
| <b>OPX</b>                                                  | <b>Analysis point ID (comment)</b> | <b>SiO2</b> | <b>TiO2</b> | <b>Al2O3</b> | <b>FeO</b>  | <b>MnO</b>  | <b>MgO</b>  | <b>CaO</b>  | <b>Na2O</b> | <b>K2O</b>  | <b>Cr2O3</b> | <b>V2O3</b> | <b>NiO</b>  | <b>TOTAL</b> | <b>Mg#</b> |
| <b>Detection limit</b>                                      |                                    | <b>0.01</b> | <b>0.01</b> | <b>0.01</b>  | <b>0.02</b> | <b>0.02</b> | <b>0.01</b> | <b>0.01</b> | <b>0.02</b> | <b>0.01</b> | <b>0.02</b>  | <b>0.02</b> | <b>0.01</b> |              |            |
| <u>Normally zoned - Mg rich core</u>                        |                                    |             |             |              |             |             |             |             |             |             |              |             |             |              |            |
| 220620-4 circle c opx                                       | 522 rim                            | 53.37       | 0.40        | 0.99         | 19.65       | 0.50        | 23.07       | 2.05        | 0.05        | 0.02        | bdl          | bdl         | bdl         | 100.08       | 67.67      |
| 220620-4 circle c opx                                       | 523 (mantle)                       | 53.10       | 0.31        | 1.94         | 18.50       | 0.47        | 23.95       | 1.63        | 0.05        | 0.03        | 0.01         | 0.05        | bdl         | 100.02       | 69.77      |
| 220620-4 circle c opx                                       | 524 core                           | 53.96       | 0.30        | 1.28         | 16.82       | 0.42        | 25.39       | 1.70        | 0.04        | 0.02        | bdl          | 0.03        | 0.02        | 99.98        | 72.91      |
| 220620-4 circle c opx                                       | 525 core                           | 53.03       | 0.28        | 2.30         | 16.93       | 0.43        | 24.89       | 1.75        | 0.02        | 0.02        | bdl          | 0.04        | 0.01        | 99.70        | 72.38      |
|                                                             |                                    |             |             |              |             |             |             |             |             |             |              |             |             |              |            |
| <u>opx rim around ol</u>                                    |                                    |             |             |              |             |             |             |             |             |             |              |             |             |              |            |
| 220620-4 circle a pyroxene rim1                             | 428                                | 52.53       | 0.37        | 0.57         | 20.24       | 0.60        | 20.21       | 4.04        | 0.04        | 0.03        | bdl          | 0.02        | bdl         | 98.67        | 64.03      |
| 220620-4 circle a pyroxene rim1                             | 429                                | 52.36       | 0.36        | 0.58         | 19.93       | 0.70        | 20.18       | 4.41        | 0.03        | 0.03        | 0.01         | 0.04        | bdl         | 98.62        | 64.35      |
| 220620-4 circle a pyroxene rim1                             | 430                                | 52.46       | 0.34        | 0.59         | 19.79       | 0.60        | 20.67       | 3.79        | 0.06        | 0.02        | bdl          | 0.01        | 0.01        | 98.35        | 65.05      |
| average                                                     |                                    | 52.45       | 0.36        | 0.58         | 19.99       | 0.63        | 20.36       | 4.08        | 0.05        | 0.03        | bdl          | 0.02        | 0.01        | 98.55        | 64.48      |

| <b>SAMPLE ID</b>                          | <b>Analysis point ID (comment)</b> | <b>SiO2</b> | <b>TiO2</b> | <b>Al2O3</b> | <b>FeO</b>  | <b>MnO</b>  | <b>MgO</b>  | <b>CaO</b>  | <b>Na2O</b> | <b>K2O</b>  | <b>Cr2O3</b> | <b>V2O3</b> | <b>NiO</b>  | <b>TOTAL</b> | <b>Mg#</b> |
|-------------------------------------------|------------------------------------|-------------|-------------|--------------|-------------|-------------|-------------|-------------|-------------|-------------|--------------|-------------|-------------|--------------|------------|
| <b>Detection limit</b>                    |                                    | <b>0.01</b> | <b>0.01</b> | <b>0.01</b>  | <b>0.02</b> | <b>0.02</b> | <b>0.01</b> | <b>0.01</b> | <b>0.02</b> | <b>0.01</b> | <b>0.02</b>  | <b>0.02</b> | <b>0.01</b> |              |            |
| <b>sample 220623-1</b>                    |                                    |             |             |              |             |             |             |             |             |             |              |             |             |              |            |
| <b>CPX</b>                                |                                    |             |             |              |             |             |             |             |             |             |              |             |             |              |            |
| <u>Reverse zoned cpx inclusion in opx</u> |                                    |             |             |              |             |             |             |             |             |             |              |             |             |              |            |
| 220623-1 circle b cpx core                | 282 core                           | 52.70       | 0.39        | 2.17         | 9.64        | 0.26        | 17.27       | 17.03       | 0.23        | 0.01        | 0.21         | 0.03        | 0.02        | 99.97        | 76.16      |
| 220623-1 circle b cpx core                | 285 mantle                         | 52.29       | 0.41        | 3.45         | 7.70        | 0.19        | 16.69       | 19.11       | 0.29        | 0.01        | 0.24         | 0.05        | 0.03        | 100.46       | 79.44      |
| 220623-1 circle b cpx core                | 286 mantle                         | 52.33       | 0.38        | 3.25         | 7.68        | 0.21        | 16.99       | 18.44       | 0.30        | 0.01        | 0.22         | 0.04        | 0.03        | 99.88        | 79.76      |



|                                                           |                                    |             |             |              |             |             |             |             |             |             |              |             |             |              |            |
|-----------------------------------------------------------|------------------------------------|-------------|-------------|--------------|-------------|-------------|-------------|-------------|-------------|-------------|--------------|-------------|-------------|--------------|------------|
| mantle avg (n=2)                                          |                                    | 52.31       | 0.39        | 3.35         | 7.69        | 0.20        | 16.84       | 18.78       | 0.30        | 0.01        | 0.23         | 0.04        | 0.03        | 100.17       | 79.60      |
| 220623-1 circle b cpx core                                | 284 rim                            | 54.12       | 0.14        | 2.03         | 6.08        | 0.17        | 19.52       | 18.06       | 0.29        | 0.02        | 0.21         | bdl         | 0.05        | 100.66       | 85.12      |
|                                                           |                                    |             |             |              |             |             |             |             |             |             |              |             |             |              |            |
| <u>Unzoned cpx inclusion in opx</u>                       |                                    |             |             |              |             |             |             |             |             |             |              |             |             |              |            |
| 220623-1 circle c cpx core1                               | 298                                | 52.52       | 0.40        | 2.48         | 8.58        | 0.23        | 16.47       | 18.73       | 0.24        | 0.03        | 0.11         | 0.07        | 0.01        | 99.86        | 77.39      |
| 220623-1 circle c cpx core1                               | 299                                | 52.42       | 0.39        | 2.80         | 8.88        | 0.25        | 16.72       | 18.17       | 0.35        | 0.02        | 0.10         | 0.06        | 0.01        | 100.17       | 77.04      |
| 220623-1 circle c cpx core1                               | 300                                | 52.86       | 0.36        | 2.36         | 8.01        | 0.22        | 16.70       | 19.09       | 0.27        | 0.02        | 0.09         | 0.06        | 0.01        | 100.05       | 78.80      |
| 220623-1 circle c cpx core1                               | 301                                | 52.46       | 0.41        | 2.90         | 8.41        | 0.20        | 16.36       | 18.70       | 0.34        | 0.02        | 0.11         | 0.05        | 0.03        | 99.98        | 77.61      |
| average                                                   |                                    | 52.57       | 0.39        | 2.63         | 8.47        | 0.22        | 16.56       | 18.67       | 0.30        | 0.02        | 0.10         | 0.06        | 0.02        | 100.01       | 77.71      |
|                                                           |                                    |             |             |              |             |             |             |             |             |             |              |             |             |              |            |
| <u>Normally zoned (Mg rich core) cpx inclusion in opx</u> |                                    |             |             |              |             |             |             |             |             |             |              |             |             |              |            |
| <u>rim</u>                                                |                                    |             |             |              |             |             |             |             |             |             |              |             |             |              |            |
| 220623-1 circle c cpx core2                               | 308                                | 53.07       | 0.35        | 2.29         | 9.26        | 0.24        | 17.10       | 17.29       | 0.28        | 0.01        | 0.10         | 0.05        | 0.01        | 100.04       | 76.70      |
| 220623-1 circle c cpx core2                               | 311                                | 52.09       | 0.42        | 2.82         | 9.15        | 0.23        | 16.47       | 18.18       | 0.32        | 0.02        | 0.15         | 0.06        | 0.02        | 99.92        | 76.25      |
| 220623-1 circle c cpx core2                               | 313                                | 52.36       | 0.41        | 2.66         | 9.20        | 0.23        | 16.90       | 17.72       | 0.28        | 0.01        | 0.16         | 0.07        | bdl         | 100.00       | 76.60      |
| rim avg (n=2)                                             |                                    | 52.51       | 0.39        | 2.59         | 9.20        | 0.24        | 16.82       | 17.73       | 0.29        | 0.01        | 0.13         | 0.06        | 0.01        | 99.99        | 76.52      |
| <u>core</u>                                               |                                    |             |             |              |             |             |             |             |             |             |              |             |             |              |            |
| 220623-1 circle c cpx core2                               | 309                                | 52.50       | 0.36        | 3.11         | 7.45        | 0.19        | 16.48       | 19.47       | 0.30        | 0.01        | 0.21         | 0.05        | 0.01        | 100.15       | 79.77      |
| 220623-1 circle c cpx core2                               | 310                                | 52.09       | 0.36        | 3.00         | 7.57        | 0.17        | 17.06       | 18.62       | 0.27        | 0.01        | 0.21         | 0.06        | 0.01        | 99.44        | 80.08      |
| 220623-1 circle c cpx core2                               | 312                                | 52.31       | 0.39        | 3.41         | 7.42        | 0.17        | 16.53       | 19.51       | 0.30        | 0.02        | 0.21         | 0.02        | 0.02        | 100.31       | 79.89      |
| core avg (n=3)                                            |                                    | 52.30       | 0.37        | 3.17         | 7.48        | 0.18        | 16.69       | 19.20       | 0.29        | 0.01        | 0.21         | 0.04        | 0.01        | 99.97        | 79.91      |
|                                                           |                                    |             |             |              |             |             |             |             |             |             |              |             |             |              |            |
| <u>Patchy zoned cpx inclusion in opx</u>                  |                                    |             |             |              |             |             |             |             |             |             |              |             |             |              |            |
| 220623-1 circle a cpx core                                | 319 (dark area in BSE)             | 52.36       | 0.34        | 2.71         | 7.64        | 0.20        | 17.20       | 18.42       | 0.27        | 0.01        | 0.26         | 0.05        | 0.02        | 99.49        | 80.05      |
| 220623-1 circle a cpx core                                | 322 (dark area in BSE)             | 52.82       | 0.37        | 2.52         | 7.69        | 0.23        | 16.86       | 19.17       | 0.26        | 0.01        | 0.17         | 0.05        | 0.01        | 100.16       | 79.64      |
| dark avg (n=2)                                            |                                    | 52.59       | 0.36        | 2.62         | 7.66        | 0.21        | 17.03       | 18.79       | 0.27        | 0.01        | 0.21         | 0.05        | 0.01        | 99.83        | 79.84      |
| 220623-1 circle a cpx core                                | 320 (light area in BSE)            | 51.82       | 0.40        | 3.13         | 9.20        | 0.24        | 16.19       | 18.23       | 0.38        | 0.01        | 0.19         | 0.06        | 0.01        | 99.86        | 75.83      |
| 220623-1 circle a cpx core                                | 323 (light area in BSE)            | 52.11       | 0.40        | 2.73         | 9.17        | 0.27        | 17.19       | 16.80       | 0.26        | 0.03        | 0.15         | 0.06        | 0.03        | 99.20        | 76.95      |
| light avg (n=2)                                           |                                    | 51.96       | 0.40        | 2.93         | 9.19        | 0.25        | 16.69       | 17.52       | 0.32        | 0.02        | 0.17         | 0.06        | 0.02        | 99.53        | 76.39      |
|                                                           |                                    |             |             |              |             |             |             |             |             |             |              |             |             |              |            |
| <b>OPX</b>                                                | <b>Analysis point ID (comment)</b> | <b>SiO2</b> | <b>TiO2</b> | <b>Al2O3</b> | <b>FeO</b>  | <b>MnO</b>  | <b>MgO</b>  | <b>CaO</b>  | <b>Na2O</b> | <b>K2O</b>  | <b>Cr2O3</b> | <b>V2O3</b> | <b>NiO</b>  | <b>TOTAL</b> | <b>Mg#</b> |
| <u>Detection limit</u>                                    |                                    | <b>0.01</b> | <b>0.01</b> | <b>0.01</b>  | <b>0.02</b> | <b>0.02</b> | <b>0.01</b> | <b>0.01</b> | <b>0.02</b> | <b>0.01</b> | <b>0.02</b>  | <b>0.02</b> | <b>0.01</b> |              |            |
| <u>Normal zoned</u>                                       |                                    |             |             |              |             |             |             |             |             |             |              |             |             |              |            |
| <u>rim</u>                                                |                                    |             |             |              |             |             |             |             |             |             |              |             |             |              |            |

|                                                                               |                               |       |      |      |       |      |       |      |      |      |      |      |      |        |       |
|-------------------------------------------------------------------------------|-------------------------------|-------|------|------|-------|------|-------|------|------|------|------|------|------|--------|-------|
| 220623-1 circle b opx                                                         | 287 (rim)                     | 55.09 | 0.15 | 1.08 | 13.96 | 0.32 | 27.63 | 1.92 | 0.04 | 0.01 | 0.09 | 0.02 | 0.04 | 100.35 | 77.92 |
| <u>core</u>                                                                   |                               |       |      |      |       |      |       |      |      |      |      |      |      |        |       |
| 220623-1 circle b opx                                                         | 288 (core)                    | 56.86 | 0.06 | 1.10 | 8.25  | 0.20 | 32.29 | 1.57 | 0.02 | 0.01 | 0.26 | 0.01 | 0.06 | 100.71 | 87.46 |
| 220623-1 circle b opx                                                         | 290 (core)                    | 55.61 | 0.11 | 1.76 | 8.29  | 0.19 | 31.65 | 1.62 | 0.03 | 0.01 | 0.46 | 0.01 | 0.07 | 99.80  | 87.19 |
| core avg (n=2)                                                                |                               | 56.24 | 0.09 | 1.43 | 8.27  | 0.19 | 31.97 | 1.59 | 0.02 | 0.01 | 0.36 | 0.01 | 0.07 | 100.25 | 87.33 |
|                                                                               |                               |       |      |      |       |      |       |      |      |      |      |      |      |        |       |
| <u>Oscillatory zoned (from rim to core)</u>                                   |                               |       |      |      |       |      |       |      |      |      |      |      |      |        |       |
| 220623-1 circle c opx 1                                                       | 297 (rim)                     | 53.45 | 0.17 | 2.58 | 14.55 | 0.30 | 26.74 | 1.70 | 0.04 | 0.02 | 0.08 | 0.05 | 0.03 | 99.71  | 76.61 |
| 220623-1 circle c opx 1                                                       | 292 (mantle)                  | 54.56 | 0.19 | 2.29 | 12.88 | 0.26 | 28.43 | 1.65 | 0.03 | 0.01 | 0.15 | 0.05 | 0.03 | 100.53 | 79.73 |
| 220623-1 circle c opx 1                                                       | 294 (mantle)                  | 54.46 | 0.20 | 1.99 | 12.66 | 0.27 | 28.45 | 1.74 | 0.01 | 0.02 | 0.17 | 0.04 | 0.02 | 100.04 | 80.02 |
| mantle average (n=2)                                                          |                               | 54.51 | 0.19 | 2.14 | 12.77 | 0.27 | 28.44 | 1.70 | 0.02 | 0.01 | 0.16 | 0.04 | 0.02 | 100.28 | 79.88 |
| 220623-1 circle c opx 1                                                       | 293 (core)                    | 53.60 | 0.28 | 1.73 | 14.54 | 0.36 | 26.97 | 1.99 | 0.04 | 0.01 | 0.11 | 0.03 | 0.02 | 99.67  | 76.77 |
| 220623-1 circle c opx 1                                                       | 295 (core)                    | 54.38 | 0.25 | 1.56 | 14.86 | 0.37 | 27.09 | 1.86 | 0.04 | 0.02 | 0.12 | 0.05 | 0.01 | 100.63 | 76.47 |
| 220623-1 circle c opx 1                                                       | 296 (core)                    | 54.57 | 0.20 | 1.90 | 14.20 | 0.34 | 27.41 | 1.61 | 0.01 | 0.01 | 0.04 | 0.02 | 0.02 | 100.33 | 77.48 |
| average of core (n=3)                                                         |                               | 54.18 | 0.24 | 1.73 | 14.54 | 0.36 | 27.16 | 1.82 | 0.03 | 0.02 | 0.09 | 0.03 | 0.02 | 100.21 | 76.91 |
|                                                                               |                               |       |      |      |       |      |       |      |      |      |      |      |      |        |       |
| <u>oscillatory zoned (rim to core, three "stages/layers")</u>                 |                               |       |      |      |       |      |       |      |      |      |      |      |      |        |       |
| 220623-1 circle c opx2                                                        | 302 (stage 3, rim)            | 53.77 | 0.26 | 1.44 | 14.03 | 0.33 | 27.04 | 1.99 | 0.02 | 0.01 | 0.15 | 0.02 | 0.03 | 99.10  | 77.46 |
| 220623-1 circle c opx2                                                        | 307 stage 3, rim)             | 54.13 | 0.22 | 1.74 | 14.21 | 0.34 | 27.02 | 2.19 | 0.04 | 0.01 | 0.15 | 0.03 | 0.02 | 100.10 | 77.22 |
| stage 3 avg (rim) (n=2)                                                       |                               | 53.95 | 0.24 | 1.59 | 14.12 | 0.34 | 27.03 | 2.09 | 0.03 | 0.01 | 0.15 | 0.02 | 0.02 | 99.60  | 77.34 |
| 220623-1 circle c opx2                                                        | 303 (stage 2, rim)            | 54.44 | 0.18 | 2.31 | 12.98 | 0.25 | 28.18 | 1.73 | 0.01 | 0.01 | 0.16 | 0.02 | 0.04 | 100.30 | 79.47 |
| 220623-1 circle c opx2                                                        | 306 (stage 2, rim)            | 54.53 | 0.22 | 1.98 | 13.02 | 0.29 | 28.44 | 1.70 | 0.02 | 0.02 | 0.20 | 0.03 | 0.03 | 100.50 | 79.57 |
| stage 2 avg (mantle) (n=2)                                                    |                               | 54.48 | 0.20 | 2.15 | 13.00 | 0.27 | 28.31 | 1.72 | 0.02 | 0.02 | 0.18 | 0.02 | 0.04 | 100.40 | 79.52 |
| 220623-1 circle c opx2                                                        | 304 (stage 1, rim)            | 53.96 | 0.22 | 1.70 | 14.21 | 0.31 | 27.04 | 1.83 | 0.01 | 0.01 | 0.18 | 0.02 | 0.02 | 99.50  | 77.24 |
| 220623-1 circle c opx2                                                        | 305 (stage 1, rim)            | 54.45 | 0.21 | 1.48 | 15.04 | 0.31 | 27.32 | 1.71 | 0.04 | 0.01 | 0.06 | 0.03 | 0.04 | 100.71 | 76.41 |
| stage 1 avg (core) (n=2)                                                      |                               | 54.20 | 0.22 | 1.59 | 14.62 | 0.31 | 27.18 | 1.77 | 0.03 | 0.01 | 0.12 | 0.03 | 0.03 | 100.11 | 76.83 |
|                                                                               |                               |       |      |      |       |      |       |      |      |      |      |      |      |        |       |
| <u>oscillatory zoned (from rim to core) each point is treated differently</u> |                               |       |      |      |       |      |       |      |      |      |      |      |      |        |       |
| 220623-1 circle a opx                                                         | 314 (rim) (from rim to core)  | 53.75 | 0.25 | 1.54 | 15.56 | 0.32 | 26.09 | 2.13 | 0.04 | 0.01 | 0.12 | 0.02 | 0.05 | 99.88  | 74.93 |
| 220623-1 circle a opx                                                         | 315                           | 54.66 | 0.23 | 1.63 | 14.05 | 0.33 | 27.36 | 1.93 | 0.02 | 0.02 | 0.19 | 0.03 | 0.02 | 100.47 | 77.64 |
| 220623-1 circle a opx                                                         | 316                           | 54.02 | 0.24 | 1.86 | 14.05 | 0.30 | 26.91 | 1.91 | 0.02 | 0.01 | 0.16 | 0.04 | 0.03 | 99.55  | 77.35 |
| 220623-1 circle a opx                                                         | 318                           | 54.57 | 0.17 | 1.00 | 14.42 | 0.34 | 27.20 | 1.89 | 0.03 | 0.02 | 0.03 | 0.01 | 0.03 | 99.69  | 77.08 |
| 220623-1 circle a opx                                                         | 317 (core) (from rim to core) | 54.31 | 0.22 | 2.02 | 12.65 | 0.27 | 28.38 | 1.72 | 0.01 | 0.01 | 0.20 | 0.02 | 0.02 | 99.82  | 80.00 |

|         |  |       |      |      |       |      |       |      |      |      |      |      |      |       |       |
|---------|--|-------|------|------|-------|------|-------|------|------|------|------|------|------|-------|-------|
| average |  | 54.26 | 0.22 | 1.61 | 14.14 | 0.31 | 27.19 | 1.92 | 0.02 | 0.01 | 0.14 | 0.02 | 0.03 | 99.88 | 77.40 |
|---------|--|-------|------|------|-------|------|-------|------|------|------|------|------|------|-------|-------|

| SAMPLE ID                                                  | Analysis point ID<br>(comment) | SiO2  | TiO2 | Al2O3 | FeO  | MnO  | MgO   | CaO   | Na2O | K2O  | Cr2O3 | V2O3 | NiO  | TOTAL  | Mg#   |
|------------------------------------------------------------|--------------------------------|-------|------|-------|------|------|-------|-------|------|------|-------|------|------|--------|-------|
| Detection limit                                            |                                | 0.01  | 0.01 | 0.01  | 0.02 | 0.02 | 0.01  | 0.01  | 0.02 | 0.01 | 0.02  | 0.02 | 0.01 |        |       |
| sample 220621-5                                            |                                |       |      |       |      |      |       |       |      |      |       |      |      |        |       |
| CPX                                                        |                                |       |      |       |      |      |       |       |      |      |       |      |      |        |       |
| <i>oscillatory zoned each point is treated differently</i> |                                |       |      |       |      |      |       |       |      |      |       |      |      |        |       |
| 220621-5 circle b cpx                                      | 625                            | 52.63 | 0.29 | 2.86  | 5.37 | 0.13 | 16.23 | 21.89 | 0.24 | 0.01 | 0.34  | 0.04 | 0.01 | 100.04 | 84.34 |
| 220621-5 circle b cpx                                      | 626                            | 51.16 | 0.42 | 4.08  | 6.87 | 0.19 | 15.18 | 21.30 | 0.29 | 0.02 | 0.24  | 0.04 | bdl  | 99.79  | 79.76 |
| 220621-5 circle b cpx                                      | 627 (same area as 628)         | 52.88 | 0.34 | 1.43  | 9.20 | 0.36 | 14.46 | 20.99 | 0.26 | bdl  | 0.01  | 0.01 | bdl  | 99.95  | 73.69 |
| 220621-5 circle b cpx                                      | 628 (same area as 627)         | 52.71 | 0.33 | 1.44  | 9.06 | 0.38 | 14.37 | 21.15 | 0.28 | 0.01 | 0.04  | 0.03 | bdl  | 99.79  | 73.87 |
| 220621-5 circle b cpx                                      | 629                            | 51.82 | 0.38 | 3.82  | 6.72 | 0.18 | 15.69 | 21.31 | 0.21 | 0.01 | 0.04  | 0.03 | bdl  | 100.22 | 80.62 |
| 220621-5 circle b cpx                                      | 630                            | 51.74 | 0.41 | 3.33  | 8.35 | 0.22 | 15.29 | 20.66 | 0.27 | 0.03 | bdl   | 0.04 | bdl  | 100.31 | 76.55 |
| 220621-5 circle b cpx                                      | 632                            | 52.35 | 0.30 | 3.21  | 5.64 | 0.14 | 16.21 | 21.39 | 0.23 | 0.01 | 0.35  | 0.03 | bdl  | 99.85  | 83.68 |
|                                                            |                                |       |      |       |      |      |       |       |      |      |       |      |      |        |       |
| <i>Patchy zoned</i>                                        |                                |       |      |       |      |      |       |       |      |      |       |      |      |        |       |
| 220621-5 circle b cpx2                                     | 633 (light area in BSE)        | 51.22 | 0.47 | 3.65  | 8.19 | 0.19 | 15.06 | 20.64 | 0.31 | 0.02 | 0.03  | 0.06 | bdl  | 99.83  | 76.61 |
| 220621-5 circle b cpx2                                     | 634 (dark area in BSE)         | 50.99 | 0.44 | 3.82  | 7.59 | 0.18 | 15.30 | 21.02 | 0.27 | 0.02 | 0.05  | 0.02 | bdl  | 99.71  | 78.23 |
| 220621-5 circle b cpx2                                     | 635 (rim, dark area in BSE)    | 51.42 | 0.45 | 3.97  | 7.26 | 0.18 | 15.12 | 21.01 | 0.25 | 0.03 | 0.16  | 0.04 | 0.01 | 99.88  | 78.79 |
| 220621-5 circle b cpx2                                     | 636 (core, light area in BSE)  | 52.23 | 0.50 | 2.53  | 9.37 | 0.27 | 15.01 | 19.99 | 0.32 | 0.01 | bdl   | 0.07 | 0.02 | 100.33 | 74.07 |
| 220621-5 circle b cpx2                                     | 637 (dark area in BSE)         | 51.04 | 0.52 | 4.42  | 7.53 | 0.17 | 15.09 | 20.54 | 0.28 | 0.02 | 0.13  | 0.04 | 0.01 | 99.78  | 78.13 |
|                                                            |                                |       |      |       |      |      |       |       |      |      |       |      |      |        |       |
| <i>unzoned</i>                                             |                                |       |      |       |      |      |       |       |      |      |       |      |      |        |       |
| 220621-5 circle c cpx                                      | 643                            | 52.76 | 0.33 | 1.57  | 9.07 | 0.35 | 14.61 | 21.05 | 0.29 | bdl  | bdl   | 0.05 | bdl  | 100.09 | 74.16 |
| 220621-5 circle c cpx                                      | 644                            | 52.60 | 0.36 | 1.52  | 9.12 | 0.41 | 14.43 | 21.04 | 0.30 | 0.02 | bdl   | 0.03 | bdl  | 99.81  | 73.82 |
| 220621-5 circle c cpx                                      | 645                            | 53.26 | 0.27 | 1.19  | 9.44 | 0.41 | 14.44 | 21.07 | 0.26 | 0.02 | bdl   | 0.02 | bdl  | 100.40 | 73.17 |
| 220621-5 circle c cpx                                      | 646                            | 52.80 | 0.29 | 1.17  | 9.43 | 0.39 | 14.50 | 21.06 | 0.31 | 0.01 | 0.01  | 0.01 | bdl  | 99.97  | 73.27 |
| average                                                    |                                | 52.85 | 0.32 | 1.36  | 9.27 | 0.39 | 14.49 | 21.06 | 0.29 | 0.01 | bdl   | 0.03 | bdl  | 100.07 | 73.60 |
|                                                            |                                |       |      |       |      |      |       |       |      |      |       |      |      |        |       |
| <i>reverse zoned (mg rich rim)</i>                         |                                |       |      |       |      |      |       |       |      |      |       |      |      |        |       |
| 220621-5 circle c cpx2                                     | 647 rim                        | 51.71 | 0.45 | 3.21  | 7.75 | 0.18 | 15.49 | 20.79 | 0.26 | 0.01 | 0.06  | 0.04 | bdl  | 99.95  | 78.08 |
| 220621-5 circle c cpx2                                     | 648 rim                        | 51.68 | 0.46 | 3.40  | 8.07 | 0.22 | 15.54 | 20.39 | 0.26 | 0.02 | 0.07  | 0.04 | 0.01 | 100.17 | 77.45 |
| rim average (n=2)                                          |                                | 51.70 | 0.46 | 3.31  | 7.91 | 0.20 | 15.52 | 20.59 | 0.26 | 0.02 | 0.07  | 0.04 | 0.01 | 100.06 | 77.76 |

|                        |          |       |      |      |      |      |       |       |      |      |      |      |     |        |       |
|------------------------|----------|-------|------|------|------|------|-------|-------|------|------|------|------|-----|--------|-------|
| 220621-5 circle c cpx2 | 649 core | 52.65 | 0.27 | 1.13 | 9.44 | 0.38 | 14.55 | 20.88 | 0.27 | 0.01 | bdl  | 0.02 | bdl | 99.59  | 73.32 |
| 220621-5 circle c cpx2 | 651 core | 52.88 | 0.39 | 1.53 | 9.70 | 0.43 | 14.42 | 20.77 | 0.33 | 0.02 | 0.02 | 0.04 | bdl | 100.53 | 72.60 |
| core average (n=2)     |          | 52.77 | 0.33 | 1.33 | 9.57 | 0.40 | 14.49 | 20.83 | 0.30 | 0.01 | 0.02 | 0.03 | bdl | 100.06 | 72.96 |

| SAMPLE ID                                                       | Analysis point ID<br>(comment) | SiO2  | TiO2 | Al2O3 | FeO   | MnO  | MgO   | CaO   | Na2O | K2O  | Cr2O3 | V2O3 | NiO  | TOTAL  | Mg#   |
|-----------------------------------------------------------------|--------------------------------|-------|------|-------|-------|------|-------|-------|------|------|-------|------|------|--------|-------|
| Detection limit                                                 |                                | 0.01  | 0.01 | 0.01  | 0.02  | 0.02 | 0.01  | 0.01  | 0.02 | 0.01 | 0.02  | 0.02 | 0.01 |        |       |
| sample 220621-6                                                 |                                |       |      |       |       |      |       |       |      |      |       |      |      |        |       |
| CPX                                                             |                                |       |      |       |       |      |       |       |      |      |       |      |      |        |       |
| <u>reverse zoned (mg rich rim)</u>                              |                                |       |      |       |       |      |       |       |      |      |       |      |      |        |       |
| 220621-6 circle b cpx                                           | 364 (rim)                      | 52.42 | 0.50 | 1.99  | 9.04  | 0.29 | 15.49 | 20.24 | 0.29 | 0.02 | bdl   | 0.05 | bdl  | 100.30 | 75.34 |
| 220621-6 circle b cpx                                           | 367 (core)                     | 52.80 | 0.49 | 1.60  | 9.58  | 0.31 | 15.20 | 20.02 | 0.29 | bdl  | 0.01  | 0.05 | bdl  | 100.34 | 73.89 |
| 220621-6 circle b cpx                                           | 365 (core)                     | 50.08 | 0.76 | 4.29  | 9.06  | 0.27 | 14.30 | 20.16 | 0.35 | 0.02 | 0.05  | 0.06 | bdl  | 99.40  | 73.78 |
| 220621-6 circle b cpx                                           | 366 (rim)                      | 51.83 | 0.52 | 2.10  | 8.87  | 0.30 | 15.30 | 20.10 | 0.26 | 0.02 | bdl   | 0.02 | bdl  | 99.33  | 75.45 |
|                                                                 |                                |       |      |       |       |      |       |       |      |      |       |      |      |        |       |
| <u>reverse zoned (mg rich rim)</u>                              |                                |       |      |       |       |      |       |       |      |      |       |      |      |        |       |
| <u>rim</u>                                                      |                                |       |      |       |       |      |       |       |      |      |       |      |      |        |       |
| 220621-6 circle a cpx1                                          | 380                            | 52.08 | 0.48 | 1.52  | 9.74  | 0.37 | 15.12 | 20.28 | 0.28 | 0.02 | bdl   | 0.04 | bdl  | 99.92  | 73.46 |
| 220621-6 circle a cpx1                                          | 384                            | 52.43 | 0.42 | 1.37  | 9.29  | 0.38 | 15.19 | 20.36 | 0.31 | 0.01 | 0.02  | 0.04 | bdl  | 99.82  | 74.45 |
| rim average (n=2)                                               |                                | 52.25 | 0.45 | 1.44  | 9.52  | 0.38 | 15.15 | 20.32 | 0.29 | 0.02 | 0.01  | 0.04 | bdl  | 99.87  | 73.95 |
| <u>core</u>                                                     |                                |       |      |       |       |      |       |       |      |      |       |      |      |        |       |
| 220621-6 circle a cpx1                                          | 381                            | 51.85 | 0.52 | 1.99  | 10.51 | 0.36 | 14.96 | 19.10 | 0.32 | 0.01 | bdl   | 0.05 | 0.02 | 99.69  | 71.73 |
| 220621-6 circle a cpx1                                          | 382                            | 52.24 | 0.49 | 1.70  | 9.86  | 0.38 | 14.93 | 19.93 | 0.24 | 0.01 | 0.02  | 0.04 | 0.01 | 99.84  | 72.96 |
| 220621-6 circle a cpx1                                          | 383                            | 52.10 | 0.48 | 1.83  | 10.09 | 0.37 | 14.89 | 19.86 | 0.32 | 0.01 | 0.01  | 0.01 | 0.01 | 99.99  | 72.46 |
| core average (n=3)                                              |                                | 52.06 | 0.50 | 1.84  | 10.15 | 0.37 | 14.92 | 19.63 | 0.29 | 0.01 | 0.01  | 0.04 | 0.01 | 99.84  | 72.38 |
|                                                                 |                                |       |      |       |       |      |       |       |      |      |       |      |      |        |       |
| oscillatory zoned (rim to core) each point treated individually |                                |       |      |       |       |      |       |       |      |      |       |      |      |        |       |
| 220621-6 circle a cpx new 1um                                   | 395 rim (from rim to core)     | 50.89 | 0.62 | 3.11  | 9.06  | 0.27 | 15.48 | 19.10 | 0.22 | 0.05 | 0.04  | 0.05 | 0.02 | 98.90  | 75.30 |
| 220621-6 circle a cpx new 1um                                   | 396                            | 51.12 | 0.68 | 2.69  | 10.53 | 0.38 | 15.36 | 18.41 | 0.26 | 0.03 | bdl   | 0.03 | bdl  | 99.45  | 72.21 |
| 220621-6 circle a cpx new 1um                                   | 397                            | 51.01 | 0.59 | 3.12  | 8.93  | 0.21 | 15.36 | 19.88 | 0.22 | 0.03 | 0.01  | 0.06 | 0.01 | 99.44  | 75.41 |
| 220621-6 circle a cpx new 1um                                   | 398                            | 51.16 | 0.47 | 3.88  | 7.84  | 0.22 | 15.56 | 20.09 | 0.36 | 0.02 | 0.16  | 0.04 | 0.02 | 99.82  | 77.97 |
| 220621-6 circle a cpx new 1um                                   | 399 core (from rim to core)    | 52.20 | 0.36 | 3.42  | 5.74  | 0.14 | 16.95 | 20.42 | 0.28 | 0.03 | 0.40  | 0.03 | 0.01 | 99.98  | 84.04 |
|                                                                 |                                |       |      |       |       |      |       |       |      |      |       |      |      |        |       |
| OPX                                                             | Analysis point ID<br>(comment) | SiO2  | TiO2 | Al2O3 | FeO   | MnO  | MgO   | CaO   | Na2O | K2O  | Cr2O3 | V2O3 | NiO  | TOTAL  | Mg#   |



|                                     |     | 0.01  | 0.01 | 0.01 | 0.02  | 0.02 | 0.01  | 0.01 | 0.02 | 0.01 | 0.02 | 0.02 | 0.01 |        |       |
|-------------------------------------|-----|-------|------|------|-------|------|-------|------|------|------|------|------|------|--------|-------|
| <u>unzoned opx inclusion in cpx</u> |     |       |      |      |       |      |       |      |      |      |      |      |      |        |       |
| 220621-6 circle b opx core          | 368 | 53.59 | 0.25 | 1.07 | 17.65 | 0.47 | 25.55 | 1.37 | 0.02 | 0.02 | 0.01 | bdl  | 0.01 | 99.99  | 72.07 |
| 220621-6 circle b opx core          | 369 | 53.90 | 0.27 | 1.14 | 17.43 | 0.55 | 25.54 | 1.38 | 0.02 | 0.02 | bdl  | 0.02 | 0.01 | 100.28 | 72.32 |
| 220621-6 circle b opx core          | 370 | 53.56 | 0.33 | 1.39 | 17.66 | 0.49 | 24.84 | 2.06 | 0.02 | 0.02 | 0.01 | 0.01 | bdl  | 100.39 | 71.49 |
| 220621-6 circle b opx core          | 371 | 53.64 | 0.27 | 1.13 | 17.71 | 0.49 | 25.35 | 1.40 | 0.02 | 0.02 | bdl  | 0.03 | bdl  | 100.06 | 71.84 |
| average                             |     | 53.67 | 0.28 | 1.18 | 17.61 | 0.50 | 25.32 | 1.55 | 0.02 | 0.02 | 0.01 | 0.02 | bdl  | 100.18 | 71.93 |
|                                     |     |       |      |      |       |      |       |      |      |      |      |      |      |        |       |
| <u>unzoned</u>                      |     |       |      |      |       |      |       |      |      |      |      |      |      |        |       |
| 220621-6 circle b opx new           | 372 | 53.37 | 0.26 | 0.92 | 20.71 | 0.61 | 23.70 | 1.32 | 0.01 | 0.01 | bdl  | 0.02 | 0.01 | 100.95 | 67.10 |
| 220621-6 circle b opx new           | 373 | 53.13 | 0.25 | 0.88 | 20.65 | 0.56 | 23.41 | 1.30 | bdl  | 0.02 | 0.01 | 0.02 | 0.01 | 100.24 | 66.90 |
| 220621-6 circle b opx new           | 374 | 53.16 | 0.26 | 0.89 | 20.72 | 0.64 | 23.63 | 1.29 | 0.02 | 0.02 | 0.01 | 0.02 | 0.01 | 100.66 | 67.02 |
| 220621-6 circle b opx new           | 375 | 53.17 | 0.26 | 0.89 | 20.16 | 0.63 | 23.64 | 1.29 | 0.02 | 0.01 | bdl  | 0.01 | bdl  | 100.08 | 67.64 |
| average                             |     | 53.21 | 0.26 | 0.90 | 20.56 | 0.61 | 23.59 | 1.30 | 0.02 | 0.01 | 0.01 | 0.02 | 0.01 | 100.48 | 67.17 |
|                                     |     |       |      |      |       |      |       |      |      |      |      |      |      |        |       |
| <u>reverse zoned (Mg rich rim)</u>  |     |       |      |      |       |      |       |      |      |      |      |      |      |        |       |
| <u>core</u>                         |     |       |      |      |       |      |       |      |      |      |      |      |      |        |       |
| 220621-6 circle a opx new           | 392 | 52.10 | 0.27 | 2.71 | 20.29 | 0.57 | 23.25 | 1.24 | 0.02 | 0.01 | 0.02 | 0.05 | 0.01 | 100.54 | 67.14 |
| <u>rim</u>                          |     |       |      |      |       |      |       |      |      |      |      |      |      |        |       |
| 220621-6 circle a opx new           | 393 | 53.00 | 0.29 | 1.17 | 19.28 | 0.56 | 24.80 | 1.36 | 0.03 | 0.02 | bdl  | 0.02 | bdl  | 100.52 | 69.64 |
| 220621-6 circle a opx new           | 394 | 53.01 | 0.30 | 1.01 | 18.42 | 0.52 | 25.11 | 1.36 | 0.02 | 0.02 | 0.02 | 0.01 | bdl  | 99.80  | 70.85 |
| rim average (n=2)                   |     | 53.01 | 0.29 | 1.09 | 18.85 | 0.54 | 24.96 | 1.36 | 0.02 | 0.02 | 0.01 | 0.01 | bdl  | 100.16 | 70.24 |
|                                     |     |       |      |      |       |      |       |      |      |      |      |      |      |        |       |

| SAMPLE ID           | Analysis point (description) | SiO2  | TiO2 | Al2O3 | FeO(T) | MnO  | MgO   | CaO   | Na2O | K2O  | Cr2O3 | V2O3 | NiO  | TOTAL  | Mg#   |
|---------------------|------------------------------|-------|------|-------|--------|------|-------|-------|------|------|-------|------|------|--------|-------|
| detection limit     |                              | 0.01  | 0.01 | 0.01  | 0.02   | 0.02 | 0.01  | 0.01  | 0.02 | 0.01 | 0.02  | 0.02 | 0.01 |        |       |
| sample YAM002       |                              |       |      |       |        |      |       |       |      |      |       |      |      |        |       |
| CPX                 |                              |       |      |       |        |      |       |       |      |      |       |      |      |        |       |
| ZONED               |                              |       |      |       |        |      |       |       |      |      |       |      |      |        |       |
| <u>core</u>         |                              |       |      |       |        |      |       |       |      |      |       |      |      |        |       |
| YAM002 circle c cpx | 216                          | 53.56 | 0.26 | 1.72  | 7.27   | 0.28 | 16.65 | 20.64 | 0.25 | 0.01 | 0.09  | 0.03 | n/a  | 100.75 | 80.34 |

|                          |                 |       |      |      |      |      |       |       |      |      |      |      |      |        |       |
|--------------------------|-----------------|-------|------|------|------|------|-------|-------|------|------|------|------|------|--------|-------|
| YAM002 circle c cpx      | 217             | 53.54 | 0.30 | 2.20 | 6.84 | 0.17 | 16.29 | 20.96 | 0.28 | 0.02 | 0.08 | 0.04 | n/a  | 100.71 | 80.93 |
| <i>Average</i>           |                 | 53.55 | 0.28 | 1.96 | 7.05 | 0.23 | 16.47 | 20.80 | 0.26 | 0.01 | 0.09 | 0.04 | n/a  | 100.73 | 80.63 |
| <u>rim</u>               |                 |       |      |      |      |      |       |       |      |      |      |      |      |        |       |
| YAM002 circle c cpx      | 218             | 51.75 | 0.63 | 2.70 | 9.91 | 0.33 | 15.12 | 19.33 | 0.36 | 0.01 | 0.03 | 0.05 | n/a  | 100.21 | 73.12 |
| YAM002 circle c cpx      | 219             | 51.79 | 0.68 | 2.57 | 9.16 | 0.26 | 15.49 | 19.18 | 0.29 | 0.01 | n/a  | 0.03 | 0.00 | 99.46  | 75.10 |
| <i>Average</i>           |                 | 51.77 | 0.66 | 2.63 | 9.53 | 0.29 | 15.31 | 19.25 | 0.32 | 0.01 | 0.03 | 0.04 | 0.00 | 99.84  | 74.11 |
|                          |                 |       |      |      |      |      |       |       |      |      |      |      |      |        |       |
| <b>UNZONED</b>           |                 |       |      |      |      |      |       |       |      |      |      |      |      |        |       |
| YAM002 circle c cpx2     | 220             | 51.78 | 0.66 | 2.74 | 9.15 | 0.33 | 15.11 | 19.87 | 0.35 | 0.02 | 0.00 | 0.04 | 0.00 | 100.04 | 74.63 |
| YAM002 circle c cpx2     | 221             | 51.48 | 0.67 | 2.73 | 9.59 | 0.34 | 14.90 | 19.68 | 0.35 | 0.02 | 0.02 | 0.05 | n/a  | 99.82  | 73.49 |
| YAM002 circle c cpx2     | 222             | 51.61 | 0.65 | 2.75 | 9.64 | 0.29 | 15.01 | 19.50 | 0.33 | 0.01 | 0.00 | 0.05 | 0.01 | 99.84  | 73.50 |
| YAM002 circle c cpx2     | 223             | 51.13 | 0.76 | 3.34 | 9.94 | 0.33 | 15.41 | 18.63 | 0.30 | 0.02 | 0.01 | 0.04 | 0.00 | 99.92  | 73.43 |
| YAM002 circle c cpx2     | 224             | 51.16 | 0.77 | 2.97 | 9.43 | 0.27 | 15.28 | 19.27 | 0.33 | 0.02 | 0.01 | 0.05 | 0.02 | 99.59  | 74.28 |
| <i>Average</i>           |                 | 51.43 | 0.70 | 2.90 | 9.55 | 0.31 | 15.14 | 19.39 | 0.33 | 0.02 | 0.01 | 0.05 | 0.01 | 99.84  | 73.86 |
|                          |                 |       |      |      |      |      |       |       |      |      |      |      |      |        |       |
| <b>UNZONED</b>           |                 |       |      |      |      |      |       |       |      |      |      |      |      |        |       |
| YAM002 circle b cpx1     | 225             | 52.63 | 0.54 | 2.00 | 9.25 | 0.29 | 16.45 | 19.01 | 0.29 | 0.01 | 0.00 | 0.04 | 0.02 | 100.53 | 76.02 |
| YAM002 circle b cpx1     | 226             | 52.07 | 0.59 | 2.42 | 9.82 | 0.33 | 15.51 | 18.80 | 0.33 | 0.01 | n/a  | 0.05 | 0.00 | 99.92  | 73.80 |
| YAM002 circle b cpx1     | 227             | 52.06 | 0.57 | 2.10 | 9.56 | 0.35 | 15.79 | 18.95 | 0.30 | 0.02 | n/a  | 0.03 | 0.00 | 99.70  | 74.65 |
| YAM002 circle b cpx1     | 228             | 50.76 | 0.83 | 3.38 | 9.71 | 0.29 | 15.12 | 18.85 | 0.31 | 0.01 | 0.01 | 0.04 | 0.00 | 99.30  | 73.51 |
| YAM002 circle b cpx1     | 229             | 51.81 | 0.57 | 2.37 | 9.54 | 0.29 | 15.52 | 18.86 | 0.33 | 0.02 | n/a  | 0.05 | 0.00 | 99.35  | 74.36 |
| <i>Average</i>           |                 | 51.87 | 0.62 | 2.45 | 9.57 | 0.31 | 15.67 | 18.89 | 0.31 | 0.01 | 0.01 | 0.04 | 0.00 | 99.76  | 74.47 |
|                          |                 |       |      |      |      |      |       |       |      |      |      |      |      |        |       |
| <b>OSCILLATORY ZONED</b> |                 |       |      |      |      |      |       |       |      |      |      |      |      |        |       |
| YAM002 circle b cpx2     | 230 rim         | 52.36 | 0.55 | 2.19 | 8.80 | 0.26 | 16.07 | 19.32 | 0.28 | 0.02 | 0.07 | 0.03 | 0.00 | 99.96  | 76.50 |
| YAM002 circle b cpx2     | 231 next ring 1 | 51.79 | 0.62 | 2.88 | 9.39 | 0.31 | 15.12 | 19.40 | 0.36 | 0.01 | n/a  | 0.07 | 0.00 | 99.92  | 74.17 |
| YAM002 circle b cpx2     | 232 next ring 2 | 52.35 | 0.49 | 1.97 | 9.63 | 0.34 | 15.23 | 19.39 | 0.28 | 0.01 | 0.00 | 0.04 | n/a  | 99.72  | 73.81 |
| YAM002 circle b cpx2     | 233 core        | 51.66 | 0.50 | 2.55 | 9.05 | 0.28 | 15.09 | 19.81 | 0.38 | 0.01 | 0.18 | 0.06 | 0.00 | 99.56  | 74.83 |
|                          |                 |       |      |      |      |      |       |       |      |      |      |      |      |        |       |
| <b>UNZONED</b>           |                 |       |      |      |      |      |       |       |      |      |      |      |      |        |       |
| YAM002 circle a cpx1     | 235             | 50.55 | 0.84 | 3.78 | 9.25 | 0.27 | 15.01 | 19.18 | 0.34 | 0.02 | 0.03 | 0.05 | 0.00 | 99.32  | 74.32 |
| YAM002 circle a cpx1     | 236             | 51.90 | 0.63 | 2.27 | 9.61 | 0.36 | 15.36 | 19.24 | 0.28 | 0.02 | 0.01 | 0.02 | n/a  | 99.67  | 74.02 |
| YAM002 circle a cpx1     | 237             | 51.01 | 0.82 | 3.47 | 9.99 | 0.27 | 15.30 | 19.04 | 0.30 | 0.02 | 0.02 | 0.05 | 0.00 | 100.29 | 73.20 |
| YAM002 circle a cpx1     | 238             | 51.43 | 0.66 | 3.13 | 9.05 | 0.28 | 15.18 | 19.45 | 0.31 | 0.02 | 0.02 | 0.05 | 0.00 | 99.58  | 74.95 |

|                           |                                         |             |             |              |            |            |            |            |             |            |              |             |            |              |            |
|---------------------------|-----------------------------------------|-------------|-------------|--------------|------------|------------|------------|------------|-------------|------------|--------------|-------------|------------|--------------|------------|
| <i>Average</i>            |                                         | 51.22       | 0.74        | 3.16         | 9.47       | 0.30       | 15.21      | 19.23      | 0.31        | 0.02       | 0.02         | 0.04        | 0.00       | 99.72        | 74.12      |
|                           |                                         |             |             |              |            |            |            |            |             |            |              |             |            |              |            |
| <b>UNZONED</b>            |                                         |             |             |              |            |            |            |            |             |            |              |             |            |              |            |
| YAM002 circle a cpx2      | 239                                     | 51.32       | 0.66        | 3.15         | 8.75       | 0.25       | 15.46      | 19.35      | 0.34        | 0.01       | 0.07         | 0.06        | 0.00       | 99.44        | 75.89      |
| YAM002 circle a cpx2      | 240                                     | 52.53       | 0.47        | 1.92         | 9.93       | 0.37       | 15.81      | 18.64      | 0.25        | 0.01       | 0.00         | 0.04        | 0.00       | 99.97        | 73.94      |
| YAM002 circle a cpx2      | 241                                     | 50.90       | 0.79        | 3.26         | 9.22       | 0.30       | 15.23      | 19.44      | 0.33        | 0.01       | 0.00         | 0.05        | 0.01       | 99.54        | 74.64      |
| YAM002 circle a cpx2      | 242                                     | 51.19       | 0.69        | 2.76         | 9.80       | 0.30       | 15.30      | 19.22      | 0.33        | 0.01       | 0.01         | 0.05        | 0.00       | 99.66        | 73.57      |
| <i>Average</i>            |                                         | 51.34       | 0.70        | 2.99         | 9.45       | 0.30       | 15.32      | 19.20      | 0.31        | 0.02       | 0.02         | 0.05        | 0.00       | 99.69        | 74.29      |
|                           |                                         |             |             |              |            |            |            |            |             |            |              |             |            |              |            |
| <b>OPX</b>                | <b>Analysis point<br/>(description)</b> | <b>SiO2</b> | <b>TiO2</b> | <b>Al2O3</b> | <b>FeO</b> | <b>MnO</b> | <b>MgO</b> | <b>CaO</b> | <b>Na2O</b> | <b>K2O</b> | <b>Cr2O3</b> | <b>V2O3</b> | <b>NiO</b> | <b>TOTAL</b> | <b>Mg#</b> |
|                           |                                         | 0.01        | 0.01        | 0.01         | 0.02       | 0.02       | 0.01       | 0.01       | 0.02        | 0.01       | 0.02         | 0.02        | 0.01       |              |            |
| <b>UNZONED</b>            |                                         |             |             |              |            |            |            |            |             |            |              |             |            |              |            |
| YAM002 circle a opx core1 | 243                                     | 53.19       | 0.32        | 1.83         | 16.34      | 0.42       | 25.46      | 1.58       | 0.03        | 0.02       | 0.02         | 0.01        | 0.02       | 99.24        | 73.53      |
| YAM002 circle a opx core1 | 244                                     | 53.07       | 0.36        | 1.95         | 16.26      | 0.43       | 25.26      | 1.83       | 0.10        | 0.04       | 0.00         | 0.01        | 0.00       | 99.31        | 73.47      |
| YAM002 circle a opx core1 | 245                                     | 54.78       | 0.30        | 1.72         | 16.87      | 0.45       | 26.38      | 1.54       | 0.02        | 0.01       | 0.02         | 0.03        | 0.01       | 102.12       | 73.60      |
| YAM002 circle a opx core1 | 246                                     | 54.95       | 0.33        | 1.95         | 16.09      | 0.45       | 26.53      | 1.56       | 0.01        | 0.02       | 0.00         | 0.03        | 0.01       | 101.94       | 74.62      |
| <i>Average</i>            |                                         | 54.00       | 0.33        | 1.86         | 16.39      | 0.44       | 25.91      | 1.63       | 0.04        | 0.02       | 0.01         | 0.02        | 0.01       | 100.65       | 73.80      |
|                           |                                         |             |             |              |            |            |            |            |             |            |              |             |            |              |            |
| <b>UNZONED</b>            |                                         |             |             |              |            |            |            |            |             |            |              |             |            |              |            |
| YAM002 circle a opx core2 | 247                                     | 53.54       | 0.28        | 1.43         | 16.77      | 0.47       | 25.74      | 1.54       | 0.02        | 0.02       | 0.01         | 0.02        | 0.00       | 99.84        | 73.23      |
| YAM002 circle a opx core2 | 248                                     | 53.86       | 0.26        | 1.24         | 16.39      | 0.50       | 25.94      | 1.53       | 0.02        | 0.02       | n/a          | 0.03        | 0.00       | 99.79        | 73.83      |
| YAM002 circle a opx core2 | 249                                     | 54.27       | 0.22        | 1.12         | 16.45      | 0.42       | 26.10      | 1.58       | 0.02        | 0.01       | 0.00         | 0.00        | 0.00       | 100.19       | 73.87      |
| YAM002 circle a opx core2 | 250                                     | 54.50       | 0.23        | 1.00         | 16.30      | 0.47       | 26.31      | 1.59       | 0.02        | 0.02       | 0.00         | 0.00        | 0.00       | 100.44       | 74.20      |
| <i>Average</i>            |                                         | 54.04       | 0.25        | 1.20         | 16.48      | 0.46       | 26.02      | 1.56       | 0.02        | 0.02       | 0.00         | 0.01        | 0.00       | 100.07       | 73.78      |
|                           |                                         |             |             |              |            |            |            |            |             |            |              |             |            |              |            |
| <b>OSCILLATORY ZONED</b>  |                                         |             |             |              |            |            |            |            |             |            |              |             |            |              |            |
| YAM002 circle a opx       | 251 core (Mg rich)                      | 54.64       | 0.25        | 1.10         | 15.83      | 0.45       | 26.88      | 1.61       | 0.02        | 0.02       | 0.00         | 0.01        | 0.01       | 100.81       | 75.17      |
| YAM002 circle a opx       | 255 (Mg poor near core)                 | 53.27       | 0.37        | 2.13         | 16.50      | 0.47       | 25.56      | 1.65       | 0.01        | 0.01       | 0.01         | 0.04        | 0.00       | 100.01       | 73.41      |
| YAM002 circle a opx       | 252 (Mg poor)                           | 53.22       | 0.40        | 1.96         | 16.44      | 0.44       | 25.27      | 2.17       | 0.04        | 0.03       | n/a          | 0.03        | n/a        | 99.97        | 73.26      |
| YAM002 circle a opx       | 254 (Mg rich towards core)              | 53.17       | 0.31        | 2.08         | 15.45      | 0.42       | 26.51      | 1.47       | 0.02        | 0.02       | 0.01         | 0.03        | 0.00       | 99.49        | 75.35      |
| YAM002 circle a opx       | 253 (Mg poor towards rim)               | 53.10       | 0.35        | 2.32         | 16.32      | 0.37       | 26.12      | 1.52       | 0.02        | 0.02       | n/a          | 0.03        | 0.01       | 100.16       | 74.05      |
| <i>Average</i>            |                                         |             |             |              |            |            |            |            |             |            |              |             |            |              |            |
|                           |                                         |             |             |              |            |            |            |            |             |            |              |             |            |              |            |

|                           |     |              |             |             |              |             |              |             |             |             |             |             |             |               |              |  |
|---------------------------|-----|--------------|-------------|-------------|--------------|-------------|--------------|-------------|-------------|-------------|-------------|-------------|-------------|---------------|--------------|--|
| <b>UNZONED</b>            |     |              |             |             |              |             |              |             |             |             |             |             |             |               |              |  |
| YAM002 circle b opx core1 | 261 | 54.17        | 0.27        | 1.60        | 16.53        | 0.48        | 26.02        | 1.49        | 0.02        | 0.00        | n/a         | 0.01        | 0.01        | 100.59        | 73.72        |  |
| YAM002 circle b opx core1 | 262 | 54.10        | 0.33        | 1.65        | 16.59        | 0.47        | 25.99        | 1.57        | 0.01        | 0.01        | 0.02        | 0.01        | n/a         | 100.74        | 73.64        |  |
| YAM002 circle b opx core1 | 263 | 53.52        | 0.29        | 1.36        | 16.17        | 0.51        | 25.82        | 1.65        | 0.03        | 0.02        | 0.04        | 0.02        | 0.00        | 99.41         | 74.00        |  |
| YAM002 circle b opx core1 | 264 | 53.97        | 0.27        | 1.44        | 16.26        | 0.49        | 26.11        | 1.51        | 0.04        | 0.02        | 0.00        | 0.02        | 0.01        | 100.14        | 74.11        |  |
| <i>Average</i>            |     | <i>53.94</i> | <i>0.29</i> | <i>1.51</i> | <i>16.39</i> | <i>0.49</i> | <i>25.98</i> | <i>1.56</i> | <i>0.02</i> | <i>0.01</i> | <i>0.02</i> | <i>0.01</i> | <i>0.01</i> | <i>100.22</i> | <i>73.87</i> |  |
|                           |     |              |             |             |              |             |              |             |             |             |             |             |             |               |              |  |
| <b>UNZONED</b>            |     |              |             |             |              |             |              |             |             |             |             |             |             |               |              |  |
| YAM002 circle b opx core2 | 265 | 54.02        | 0.29        | 1.50        | 16.53        | 0.44        | 26.00        | 1.57        | 0.01        | 0.01        | 0.00        | 0.01        | n/a         | 100.36        | 73.71        |  |
| YAM002 circle b opx core2 | 266 | 53.79        | 0.32        | 1.52        | 17.70        | 0.56        | 25.11        | 1.54        | 0.02        | 0.01        | 0.01        | 0.04        | 0.00        | 100.62        | 71.66        |  |
| YAM002 circle b opx core2 | 267 | 53.49        | 0.34        | 1.44        | 17.19        | 0.51        | 25.07        | 1.95        | 0.02        | 0.03        | 0.01        | 0.02        | n/a         | 100.07        | 72.22        |  |
| YAM002 circle b opx core2 | 268 | 53.22        | 0.32        | 1.56        | 17.17        | 0.52        | 25.21        | 1.96        | 0.04        | 0.02        | 0.02        | 0.01        | n/a         | 100.04        | 72.36        |  |
| YAM002 circle b opx core2 | 269 | 52.89        | 0.30        | 1.76        | 17.86        | 0.53        | 24.76        | 1.63        | 0.03        | 0.01        | 0.00        | 0.02        | n/a         | 99.78         | 71.20        |  |
| <i>Average</i>            |     | <i>53.48</i> | <i>0.31</i> | <i>1.55</i> | <i>17.29</i> | <i>0.51</i> | <i>25.23</i> | <i>1.73</i> | <i>0.02</i> | <i>0.02</i> | <i>0.01</i> | <i>0.02</i> | <i>0.00</i> | <i>100.17</i> | <i>72.23</i> |  |
|                           |     |              |             |             |              |             |              |             |             |             |             |             |             |               |              |  |
| <b>UNZONED</b>            |     |              |             |             |              |             |              |             |             |             |             |             |             |               |              |  |
| YAM002 circle c opx core  | 274 | 53.92        | 0.24        | 1.21        | 16.29        | 0.51        | 25.66        | 1.60        | 0.01        | 0.02        | 0.03        | 0.00        | n/a         | 99.50         | 73.74        |  |
| YAM002 circle c opx core  | 275 | 54.07        | 0.27        | 1.33        | 16.73        | 0.52        | 25.88        | 1.60        | 0.04        | 0.03        | 0.01        | 0.01        | 0.01        | 100.49        | 73.38        |  |
| YAM002 circle c opx core  | 276 | 53.29        | 0.34        | 1.71        | 16.67        | 0.48        | 25.50        | 1.85        | 0.00        | 0.02        | 0.02        | 0.04        | 0.00        | 99.90         | 73.17        |  |
| YAM002 circle c opx core  | 277 | 53.73        | 0.27        | 1.57        | 16.81        | 0.49        | 26.08        | 1.58        | 0.03        | 0.02        | 0.00        | 0.00        | 0.00        | 100.59        | 73.44        |  |
| <i>Average</i>            |     | <i>53.75</i> | <i>0.28</i> | <i>1.45</i> | <i>16.63</i> | <i>0.50</i> | <i>25.78</i> | <i>1.66</i> | <i>0.02</i> | <i>0.02</i> | <i>0.02</i> | <i>0.01</i> | <i>0.00</i> | <i>100.12</i> | <i>73.44</i> |  |

**Table A4.3-3. Major element composition of magnetite determined by EPMA**

| SAMPLE ID                            | Analysis point ID | TiO2         | MgO         | MnO         | Cr2O3       | V2O3        | Al2O3       | SiO2        | FeO (T) <sup>a</sup> | NiO         | CaO         | Na2O        | K2O         | O           | TOTAL         | FeO <sup>b</sup> wt% | Fe2O3 <sup>b</sup> wt% |
|--------------------------------------|-------------------|--------------|-------------|-------------|-------------|-------------|-------------|-------------|----------------------|-------------|-------------|-------------|-------------|-------------|---------------|----------------------|------------------------|
| <b>Detection limit (all samples)</b> |                   | <b>0.01</b>  | <b>0.02</b> | <b>0.02</b> | <b>0.02</b> | <b>0.02</b> | <b>0.01</b> | <b>0.01</b> | <b>0.02</b>          | <b>0.01</b> | <b>0.01</b> | <b>0.02</b> | <b>0.01</b> |             |               |                      |                        |
| <b>sample 220621-6</b>               |                   |              |             |             |             |             |             |             |                      |             |             |             |             |             |               |                      |                        |
| 220621-6 circle b oxide              | 376               | 10.05        | 1.36        | 0.38        | 0.09        | 0.69        | 2.86        | 0.17        | 80.38                | 0.01        | 0.03        | bdl         | 0.02        | 4.63        | 100.66        | 38.79                | 46.22                  |
| 220621-6 circle b oxide              | 377               | 10.27        | 1.35        | 0.37        | 0.08        | 0.67        | 2.92        | 0.07        | 80.70                | 0.03        | 0.02        | bdl         | 0.03        | 4.64        | 101.16        | 39.00                | 46.34                  |
| 220621-6 circle b oxide              | 378               | 10.23        | 1.34        | 0.40        | 0.09        | 0.72        | 2.85        | 0.10        | 80.02                | 0.00        | 0.05        | 0.02        | 0.05        | 4.61        | 100.47        | 38.59                | 46.04                  |
| 220621-6 circle b oxide              | 379               | 10.33        | 1.37        | 0.39        | 0.11        | 0.69        | 2.80        | 0.14        | 80.09                | 0.01        | 0.04        | bdl         | 0.06        | 4.59        | 100.60        | 38.83                | 45.85                  |
| <i>Average</i>                       |                   | <i>10.22</i> | <i>1.35</i> | <i>0.38</i> | <i>0.09</i> | <i>0.69</i> | <i>2.86</i> | <i>0.12</i> | <i>80.30</i>         | <i>0.01</i> | <i>0.04</i> | <i>0.00</i> | <i>0.04</i> | <i>4.62</i> | <i>100.72</i> | <i>38.80</i>         | <i>46.11</i>           |
|                                      |                   |              |             |             |             |             |             |             |                      |             |             |             |             |             |               |                      |                        |
| 220621-6 circle a oxide1             | 386               | 11.48        | 1.67        | 0.45        | 0.07        | 0.67        | 2.35        | 0.02        | 81.10                | 0.01        | 0.01        | 0.00        | 0.02        | 4.60        | 102.44        | 39.82                | 45.88                  |
| 220621-6 circle a oxide1             | 387               | 11.44        | 1.65        | 0.41        | 0.06        | 0.68        | 2.48        | 0.04        | 79.76                | 0.00        | 0.03        | bdl         | 0.03        | 4.49        | 101.06        | 39.48                | 44.77                  |



|                                    |                   |       |      |      |       |      |       |      |          |      |      |      |      |      |        |          |            |
|------------------------------------|-------------------|-------|------|------|-------|------|-------|------|----------|------|------|------|------|------|--------|----------|------------|
| 220621-6 circle a oxide1           | 388               | 11.37 | 1.70 | 0.40 | 0.07  | 0.64 | 2.39  | 0.04 | 80.67    | 0.01 | 0.02 | bdl  | 0.03 | 4.56 | 101.86 | 39.68    | 45.56      |
| 220621-6 circle a oxide1           | 389               | 11.55 | 1.59 | 0.44 | 0.06  | 0.69 | 2.43  | 0.06 | 79.53    | 0.02 | 0.01 | 0.02 | 0.03 | 4.46 | 100.88 | 39.48    | 44.51      |
| Average                            |                   | 11.46 | 1.65 | 0.43 | 0.06  | 0.67 | 2.41  | 0.04 | 80.27    | 0.01 | 0.02 | 0.01 | 0.03 | 4.53 | 101.56 | 39.61    | 45.18      |
|                                    |                   |       |      |      |       |      |       |      |          |      |      |      |      |      |        |          |            |
| sample 220620-4                    | Analysis point ID | TiO2  | MgO  | MnO  | Cr2O3 | V2O3 | Al2O3 | SiO2 | FeO (T)a | NiO  | CaO  | Na2O | K2O  | O    | TOTAL  | FeOb wt% | Fe2O3b wt% |
| 220620-4 circle a oxide inclusion  | 431               | 8.39  | 2.87 | 0.37 | 0.40  | 0.85 | 5.03  | 0.32 | 75.74    | 0.02 | 0.01 | 0.00 | 0.02 | 4.55 | 98.56  | 34.84    | 45.46      |
| 220620-4 circle a oxide inclusion  | 432               | 7.90  | 3.36 | 0.35 | 0.42  | 0.84 | 4.89  | 1.03 | 75.40    | 0.03 | 0.06 | bdl  | 0.03 | 4.54 | 98.85  | 34.61    | 45.34      |
| Average                            |                   | 8.14  | 3.11 | 0.36 | 0.41  | 0.84 | 4.96  | 0.67 | 75.57    | 0.03 | 0.04 | 0.00 | 0.02 | 4.55 | 98.70  | 34.72    | 45.40      |
|                                    |                   |       |      |      |       |      |       |      |          |      |      |      |      |      |        |          |            |
| 220620-4 circle a oxide            | 438               | 17.37 | 1.49 | 0.53 | 0.03  | 0.93 | 2.04  | 0.11 | 73.27    | 0.00 | 0.06 | bdl  | 0.04 | 3.20 | 99.01  | 44.57    | 31.90      |
| 220620-4 circle a oxide            | 441               | 17.83 | 1.38 | 0.46 | 0.06  | 0.83 | 2.00  | 0.15 | 73.49    | 0.00 | 0.08 | 0.03 | 0.07 | 3.17 | 99.55  | 45.03    | 31.62      |
| Average                            |                   | 17.60 | 1.43 | 0.50 | 0.05  | 0.88 | 2.02  | 0.13 | 73.38    | 0.00 | 0.07 | bdl  | 0.05 | 3.18 | 99.28  | 44.80    | 31.76      |
|                                    |                   |       |      |      |       |      |       |      |          |      |      |      |      |      |        |          |            |
| 220620-4 circle a oxide2           | 442               | 17.55 | 1.99 | 0.49 | 0.05  | 1.03 | 2.20  | 0.05 | 73.22    | 0.01 | 0.02 | 0.03 | 0.02 | 3.25 | 99.91  | 44.05    | 32.42      |
| 220620-4 circle a oxide2           | 443               | 18.26 | 1.82 | 0.49 | 0.05  | 0.95 | 2.11  | 0.10 | 72.64    | 0.01 | 0.03 | 0.01 | 0.04 | 3.09 | 99.59  | 44.93    | 30.80      |
| 220620-4 circle a oxide2           | 444               | 17.83 | 1.73 | 0.47 | 0.05  | 0.94 | 2.14  | 0.08 | 73.59    | 0.00 | 0.06 | 0.00 | 0.04 | 3.20 | 100.15 | 44.81    | 31.99      |
| 220620-4 circle a oxide2           | 445               | 17.91 | 1.85 | 0.45 | 0.06  | 0.97 | 2.17  | 0.10 | 73.46    | 0.00 | 0.05 | bdl  | 0.04 | 3.18 | 100.23 | 44.88    | 31.77      |
| Average                            |                   | 17.89 | 1.85 | 0.48 | 0.05  | 0.97 | 2.15  | 0.08 | 73.23    | 0.01 | 0.04 | 0.01 | 0.03 | 3.18 | 99.97  | 44.67    | 31.74      |
|                                    |                   |       |      |      |       |      |       |      |          |      |      |      |      |      |        |          |            |
| 220620-4 circle a oxide3           | 451               | 18.30 | 1.88 | 0.53 | 0.05  | 0.92 | 2.17  | 0.07 | 73.84    | 0.00 | 0.02 | 0.01 | 0.03 | 3.18 | 101.01 | 45.26    | 31.77      |
| 220620-4 circle a oxide3           | 452               | 18.15 | 1.73 | 0.49 | 0.06  | 0.94 | 2.08  | 0.13 | 73.84    | 0.00 | 0.03 | 0.02 | 0.03 | 3.18 | 100.66 | 45.33    | 31.69      |
| 220620-4 circle a oxide3           | 453               | 17.95 | 1.66 | 0.52 | 0.05  | 0.92 | 2.15  | 0.12 | 74.30    | 0.00 | 0.05 | bdl  | 0.05 | 3.22 | 100.95 | 45.41    | 32.11      |
| 220620-4 circle a oxide3           | 454               | 17.94 | 1.77 | 0.52 | 0.06  | 0.96 | 2.17  | 0.09 | 73.80    | 0.01 | 0.06 | 0.00 | 0.03 | 3.20 | 100.61 | 45.03    | 31.98      |
| 220620-4 circle a oxide3           | 455               | 17.74 | 1.74 | 0.53 | 0.04  | 0.98 | 2.17  | 0.14 | 73.77    | 0.02 | 0.06 | 0.02 | 0.06 | 3.23 | 100.50 | 44.72    | 32.29      |
| Average                            |                   | 18.01 | 1.76 | 0.52 | 0.05  | 0.94 | 2.15  | 0.11 | 73.91    | 0.01 | 0.05 | 0.00 | 0.04 | 3.20 | 100.75 | 45.15    | 31.97      |
|                                    |                   |       |      |      |       |      |       |      |          |      |      |      |      |      |        |          |            |
| 220620-4 circle a oxide3           | 491               | 18.18 | 1.92 | 0.50 | 0.04  | 0.99 | 2.11  | 0.07 | 74.48    | 0.01 | 0.02 | bdl  | 0.01 | 3.22 | 101.50 | 45.54    | 32.16      |
| 220620-4 circle a oxide3           | 492               | 18.06 | 1.76 | 0.52 | 0.02  | 1.01 | 2.03  | 0.12 | 73.91    | bdl  | 0.03 | 0.03 | 0.04 | 3.21 | 100.74 | 45.09    | 32.04      |
| 220620-4 circle a oxide3           | 493               | 18.00 | 1.66 | 0.50 | 0.04  | 0.98 | 2.09  | 0.10 | 74.31    | 0.01 | 0.06 | 0.02 | 0.05 | 3.24 | 101.07 | 45.23    | 32.32      |
| 220620-4 circle a oxide3           | 494               | 18.11 | 1.81 | 0.45 | 0.04  | 0.96 | 2.14  | 0.09 | 74.27    | bdl  | 0.06 | 0.00 | 0.04 | 3.22 | 101.18 | 45.35    | 32.14      |
| 220620-4 circle a oxide3           | 495               | 17.86 | 1.78 | 0.48 | 0.04  | 0.95 | 2.18  | 0.13 | 74.21    | 0.01 | 0.06 | bdl  | 0.05 | 3.23 | 100.97 | 45.19    | 32.26      |
| Average                            |                   | 18.04 | 1.78 | 0.49 | 0.03  | 0.98 | 2.11  | 0.10 | 74.24    | 0.01 | 0.05 | 0.00 | 0.04 | 3.22 | 101.09 | 45.28    | 32.18      |
|                                    |                   |       |      |      |       |      |       |      |          |      |      |      |      |      |        |          |            |
| 220620-4 circle c oxide inclusion1 | 496               | 10.63 | 3.46 | 0.42 | 0.26  | 0.94 | 4.27  | 0.11 | 76.54    | 0.02 | 0.02 | bdl  | 0.03 | 4.48 | 101.17 | 36.35    | 44.67      |
| 220620-4 circle c oxide inclusion1 | 497               | 10.75 | 3.30 | 0.37 | 0.24  | 0.93 | 4.34  | 0.13 | 75.44    | 0.02 | 0.00 | 0.02 | 0.02 | 4.35 | 99.91  | 36.35    | 43.45      |
| 220620-4 circle c oxide inclusion1 | 498               | 10.74 | 3.46 | 0.38 | 0.24  | 0.93 | 4.29  | 0.06 | 75.17    | 0.00 | 0.01 | bdl  | 0.02 | 4.35 | 99.61  | 36.13    | 43.39      |

|                                    |                          |             |            |            |              |             |              |             |                 |            |            |             |            |          |              |                 |                   |
|------------------------------------|--------------------------|-------------|------------|------------|--------------|-------------|--------------|-------------|-----------------|------------|------------|-------------|------------|----------|--------------|-----------------|-------------------|
| 220620-4 circle c oxide inclusion1 | 499                      | 10.67       | 3.48       | 0.39       | 0.26         | 0.92        | 4.23         | 0.25        | 75.36           | 0.01       | 0.02       | 0.00        | 0.02       | 4.36     | 99.97        | 36.20           | 43.53             |
| <i>Average</i>                     |                          | 10.70       | 3.42       | 0.39       | 0.25         | 0.93        | 4.28         | 0.14        | 75.63           | 0.01       | 0.01       | 0.01        | 0.02       | 4.38     | 100.16       | 36.26           | 43.76             |
|                                    |                          |             |            |            | 0.17         |             |              |             |                 |            |            |             |            |          |              |                 |                   |
| 220620-4 circle c oxide inclusion2 | 513                      | 14.93       | 2.73       | 0.47       | 0.06         | 0.95        | 2.74         | 0.08        | 74.14           | bdl        | 0.02       | bdl         | 0.03       | 3.72     | 99.86        | 40.75           | 37.11             |
| 220620-4 circle c oxide inclusion2 | 514                      | 14.87       | 2.76       | 0.44       | 0.05         | 0.95        | 2.70         | 0.09        | 75.04           | 0.01       | 0.00       | bdl         | 0.02       | 3.79     | 100.71       | 41.01           | 37.82             |
| 220620-4 circle c oxide inclusion2 | 515                      | 14.38       | 2.61       | 0.44       | 0.07         | 0.95        | 2.89         | 0.10        | 73.47           | 0.02       | 0.03       | bdl         | 0.03       | 3.71     | 98.67        | 40.15           | 37.02             |
| 220620-4 circle c oxide inclusion2 | 516                      | 15.06       | 2.64       | 0.47       | 0.08         | 0.97        | 2.91         | 0.11        | 74.04           | 0.00       | 0.02       | 0.03        | 0.03       | 3.68     | 100.05       | 40.95           | 36.77             |
| <i>Average</i>                     |                          | 14.81       | 2.69       | 0.46       | 0.07         | 0.95        | 2.81         | 0.09        | 74.17           | 0.01       | 0.02       | 0.03        | 0.02       | 3.73     | 99.82        | 40.72           | 37.18             |
|                                    |                          |             |            |            |              |             |              |             |                 |            |            |             |            |          |              |                 |                   |
| 220620-4 circle b oxide inclusion1 | 526                      | 15.38       | 2.96       | 0.49       | 0.07         | 1.11        | 2.87         | 0.08        | 73.23           | bdl        | 0.01       | 0.01        | 0.03       | 3.62     | 99.84        | 40.73           | 36.12             |
| 220620-4 circle b oxide inclusion1 | 527                      | 15.58       | 2.96       | 0.49       | 0.05         | 1.07        | 2.82         | 0.08        | 72.83           | 0.00       | 0.01       | bdl         | 0.03       | 3.54     | 99.40        | 41.04           | 35.34             |
| 220620-4 circle b oxide inclusion1 | 528                      | 16.39       | 2.96       | 0.47       | 0.07         | 1.10        | 2.79         | 0.07        | 74.22           | 0.00       | 0.01       | 0.00        | 0.02       | 3.55     | 101.66       | 42.30           | 35.48             |
| 220620-4 circle b oxide inclusion1 | 529                      | 16.82       | 2.77       | 0.47       | 0.06         | 1.06        | 2.76         | 0.11        | 74.07           | 0.01       | 0.03       | bdl         | 0.02       | 3.46     | 101.62       | 43.03           | 34.49             |
| <i>Average</i>                     |                          | 16.04       | 2.91       | 0.48       | 0.06         | 1.08        | 2.81         | 0.08        | 73.59           | 0.00       | 0.01       | 0.00        | 0.02       | 3.54     | 100.63       | 41.77           | 35.35             |
|                                    |                          |             |            |            |              |             |              |             |                 |            |            |             |            |          |              |                 |                   |
| 220620-4 circle b oxide inclusion2 | 539                      | 13.32       | 3.25       | 0.36       | 0.08         | 1.06        | 4.28         | 0.07        | 74.89           | 0.00       | 0.00       | bdl         | 0.03       | 3.95     | 101.27       | 39.39           | 39.45             |
| 220620-4 circle b oxide inclusion2 | 540                      | 12.70       | 3.15       | 0.34       | 0.11         | 0.99        | 4.70         | 0.08        | 74.93           | 0.02       | 0.01       | bdl         | 0.03       | 4.00     | 101.03       | 39.00           | 39.93             |
| 220620-4 circle b oxide inclusion2 | 541                      | 13.42       | 3.11       | 0.40       | 0.10         | 1.08        | 4.06         | 0.12        | 73.61           | 0.01       | 0.02       | 0.01        | 0.03       | 3.85     | 99.82        | 38.99           | 38.48             |
| 220620-4 circle b oxide inclusion2 | 542                      | 13.57       | 3.12       | 0.43       | 0.09         | 1.15        | 4.26         | 0.15        | 74.60           | 0.01       | 0.05       | bdl         | 0.04       | 3.89     | 101.34       | 39.68           | 38.81             |
| <i>Average</i>                     |                          | 13.25       | 3.16       | 0.38       | 0.10         | 1.07        | 4.33         | 0.10        | 74.51           | 0.01       | 0.02       | 0.01        | 0.03       | 3.92     | 100.86       | 39.26           | 39.17             |
|                                    |                          |             |            |            |              |             |              |             |                 |            |            |             |            |          |              |                 |                   |
| <b>sample 220622-1</b>             | <b>Analysis point ID</b> | <b>TiO2</b> | <b>MgO</b> | <b>MnO</b> | <b>Cr2O3</b> | <b>V2O3</b> | <b>Al2O3</b> | <b>SiO2</b> | <b>FeO (T)a</b> | <b>NiO</b> | <b>CaO</b> | <b>Na2O</b> | <b>K2O</b> | <b>O</b> | <b>TOTAL</b> | <b>FeOb wt%</b> | <b>Fe2O3b wt%</b> |
| 220622-1 circle b oxide1           | 556                      | 11.12       | 1.86       | 0.42       | 0.10         | 0.71        | 2.64         | 0.05        | 80.50           | 0.01       | 0.00       | bdl         | 0.03       | 4.60     | 102.02       | 39.20           | 45.89             |
| 220622-1 circle b oxide1           | 557                      | 11.10       | 1.89       | 0.46       | 0.13         | 0.75        | 2.63         | 0.06        | 79.93           | 0.01       | 0.01       | bdl         | 0.02       | 4.56     | 101.53       | 38.99           | 45.50             |
| 220622-1 circle b oxide1           | 558                      | 11.35       | 1.82       | 0.46       | 0.10         | 0.72        | 2.57         | 0.06        | 80.38           | bdl        | 0.02       | bdl         | 0.02       | 4.55     | 102.03       | 39.51           | 45.41             |
| 220622-1 circle b oxide1           | 559                      | 10.21       | 1.90       | 0.40       | 0.10         | 0.69        | 2.71         | 0.05        | 81.41           | 0.01       | 0.02       | bdl         | 0.02       | 4.78     | 102.23       | 38.52           | 47.66             |
| <i>Average</i>                     |                          | 10.95       | 1.86       | 0.44       | 0.11         | 0.72        | 2.64         | 0.05        | 80.55           | 0.00       | 0.01       | bdl         | 0.02       | 4.62     | 101.95       | 39.06           | 46.12             |
|                                    |                          |             |            |            |              |             |              |             |                 |            |            |             |            |          |              |                 |                   |
| 220622-1 circle a oxide1           | 583                      | 10.21       | 0.63       | 0.50       | 0.12         | 0.74        | 1.91         | 0.10        | 82.53           | 0.00       | 0.03       | bdl         | 0.04       | 4.75     | 101.55       | 39.89           | 47.39             |
| 220622-1 circle a oxide1           | 584                      | 10.30       | 0.81       | 0.42       | 0.09         | 0.70        | 2.04         | 0.06        | 81.96           | 0.01       | 0.03       | 0.00        | 0.05       | 4.72     | 101.18       | 39.58           | 47.09             |
| 220622-1 circle a oxide1           | 585                      | 9.66        | 0.68       | 0.44       | 0.11         | 0.67        | 1.96         | 0.07        | 81.34           | 0.01       | 0.11       | 0.00        | 0.03       | 4.75     | 99.82        | 38.67           | 47.41             |

|                                   |                          |             |            |            |              |             |              |             |                 |            |            |             |            |          |              |                 |                   |
|-----------------------------------|--------------------------|-------------|------------|------------|--------------|-------------|--------------|-------------|-----------------|------------|------------|-------------|------------|----------|--------------|-----------------|-------------------|
| 220622-1 circle a oxide1          | 586                      | 9.91        | 0.84       | 0.43       | 0.08         | 0.68        | 2.06         | 0.09        | 81.31           | 0.00       | 0.13       | bdl         | 0.03       | 4.70     | 100.21       | 39.06           | 46.96             |
| <i>Average</i>                    |                          | 10.02       | 0.74       | 0.45       | 0.10         | 0.70        | 1.99         | 0.08        | 81.78           | 0.01       | 0.08       | 0.00        | 0.04       | 4.73     | 100.69       | 39.30           | 47.21             |
|                                   |                          |             |            |            |              |             |              |             |                 |            |            |             |            |          |              |                 |                   |
| <b>sample 220620-3</b>            | <b>Analysis point ID</b> | <b>TiO2</b> | <b>MgO</b> | <b>MnO</b> | <b>Cr2O3</b> | <b>V2O3</b> | <b>Al2O3</b> | <b>SiO2</b> | <b>FeO (T)a</b> | <b>NiO</b> | <b>CaO</b> | <b>Na2O</b> | <b>K2O</b> | <b>O</b> | <b>TOTAL</b> | <b>FeOb wt%</b> | <b>Fe2O3b wt%</b> |
| 220320-3 circle c oxide           | 611                      | 17.93       | 1.55       | 0.46       | 0.14         | 1.05        | 2.15         | 0.09        | 74.01           | 0.01       | 0.03       | 0.03        | 0.02       | 3.19     | 100.66       | 45.37           | 31.83             |
| 220320-3 circle c oxide           | 612                      | 17.71       | 1.58       | 0.45       | 0.13         | 1.05        | 2.19         | 0.07        | 74.97           | 0.00       | 0.05       | 0.00        | 0.03       | 3.29     | 101.52       | 45.46           | 32.80             |
| 220320-3 circle c oxide           | 613                      | 17.79       | 1.47       | 0.52       | 0.11         | 1.01        | 2.15         | 0.10        | 75.29           | 0.02       | 0.09       | 0.02        | 0.04       | 3.31     | 101.91       | 45.57           | 33.03             |
| 220320-3 circle c oxide           | 614                      | 18.18       | 1.49       | 0.45       | 0.12         | 1.00        | 2.16         | 0.10        | 74.72           | bdl        | 0.07       | 0.02        | 0.02       | 3.20     | 101.49       | 46.00           | 31.92             |
| <i>Average</i>                    |                          | 17.90       | 1.52       | 0.47       | 0.13         | 1.03        | 2.16         | 0.09        | 74.75           | 0.01       | 0.06       | 0.02        | 0.03       | 3.25     | 101.39       | 45.60           | 32.39             |
|                                   |                          |             |            |            |              |             |              |             |                 |            |            |             |            |          |              |                 |                   |
| <b>sample 220621-5</b>            | <b>Analysis point ID</b> | <b>TiO2</b> | <b>MgO</b> | <b>MnO</b> | <b>Cr2O3</b> | <b>V2O3</b> | <b>Al2O3</b> | <b>SiO2</b> | <b>FeO (T)a</b> | <b>NiO</b> | <b>CaO</b> | <b>Na2O</b> | <b>K2O</b> | <b>O</b> | <b>TOTAL</b> | <b>FeOb wt%</b> | <b>Fe2O3b wt%</b> |
| 220621-5 circle a oxide inclusion | 619                      | 4.55        | 3.75       | 0.29       | 2.38         | 0.66        | 7.68         | 0.06        | 76.00           | 0.05       | 0.04       | bdl         | 0.02       | 5.03     | 100.46       | 30.85           | 50.18             |
| 220621-5 circle a oxide inclusion | 620                      | 4.45        | 3.72       | 0.28       | 2.42         | 0.67        | 7.70         | 0.08        | 75.01           | 0.04       | 0.02       | 0.03        | 0.01       | 4.98     | 99.39        | 30.28           | 49.71             |
| <i>Average</i>                    |                          | 4.50        | 3.73       | 0.28       | 2.40         | 0.66        | 7.69         | 0.07        | 75.50           | 0.04       | 0.03       | 0.03        | 0.01       | 5.00     | 99.92        | 30.56           | 49.95             |
|                                   |                          |             |            |            |              |             |              |             |                 |            |            |             |            |          |              |                 |                   |
| 220621-5 circle a oxide           | 621                      | 9.87        | 2.41       | 0.41       | 0.06         | 0.71        | 3.05         | 0.06        | 79.39           | 0.01       | 0.02       | bdl         | 0.03       | 4.74     | 100.75       | 36.85           | 47.28             |
| 220621-5 circle a oxide           | 622                      | 9.90        | 2.38       | 0.41       | 0.02         | 0.70        | 3.07         | 0.06        | 78.91           | 0.01       | 0.02       | bdl         | 0.03       | 4.69     | 100.19       | 36.77           | 46.83             |
| 220621-5 circle a oxide           | 623                      | 9.87        | 2.36       | 0.36       | 0.04         | 0.68        | 3.05         | 0.07        | 79.85           | 0.00       | 0.06       | bdl         | 0.03       | 4.76     | 101.11       | 37.10           | 47.51             |
| 220621-5 circle a oxide           | 624                      | 9.88        | 2.43       | 0.37       | 0.02         | 0.69        | 2.96         | 0.07        | 80.21           | 0.01       | 0.12       | 0.00        | 0.02       | 4.81     | 101.60       | 37.00           | 48.02             |
| <i>Average</i>                    |                          | 9.88        | 2.39       | 0.39       | 0.04         | 0.69        | 3.03         | 0.06        | 79.59           | 0.01       | 0.06       | 0.00        | 0.03       | 4.75     | 100.91       | 36.93           | 47.41             |
|                                   |                          |             |            |            |              |             |              |             |                 |            |            |             |            |          |              |                 |                   |
| 220621-5 circle c oxide1          | 638                      | 8.88        | 1.92       | 0.41       | 0.07         | 0.68        | 2.20         | 0.02        | 81.99           | bdl        | 0.02       | bdl         | 0.03       | 5.05     | 101.25       | 36.68           | 50.36             |
| 220621-5 circle c oxide1          | 639                      | 8.79        | 1.86       | 0.42       | 0.07         | 0.68        | 2.19         | 0.06        | 82.04           | 0.01       | 0.01       | bdl         | 0.02       | 5.03     | 101.13       | 36.91           | 50.16             |
| 220621-5 circle c oxide1          | 640                      | 8.96        | 1.85       | 0.44       | 0.07         | 0.66        | 2.21         | 0.05        | 82.00           | bdl        | 0.01       | bdl         | 0.02       | 5.01     | 101.25       | 36.99           | 50.02             |
| 220621-5 circle c oxide1          | 641                      | 8.90        | 1.77       | 0.41       | 0.06         | 0.72        | 2.20         | 0.02        | 81.55           | 0.02       | 0.03       | 0.03        | 0.02       | 5.01     | 100.73       | 36.60           | 49.96             |
| 220621-5 circle c oxide1          | 642                      | 8.93        | 1.77       | 0.37       | 0.07         | 0.67        | 2.29         | 0.05        | 82.23           | 0.00       | 0.02       | bdl         | 0.01       | 5.01     | 101.39       | 37.22           | 50.01             |
| <i>Average</i>                    |                          | 8.89        | 1.83       | 0.41       | 0.07         | 0.68        | 2.22         | 0.04        | 81.96           | 0.00       | 0.02       | 0.03        | 0.02       | 5.02     | 101.15       | 36.88           | 50.10             |

## APPENDIX 4.4 Olivine and Cpx Trace element data determined by LA-ICPMS

nd = not determined

Table A4.4-1. Olivine trace element data for all samples

|                                  |                  |                  |                  |                  |                  |                  |                 |                  |                  |                  |                  |                  |
|----------------------------------|------------------|------------------|------------------|------------------|------------------|------------------|-----------------|------------------|------------------|------------------|------------------|------------------|
| <b>Sample: 220620-3</b>          |                  |                  |                  |                  |                  |                  |                 |                  |                  |                  |                  |                  |
| <b>Group: Mafics West of HK</b>  |                  |                  |                  |                  |                  |                  |                 |                  |                  |                  |                  |                  |
| <b>Lithology: Basalt</b>         |                  |                  |                  |                  |                  |                  |                 |                  |                  |                  |                  |                  |
| <b>Standard: 170000 29Si ppm</b> |                  |                  |                  |                  |                  |                  |                 |                  |                  |                  |                  |                  |
|                                  | Li<br><i>ppm</i> | Na<br><i>ppm</i> | Al<br><i>ppm</i> | Ca<br><i>ppm</i> | Sc<br><i>ppm</i> | Ti<br><i>ppm</i> | V<br><i>ppm</i> | Cr<br><i>ppm</i> | Mn<br><i>ppm</i> | Co<br><i>ppm</i> | Ni<br><i>ppm</i> | Zn<br><i>ppm</i> |
| Avg Detection<br>limit (ppm)     | 5.74             | 15.43            | 0.70             | 53.97            | 0.09             | 0.29             | 0.03            | 0.55             | 0.18             | 0.03             | 0.35             | 0.33             |
| Grain#                           |                  |                  |                  |                  |                  |                  |                 |                  |                  |                  |                  |                  |
| 1                                | 8.7              | 23               | 85               | 961              | 12               | 70               | 12              | 22               | 3067             | 173              | 267              | 223              |
| 2                                | 8.0              | 23               | 90               | 917              | 11               | 73               | 13              | 16               | 2746             | 178              | 306              | 204              |
| 3                                | 7.3              | 20               | 78               | 883              | 10               | 64               | 11              | 20               | 2718             | 165              | 267              | 182              |
| 4                                | 7.4              | 20               | 72               | 759              | 9                | 59               | 12              | 18               | 2733             | 177              | 299              | 217              |
| 5                                | 5.4              | 30               | 101              | 927              | 11               | 34               | 13              | 25               | 2845             | 187              | nd               | nd               |
| AVG                              | 7.4              | 23               | 85               | 889              | 11               | 60               | 12              | 20               | 2822             | 176              | 285              | 206              |
| MIN                              | 5.4              | 20               | 72               | 759              | 9                | 34               | 11              | 16               | 2718             | 165              | 267              | 182              |
| MAX                              | 8.7              | 30               | 101              | 961              | 12               | 73               | 13              | 25               | 3067             | 187              | 306              | 223              |
| <b>Sample: 220620-1</b>          |                  |                  |                  |                  |                  |                  |                 |                  |                  |                  |                  |                  |
| <b>Group: Mafics West of HK</b>  |                  |                  |                  |                  |                  |                  |                 |                  |                  |                  |                  |                  |
| <b>Lithology: Basalt</b>         |                  |                  |                  |                  |                  |                  |                 |                  |                  |                  |                  |                  |
| <b>Standard: 175000 29Si ppm</b> |                  |                  |                  |                  |                  |                  |                 |                  |                  |                  |                  |                  |
|                                  | Li<br><i>ppm</i> | Na<br><i>ppm</i> | Al<br><i>ppm</i> | Ca<br><i>ppm</i> | Sc<br><i>ppm</i> | Ti<br><i>ppm</i> | V<br><i>ppm</i> | Cr<br><i>ppm</i> | Mn<br><i>ppm</i> | Co<br><i>ppm</i> | Ni<br><i>ppm</i> | Zn<br><i>ppm</i> |
| Avg Detection<br>limit (ppm)     | 2.86             | 7.96             | 0.44             | 34.43            | 0.08             | 0.22             | 0.02            | 0.46             | 0.14             | 0.02             | 0.28             | 0.22             |
| Grain#                           |                  |                  |                  |                  |                  |                  |                 |                  |                  |                  |                  |                  |
| 1 (n=2)                          | 4.5              | 12               | 93               | 1083             | 12               | 46               | 12              | 19               | 2725             | 175              | 345              | 179              |



|                                     |      |       |      |       |      |      |      |      |      |      |      |      |
|-------------------------------------|------|-------|------|-------|------|------|------|------|------|------|------|------|
| 2                                   | 5.1  | 11    | 115  | 1062  | 12   | 45   | 13   | 16   | 2875 | 182  | 359  | 183  |
| 3                                   | 4.3  | 14    | 94   | 1212  | 11   | 36   | 13   | 30   | 2892 | 180  | 425  | 182  |
| 4 (n=2)                             | 3.6  | 24    | 100  | 978   | 10   | 26   | 10   | 56   | 2417 | 166  | 623  | 173  |
| 5                                   | 2.7  | 15    | 89   | 862   | 8.1  | 31   | 7.5  | 34   | 2086 | 160  | 543  | 161  |
| 6                                   | 5.3  | 24    | 93   | 1141  | 9.4  | 29   | 9.4  | 29   | 2454 | 184  | 568  | 176  |
| 7                                   | 3.1  | 11    | 79   | 1200  | 12   | 37   | 11   | 27   | 2962 | 182  | 425  | 186  |
| 8                                   | 3.3  | 35    | 88   | 909   | 10   | 35   | 11   | 24   | 2676 | 176  | 427  | 186  |
| 9                                   | 5.8  | 27    | 128  | 912   | 11   | 33   | 17   | 25   | 2916 | 206  | nd   | nd   |
| 10                                  | 4.3  | 23    | 90   | 892   | 10   | 23   | 10   | 70   | 2628 | 196  | nd   | nd   |
| 11                                  | 4.9  | 28    | 82   | 1052  | 9.3  | 24   | 8.5  | 105  | 2535 | 187  | nd   | nd   |
| 12                                  | 6.0  | 26    | 73   | 960   | 10   | 35   | 11   | 12   | 3021 | 195  | nd   | nd   |
| AVG                                 | 4.4  | 21    | 94   | 1022  | 10   | 33   | 11   | 37   | 2682 | 182  | 464  | 178  |
| MIN                                 | 2.7  | 11    | 73   | 862   | 8.1  | 23   | 7.5  | 12   | 2086 | 160  | 345  | 161  |
| MAX                                 | 6.0  | 35    | 128  | 1212  | 12   | 46   | 17   | 105  | 3021 | 206  | 623  | 186  |
| <b>Sample: 220620-4</b>             |      |       |      |       |      |      |      |      |      |      |      |      |
| <b>Group: Mafics West of HK</b>     |      |       |      |       |      |      |      |      |      |      |      |      |
| <b>Lithology: Basaltic Andesite</b> |      |       |      |       |      |      |      |      |      |      |      |      |
| <b>Standard: 160000 29Si ppm</b>    |      |       |      |       |      |      |      |      |      |      |      |      |
|                                     | Li   | Na    | Al   | Ca    | Sc   | Ti   | V    | Cr   | Mn   | Co   | Ni   | Zn   |
|                                     | ppm  | ppm   | ppm  | ppm   | ppm  | ppm  | ppm  | ppm  | ppm  | ppm  | ppm  | ppm  |
| Avg Detection                       |      |       |      |       |      |      |      |      |      |      |      |      |
| Limit (ppm)                         | 6.32 | 17.27 | 0.77 | 61.16 | 0.10 | 0.38 | 0.03 | 0.62 | 0.20 | 0.03 | 0.38 | 0.36 |
| Grain#                              |      |       |      |       |      |      |      |      |      |      |      |      |
| 1                                   | 7.4  | 20    | 114  | 1466  | 15   | 90   | 11   | 0.7  | 3991 | 168  | 169  | 292  |
| 2                                   | 6.4  | 17    | 63   | 1439  | 15   | 75   | 12   | 0.9  | 4115 | 168  | 145  | 293  |
| 3                                   | 12   | 20    | 141  | 1179  | 14   | 70   | 11   | 2.6  | 3806 | 161  | 162  | 285  |
| 4                                   | 7.7  | 17    | 65   | 921   | 11   | 60   | 13   | 1.7  | 3251 | 172  | 249  | 256  |
| 5                                   | 5.7  | 16    | 65   | 954   | 11   | 65   | 8.3  | 1.0  | 3103 | 165  | 201  | 215  |
| 6                                   | 8.5  | 21    | 57   | 1316  | 14   | 74   | 12   | 0.8  | 3550 | 159  | 158  | 268  |
| 7                                   | 14   | 30    | 109  | 1226  | 14   | 68   | 12   | 0.7  | 4256 | 196  | 154  | 312  |
| 8                                   | 9.5  | 29    | 60   | 798   | 10   | 23   | 15   | 15   | 3526 | 190  | nd   | nd   |
| AVG                                 | 8.9  | 21    | 84   | 1162  | 13   | 66   | 12   | 2.9  | 3700 | 172  | 177  | 274  |
| MIN                                 | 5.7  | 16    | 57   | 798   | 10   | 23   | 8.3  | 1    | 3103 | 159  | 145  | 215  |

|                                                                                                                               |            |            |            |             |            |            |            |            |             |            |            |            |
|-------------------------------------------------------------------------------------------------------------------------------|------------|------------|------------|-------------|------------|------------|------------|------------|-------------|------------|------------|------------|
| <i>MAX</i>                                                                                                                    | <i>14</i>  | <i>30</i>  | <i>141</i> | <i>1466</i> | <i>15</i>  | <i>90</i>  | <i>15</i>  | <i>15</i>  | <i>4256</i> | <i>196</i> | <i>249</i> | <i>312</i> |
| <b>Sample: 119-05</b><br><b>Group: HK Mafics</b><br><b>Lithology: Basaltic Andesite</b><br><b>Standard: 172000 29Si ppm</b>   |            |            |            |             |            |            |            |            |             |            |            |            |
|                                                                                                                               | <i>Li</i>  | <i>Na</i>  | <i>Al</i>  | <i>Ca</i>   | <i>Sc</i>  | <i>Ti</i>  | <i>V</i>   | <i>Cr</i>  | <i>Mn</i>   | <i>Co</i>  | <i>Ni</i>  | <i>Zn</i>  |
|                                                                                                                               | <i>ppm</i> | <i>ppm</i> | <i>ppm</i> | <i>ppm</i>  | <i>ppm</i> | <i>ppm</i> | <i>ppm</i> | <i>ppm</i> | <i>ppm</i>  | <i>ppm</i> | <i>ppm</i> | <i>ppm</i> |
| Avg Detection Limit (ppm)                                                                                                     | 3.90       | 8.90       | 0.50       | 37.09       | 0.07       | 0.24       | 0.02       | 0.41       | 0.16        | 0.03       | 0.23       | 0.27       |
| Grain#                                                                                                                        |            |            |            |             |            |            |            |            |             |            |            |            |
| 1 (n=2)                                                                                                                       | 4.2        | 14         | 64         | 775         | 7.9        | 39         | 5.3        | 12         | 2674        | 227        | 394        | 167        |
| 2 (n=3)                                                                                                                       | 4.0        | 8.7        | 71         | 788         | 7.5        | 37         | 4.6        | 19         | 2356        | 206        | 430        | 142        |
| 3 (n=3)                                                                                                                       | 4.4        | 11         | 69         | 753         | 6.9        | 36         | 4.5        | 11         | 2217        | 204        | 426        | 136        |
| 4 (n=5)                                                                                                                       | 5.1        | 12         | 50         | 608         | 5.9        | 27         | 4.9        | 4.5        | 2400        | 219        | 421        | 168        |
| <i>AVG</i>                                                                                                                    | <i>4.5</i> | <i>11</i>  | <i>64</i>  | <i>731</i>  | <i>7.0</i> | <i>35</i>  | <i>4.8</i> | <i>12</i>  | <i>2411</i> | <i>214</i> | <i>418</i> | <i>153</i> |
| <i>MIN</i>                                                                                                                    | <i>4.0</i> | <i>8.7</i> | <i>50</i>  | <i>608</i>  | <i>5.9</i> | <i>27</i>  | <i>4.5</i> | <i>4.5</i> | <i>2217</i> | <i>204</i> | <i>394</i> | <i>136</i> |
| <i>MAX</i>                                                                                                                    | <i>5.1</i> | <i>14</i>  | <i>71</i>  | <i>788</i>  | <i>7.9</i> | <i>39</i>  | <i>5.3</i> | <i>19</i>  | <i>2674</i> | <i>227</i> | <i>430</i> | <i>168</i> |
| <b>Sample: 220621-5</b><br><b>Group: HK Mafics</b><br><b>Lithology: Basaltic Andesite</b><br><b>Standard: 172000 29Si ppm</b> |            |            |            |             |            |            |            |            |             |            |            |            |
|                                                                                                                               | <i>Li</i>  | <i>Na</i>  | <i>Al</i>  | <i>Ca</i>   | <i>Sc</i>  | <i>Ti</i>  | <i>V</i>   | <i>Cr</i>  | <i>Mn</i>   | <i>Co</i>  | <i>Ni</i>  | <i>Zn</i>  |
|                                                                                                                               | <i>ppm</i> | <i>ppm</i> | <i>ppm</i> | <i>ppm</i>  | <i>ppm</i> | <i>ppm</i> | <i>ppm</i> | <i>ppm</i> | <i>ppm</i>  | <i>ppm</i> | <i>ppm</i> | <i>ppm</i> |
| Avg Detection Limit (ppm)                                                                                                     | 2.62       | 7.29       | 0.41       | 38.17       | 0.08       | 0.22       | 0.02       | 0.42       | 0.13        | 0.02       | 0.23       | 0.21       |
| Grain #                                                                                                                       |            |            |            |             |            |            |            |            |             |            |            |            |
| 1                                                                                                                             | 3.9        | 20         | 64         | 691         | 8.0        | 36         | 5.3        | 5.3        | 2430        | 210        | 396        | 151        |
| 2                                                                                                                             | 3.4        | 6.7        | 67         | 748         | 8.0        | 35         | 4.4        | 15         | 2185        | 191        | 390        | 126        |
| 3                                                                                                                             | 2.9        | 7.9        | 64         | 690         | 7.9        | 38         | 5.2        | 6.4        | 2369        | 207        | 392        | 148        |
| 4 (n=2)                                                                                                                       | 3.0        | 6.4        | 60         | 671         | 8.0        | 37         | 5.2        | 2.5        | 2543        | 215        | 325        | 158        |
| 5                                                                                                                             | 3.0        | 6.8        | 70         | 750         | 9.3        | 56         | 5.9        | 3.3        | 2647        | 215        | 336        | 148        |

|          |     |     |    |     |     |    |     |     |      |     |     |     |
|----------|-----|-----|----|-----|-----|----|-----|-----|------|-----|-----|-----|
| 6        | 2.8 | 6.3 | 63 | 621 | 7.1 | 35 | 4.6 | 15  | 2192 | 191 | 445 | 130 |
| 7 (n=2)  | 5.9 | 31  | 64 | 621 | 7.5 | 35 | 5.2 | 15  | 2437 | 205 | 374 | 143 |
| 8        | 3.1 | 16  | 63 | 641 | 7.6 | 34 | 4.7 | 18  | 2286 | 202 | 359 | 131 |
| 9        | 4.8 | 13  | 61 | 626 | 6.9 | 34 | 5.0 | 16  | 2279 | 204 | 405 | 135 |
| 10       | 3.1 | 7.2 | 58 | 602 | 7.1 | 32 | 5.0 | 5.0 | 2292 | 203 | 365 | 146 |
| 11       | 2.6 | 7.4 | 62 | 661 | 7.0 | 29 | 4.5 | 17  | 2104 | 204 | 421 | 123 |
| 12       | 2.8 | 6.8 | 53 | 610 | 6.9 | 31 | 4.9 | 5.6 | 2437 | 205 | 359 | 140 |
| 13 (n=2) | 2.6 | 8.6 | 66 | 649 | 7.5 | 39 | 5.3 | 2.1 | 2478 | 217 | 345 | 150 |
| 14 (n=2) | 2.9 | 7.4 | 64 | 709 | 7.7 | 35 | 4.7 | 14  | 2403 | 201 | 332 | 136 |
| 15 (n=3) | 2.6 | 7.0 | 57 | 609 | 6.5 | 30 | 4.3 | 16  | 2144 | 199 | 413 | 121 |
| 16 (n=2) | 3.5 | 17  | 65 | 658 | 7.4 | 34 | 4.5 | 17  | 2335 | 207 | 383 | 133 |
| 17       | 5.7 | 10  | 71 | 736 | 7.8 | 43 | 5.2 | 15  | 2281 | 202 | 396 | 142 |
| 18 (n=2) | 3.6 | 7.4 | 68 | 773 | 8.1 | 36 | 4.5 | 12  | 2367 | 203 | 356 | 138 |
| 19       | 4.0 | 8.3 | 73 | 766 | 7.8 | 37 | 4.9 | 11  | 2290 | 204 | 414 | 131 |
| 20       | 3.8 | 12  | 75 | 607 | 9.2 | 38 | 5.1 | 6.8 | 2548 | 224 | nd  | nd  |
| 21       | 3.6 | 12  | 77 | 682 | 9.2 | 33 | 4.7 | 19  | 2390 | 219 | nd  | nd  |
| 22       | 4.4 | 15  | 75 | 672 | 10  | 35 | 4.8 | 16  | 2498 | 231 | nd  | nd  |
| 23       | 4.7 | 14  | 72 | 684 | 9.3 | 42 | 5.5 | 5.2 | 2694 | 240 | nd  | nd  |
| 24       | 4.4 | 14  | 77 | 711 | 9.1 | 39 | 5.6 | 1.7 | 2734 | 242 | nd  | nd  |
| 25       | 5.3 | 15  | 73 | 696 | 10  | 46 | 5.6 | 1.4 | 2864 | 244 | nd  | nd  |
| 26       | 4.0 | 15  | 69 | 699 | 8.5 | 38 | 5.0 | 3.9 | 2445 | 230 | nd  | nd  |
| AVG      | 3.7 | 11  | 67 | 676 | 8.0 | 37 | 5.0 | 10  | 2411 | 212 | 379 | 138 |
| MIN      | 2.6 | 6.3 | 53 | 602 | 6.5 | 29 | 4.3 | 1.4 | 2104 | 191 | 325 | 121 |
| MAX      | 5.9 | 31  | 77 | 773 | 10  | 56 | 5.9 | 19  | 2864 | 244 | 445 | 158 |

**Table A4.4-2 Cpx trace element data (ppm) sample 220623-1**

| Sample: 220623-1   Group: HK-BA lava   Standard: 230000 29Si ppm |        |      |      |      |      |      |      |      |       |       |       |  |
|------------------------------------------------------------------|--------|------|------|------|------|------|------|------|-------|-------|-------|--|
|                                                                  | Ca     | Sc   | Ti   | V    | Cr   | Mn   | Ni   | Sr   | Y     | Nb    | La    |  |
| Avg Detection limit (ppm)                                        | 46.52  | 0.12 | 0.32 | 0.04 | 0.75 | 0.23 | 0.40 | 0.01 | 0.001 | 0.002 | 0.003 |  |
| Grain ID                                                         |        |      |      |      |      |      |      |      |       |       |       |  |
| 23-1 cpx 1 avg (n=2)                                             | 158659 | 144  | 2879 | 444  | 1291 | 1704 | 173  | 43   | 22    | 0.03  | 1.6   |  |
| 23-1 cpx 3                                                       | 129830 | 130  | 2237 | 415  | 1079 | 1726 | 163  | 35   | 20    | 0.02  | 1.6   |  |
| 23-1 cpx 4 avg (n=2)                                             | 138665 | 106  | 1797 | 330  | 730  | 1769 | 171  | 35   | 16    | 0.01  | 1.1   |  |
| 23-1 cpx 5 avg (n=2)                                             | 118804 | 101  | 1873 | 389  | 976  | 1955 | 200  | 32   | 18    | 0.02  | 1.2   |  |

|                      |        |     |      |     |      |      |     |    |    |      |      |
|----------------------|--------|-----|------|-----|------|------|-----|----|----|------|------|
| 23-1 cpx 7 avg (n=2) | 128307 | 113 | 1945 | 348 | 1408 | 1859 | 177 | 34 | 18 | 0.03 | 1.2  |
| 23-1 cpx 8           | 114070 | 89  | 1631 | 306 | 621  | 1619 | 113 | 25 | 13 | 0.04 | 0.95 |
| <i>min</i>           | 114070 | 89  | 1631 | 306 | 621  | 1619 | 113 | 25 | 13 | 0.01 | 0.95 |
| <i>max</i>           | 158659 | 144 | 2879 | 444 | 1408 | 1955 | 200 | 43 | 22 | 0.04 | 1.6  |
| <i>average</i>       | 131389 | 114 | 2060 | 372 | 1017 | 1772 | 166 | 34 | 18 | 0.02 | 1.3  |

**Table A4.4-2 continued**

| Ce   | Pr    | Nd   | Sm   | Eu    | Gd   | Tb    | Dy   | Ho    | Er    | Tm    | Yb   | Lu   | Pb   |
|------|-------|------|------|-------|------|-------|------|-------|-------|-------|------|------|------|
| 0.01 | 0.003 | 0.01 | 0.01 | 0.003 | 0.01 | 0.002 | 0.01 | 0.002 | 0.004 | 0.002 | 0.01 | 0.00 | 0.03 |
| 7.3  | 1.5   | 9.0  | 3.8  | 0.97  | 4.0  | 0.61  | 4.1  | 0.83  | 2.7   | 0.34  | 1.9  | 0.26 | 0.11 |
| 6.3  | 1.5   | 8.2  | 3.3  | 0.73  | 3.7  | 0.55  | 3.9  | 0.84  | 2.4   | 0.35  | 1.8  | 0.27 | 0.07 |
| 4.3  | 1.0   | 5.7  | 2.6  | 0.72  | 2.8  | 0.47  | 2.9  | 0.70  | 1.8   | 0.24  | 1.5  | 0.21 | 0.06 |
| 4.9  | 1.1   | 6.5  | 2.7  | 0.64  | 3.5  | 0.48  | 3.3  | 0.68  | 2.2   | 0.28  | 1.8  | 0.25 | 0.06 |
| 4.9  | 1.1   | 6.1  | 2.7  | 0.71  | 3.3  | 0.48  | 3.0  | 0.66  | 2.0   | 0.24  | 1.6  | 0.23 | 0.09 |
| 3.7  | 0.76  | 4.9  | 1.8  | 0.59  | 2.3  | 0.38  | 2.6  | 0.48  | 1.7   | 0.21  | 1.6  | 0.20 | 0.12 |
| 3.7  | 0.76  | 4.9  | 1.8  | 0.59  | 2.3  | 0.38  | 2.6  | 0.48  | 1.7   | 0.21  | 1.5  | 0.20 | 0.06 |
| 7.3  | 1.5   | 9.0  | 3.8  | 0.97  | 4.0  | 0.61  | 4.1  | 0.84  | 2.7   | 0.35  | 1.9  | 0.27 | 0.12 |
| 5.2  | 1.2   | 6.8  | 2.8  | 0.73  | 3.3  | 0.49  | 3.3  | 0.70  | 2.1   | 0.28  | 1.7  | 0.24 | 0.08 |

**Table A4.4-3. Cpx trace element data (ppm) sample 220621-5**

| Sample: 220621-5   Group: HK-BA pyroclastic   Lithology: Basaltic Andesite pyroclastic   Standard: 220000 |        |      |      |      |      |      |      |      |       |       |       |
|-----------------------------------------------------------------------------------------------------------|--------|------|------|------|------|------|------|------|-------|-------|-------|
| 29Si ppm                                                                                                  | Ca     | Sc   | Ti   | V    | Cr   | Mn   | Ni   | Sr   | Y     | Nb    | La    |
| Avg Detection Limit (ppm)                                                                                 | 43.74  | 0.13 | 0.29 | 0.04 | 0.78 | 0.22 | 0.41 | 0.01 | 0.003 | 0.001 | 0.003 |
| Grain ID                                                                                                  |        |      |      |      |      |      |      |      |       |       |       |
| 21-5 cpx 1                                                                                                | nd     | 151  | 4530 | 589  | 153  | nd   | 75   | 30   | 28    | 0.04  | 1.5   |
| 21-5 cpx 2                                                                                                | nd     | 118  | 2995 | 439  | 301  | nd   | 90   | 28   | 17    | 0.02  | 0.88  |
| 21-5 cpx 3                                                                                                | nd     | 110  | 3321 | 477  | 359  | nd   | 113  | 30   | 19    | 0.02  | 1.0   |
| 21-5 cpx 1                                                                                                | 127569 | 120  | 2703 | 430  | 119  | 1859 | 72   | 24   | 19    | 0.01  | 0.97  |



|                |        |     |      |     |      |      |     |    |     |      |      |
|----------------|--------|-----|------|-----|------|------|-----|----|-----|------|------|
| 21-5 cpx 2     | 147216 | 143 | 3906 | 546 | 153  | 1598 | 74  | 31 | 24  | 0.03 | 1.0  |
| 21-5 cpx 3     | 152804 | 133 | 2295 | 360 | 1748 | 1221 | 76  | 30 | 14  | 0.02 | 0.65 |
| 21-5 cpx 4     | 145375 | 95  | 2201 | 334 | 972  | 1034 | 94  | 30 | 8.5 | 0.00 | 0.49 |
| 21-5 cpx 5     | 142324 | 130 | 2508 | 384 | 105  | 1619 | 65  | 23 | 18  | 0.01 | 0.81 |
| 21-5 cpx 8     | 129403 | 78  | 1104 | 220 | 1710 | 906  | 121 | 24 | 5.6 | 0.01 | 0.30 |
| 21-5 cpx 9     | 133275 | 116 | 1738 | 275 | 1673 | 1087 | 75  | 27 | 11  | 0.01 | 0.38 |
| 21-5 cpx 10    | 127510 | 117 | 2318 | 327 | 104  | 1563 | 62  | 20 | 17  | 0.01 | 0.76 |
| <i>min</i>     | 127510 | 78  | 1104 | 220 | 104  | 906  | 62  | 20 | 5.6 | 0.00 | 0.30 |
| <i>max</i>     | 152804 | 151 | 4530 | 589 | 1748 | 1859 | 121 | 31 | 28  | 0.04 | 1.5  |
| <i>average</i> | 138184 | 119 | 2693 | 398 | 673  | 1361 | 83  | 27 | 17  | 0.02 | 0.79 |

*Table A4.4-3 continued*

| Ce   | Pr    | Nd   | Sm   | Eu    | Gd   | Tb    | Dy   | Ho    | Er   | Tm    | Yb   | Lu    | Pb   |
|------|-------|------|------|-------|------|-------|------|-------|------|-------|------|-------|------|
| 0.01 | 0.002 | 0.01 | 0.01 | 0.003 | 0.01 | 0.002 | 0.01 | 0.002 | 0.01 | 0.002 | 0.01 | 0.002 | 0.03 |
| 7.4  | 1.6   | 9.8  | 3.8  | 1.2   | 5.3  | 0.79  | 5.5  | 1.1   | 3.2  | 0.43  | 2.6  | 0.38  | 0.09 |
| 4.3  | 0.99  | 6.5  | 2.4  | 0.82  | 3.2  | 0.52  | 3.3  | 0.67  | 1.9  | 0.26  | 1.8  | 0.25  | 0.12 |
| 5.0  | 1.0   | 7.0  | 2.8  | 0.93  | 3.7  | 0.56  | 3.5  | 0.74  | 2.3  | 0.28  | 1.8  | 0.28  | 0.10 |
| 4.4  | 1.1   | 7.0  | 2.9  | 0.81  | 3.8  | 0.59  | 4.0  | 0.82  | 2.6  | 0.33  | 2.3  | 0.27  | 0.05 |
| 4.5  | 1.1   | 7.8  | 3.3  | 1.0   | 5.0  | 0.76  | 4.6  | 1.1   | 3.3  | 0.42  | 2.6  | 0.38  | 0.06 |
| 2.8  | 0.73  | 4.9  | 2.0  | 0.68  | 2.4  | 0.35  | 2.3  | 0.53  | 1.7  | 0.21  | 1.2  | 0.19  | 0.04 |
| 2.7  | 0.56  | 3.4  | 1.3  | 0.51  | 1.4  | 0.24  | 1.7  | 0.32  | 1.1  | 0.13  | 0.85 | 0.14  | 0.03 |
| 3.9  | 1.0   | 6.0  | 2.7  | 0.75  | 3.6  | 0.59  | 3.9  | 0.81  | 2.9  | 0.35  | 2.3  | 0.33  | 0.09 |
| 1.4  | 0.31  | 1.9  | 0.93 | 0.31  | 1.2  | 0.19  | 1.2  | 0.26  | 0.73 | 0.10  | 0.64 | 0.10  | 0.04 |
| 1.9  | 0.40  | 3.2  | 1.3  | 0.41  | 2.0  | 0.29  | 2.0  | 0.45  | 1.4  | 0.14  | 1.1  | 0.14  | 0.04 |
| 4.1  | 1.0   | 6.9  | 2.9  | 0.81  | 3.8  | 0.52  | 3.7  | 0.75  | 2.1  | 0.29  | 1.9  | 0.26  | 0.04 |
| 1.4  | 0.31  | 1.9  | 0.93 | 0.31  | 1.2  | 0.19  | 1.2  | 0.26  | 0.73 | 0.10  | 0.64 | 0.10  | 0.03 |
| 7.4  | 1.6   | 9.8  | 3.8  | 1.2   | 5.3  | 0.79  | 5.5  | 1.1   | 3.3  | 0.43  | 2.6  | 0.38  | 0.12 |
| 3.8  | 0.90  | 5.8  | 2.4  | 0.75  | 3.2  | 0.49  | 3.3  | 0.68  | 2.1  | 0.27  | 1.7  | 0.25  | 0.06 |

**Table A4.4-4. Cpx trace element data (ppm) sample 220621-6**

| Sample: 220621-6   Group: HK-A   Lithology: Andesite   Standard: 230000 29Si ppm |        |      |      |      |      |      |      |      |       |       |       |
|----------------------------------------------------------------------------------|--------|------|------|------|------|------|------|------|-------|-------|-------|
|                                                                                  | Ca     | Sc   | Ti   | V    | Cr   | Mn   | Ni   | Sr   | Y     | Nb    | La    |
| Avg Detection limit (ppm)                                                        | 45.67  | 0.12 | 0.31 | 0.03 | 0.80 | 0.21 | 0.39 | 0.01 | 0.002 | 0.002 | 0.003 |
| Grain ID                                                                         |        |      |      |      |      |      |      |      |       |       |       |
| 21-6 cpx 1                                                                       | nd     | 137  | 2312 | 295  | 21   | nd   | 40   | 21   | 49    | 0.03  | 3.6   |
| 21-6 cpx 2                                                                       | nd     | 140  | 2030 | 233  | 14   | nd   | 30   | 20   | 57    | 0.04  | 4.1   |
| 21-6 cpx 1                                                                       | 138869 | 172  | 2303 | 220  | 15   | 2642 | 31   | 21   | 71    | 0.03  | 4.5   |
| 21-6 cpx 2                                                                       | 142749 | 170  | 1845 | 212  | 16   | 2506 | 31   | 20   | 75    | 0.02  | 5.8   |
| 21-6 cpx 3                                                                       | 151774 | 179  | 2497 | 250  | 16   | 2420 | 40   | 22   | 66    | 0.02  | 4.5   |
| 21-6 cpx 4                                                                       | 153923 | 199  | 1644 | 193  | 8.8  | 2603 | 26   | 21   | 85    | 0.04  | 6.2   |
| 21-6 cpx 6                                                                       | 152218 | 170  | 2207 | 220  | 15   | 2303 | 32   | 20   | 67    | 0.03  | 4.4   |
| 21-6 cpx 7                                                                       | 145788 | 163  | 2371 | 250  | 28   | 2517 | 41   | 20   | 58    | 0.02  | 4.4   |
| 21-6 cpx 8                                                                       | 146088 | 179  | 2164 | 212  | 14   | 2482 | 27   | 21   | 74    | 0.03  | 4.7   |
| 21-6 cpx 9                                                                       | 148540 | 192  | 2138 | 236  | 17   | 2392 | 29   | 19   | 70    | 0.04  | 4.4   |
| <i>min</i>                                                                       | 138869 | 137  | 1644 | 193  | 9    | 2303 | 26   | 19   | 49    | 0.02  | 3.6   |
| <i>max</i>                                                                       | 153923 | 199  | 2497 | 295  | 28   | 2642 | 41   | 22   | 85    | 0.04  | 6.2   |
| <i>average</i>                                                                   | 147494 | 170  | 2151 | 232  | 17   | 2483 | 33   | 21   | 67    | 0.03  | 4.7   |

*Table A4.4-4 continued*

| Ce   | Pr    | Nd   | Sm   | Eu    | Gd   | Tb    | Dy   | Ho    | Er    | Tm    | Yb   | Lu    | Pb   |
|------|-------|------|------|-------|------|-------|------|-------|-------|-------|------|-------|------|
| 0.01 | 0.002 | 0.01 | 0.01 | 0.003 | 0.01 | 0.002 | 0.01 | 0.002 | 0.004 | 0.002 | 0.01 | 0.002 | 0.03 |
| 20   | 3.8   | 22   | 7.8  | 1.2   | 9.2  | 1.4   | 9.5  | 1.9   | 5.7   | 0.72  | 5.1  | 0.75  | 0.24 |
| 22   | 4.5   | 26   | 9.7  | 1.5   | 11   | 1.6   | 11   | 2.1   | 6.6   | 0.85  | 5.7  | 0.84  | 0.29 |
| 21   | 4.2   | 25   | 9.4  | 1.3   | 11   | 1.7   | 13   | 2.5   | 7.9   | 1.0   | 6.3  | 0.97  | 0.27 |
| 26   | 4.7   | 33   | 11   | 1.6   | 13   | 2.0   | 14   | 2.9   | 8.8   | 1.1   | 6.6  | 1.0   | 0.22 |
| 20   | 4.1   | 27   | 9.6  | 1.4   | 12   | 1.8   | 13   | 2.5   | 7.8   | 1.1   | 6.6  | 0.96  | 0.25 |
| 29   | 5.7   | 34   | 13   | 1.5   | 15   | 2.3   | 16   | 3.3   | 9.3   | 1.2   | 7.9  | 1.2   | 0.27 |
| 20   | 4.1   | 27   | 9.7  | 1.4   | 11   | 1.9   | 13   | 2.7   | 8.0   | 1.0   | 6.6  | 1.0   | 0.25 |
| 19   | 3.6   | 23   | 8.3  | 1.2   | 10   | 1.6   | 11   | 2.0   | 6.9   | 0.89  | 5.8  | 0.89  | 0.23 |
| 22   | 4.4   | 28   | 11   | 1.6   | 13   | 2.0   | 14   | 2.7   | 8.6   | 1.1   | 6.9  | 1.1   | 0.30 |

|    |     |    |     |     |      |     |     |     |     |      |     |      |      |
|----|-----|----|-----|-----|------|-----|-----|-----|-----|------|-----|------|------|
| 23 | 4.7 | 29 | 10  | 1.6 | 13   | 1.8 | 14  | 2.8 | 9.2 | 1.1  | 7.1 | 1.1  | 0.24 |
| 19 | 3.6 | 22 | 7.8 | 1.2 | 9.2  | 1.4 | 9.5 | 1.9 | 5.7 | 0.72 | 5.1 | 0.75 | 0.22 |
| 29 | 5.7 | 34 | 13  | 1.6 | 15   | 2.3 | 16  | 3.3 | 9.3 | 1.2  | 7.9 | 1.2  | 0.30 |
| 22 | 4.4 | 27 | 9.9 | 1.4 | 11.8 | 1.8 | 13  | 2.5 | 7.9 | 1.0  | 6.5 | 0.98 | 0.26 |

**Table A4.4-5. Cpx trace element data sample (ppm) 220620-1**

| Sample: 220620-1   Group: HKWest-BBA   Lithology: Basalt   Standard: 225100 29Si ppm |        |      |      |      |      |      |      |      |       |       |       |  |  |
|--------------------------------------------------------------------------------------|--------|------|------|------|------|------|------|------|-------|-------|-------|--|--|
|                                                                                      | Ca     | Sc   | Ti   | V    | Cr   | Mn   | Ni   | Sr   | Y     | Nb    | La    |  |  |
| Average Detection Limit (ppm)                                                        | 46.76  | 0.14 | 0.30 | 0.03 | 0.82 | 0.23 | 0.39 | 0.01 | 0.002 | 0.001 | 0.003 |  |  |
| Grain ID                                                                             |        |      |      |      |      |      |      |      |       |       |       |  |  |
| 20-1 cpx 1                                                                           | nd     | 89   | 1810 | 314  | 1843 | nd   | 84   | 31   | 7.3   | 0.01  | 0.47  |  |  |
| 20-1 cpx 2                                                                           | nd     | 96   | 1875 | 289  | 3403 | nd   | 90   | 39   | 7.9   | 0.01  | 0.76  |  |  |
| 20-1 cpx 1                                                                           | 134387 | 114  | 3208 | 478  | 439  | 1636 | 88   | 33   | 15    | 0.02  | 1.2   |  |  |
| 20-1 cpx 3 avg (n=2)                                                                 | 135589 | 143  | 3862 | 542  | 625  | 1818 | 62   | 35   | 23    | 0.04  | 1.9   |  |  |
| 20-1 cpx 4                                                                           | 133407 | 130  | 3627 | 624  | 355  | 1955 | 45   | 27   | 15    | 0.03  | 1.6   |  |  |
| 20-1 cpx 5                                                                           | 137543 | 129  | 3519 | 521  | 391  | 1614 | 59   | 31   | 18    | 0.03  | 1.5   |  |  |
| 20-1 cpx 6                                                                           | 114484 | 111  | 2180 | 408  | 335  | 1883 | 44   | 24   | 14    | 0.03  | 0.93  |  |  |
| 20-1 cpx 7                                                                           | 118828 | 92   | 2384 | 504  | 212  | 1580 | 64   | 26   | 13    | 0.02  | 1.0   |  |  |
| <i>min</i>                                                                           | 114484 | 92   | 1875 | 289  | 212  | 1580 | 44   | 24   | 7.9   | 0.01  | 0.76  |  |  |
| <i>max</i>                                                                           | 137543 | 143  | 3862 | 624  | 3403 | 1955 | 90   | 39   | 23    | 0.04  | 1.9   |  |  |
| <i>average</i>                                                                       | 129040 | 113  | 2808 | 460  | 950  | 1748 | 67   | 30   | 14    | 0.02  | 1.2   |  |  |

**Table A4.4-5 continued**

| Ce   | Pr    | Nd   | Sm   | Eu    | Gd   | Tb    | Dy   | Ho    | Er    | Tm    | Yb   | Lu    | Pb   |
|------|-------|------|------|-------|------|-------|------|-------|-------|-------|------|-------|------|
| 0.01 | 0.002 | 0.01 | 0.01 | 0.003 | 0.01 | 0.002 | 0.01 | 0.002 | 0.005 | 0.002 | 0.01 | 0.002 | 0.03 |
| 2.7  | 0.55  | 3.6  | 1.6  | 0.47  | 1.5  | 0.24  | 1.3  | 0.24  | 0.82  | 0.11  | 0.74 | 0.12  | 0.03 |
| 4.4  | 0.86  | 4.7  | 1.7  | 0.54  | 2.0  | 0.29  | 1.6  | 0.30  | 0.91  | 0.10  | 0.70 | 0.10  | 0.05 |
| 6.2  | 1.3   | 7.4  | 2.6  | 0.75  | 3.7  | 0.48  | 3.4  | 0.60  | 1.8   | 0.24  | 1.5  | 0.14  | 0.06 |
| 8.7  | 1.8   | 11   | 4.2  | 1.2   | 4.6  | 0.77  | 4.8  | 0.98  | 2.9   | 0.40  | 2.5  | 0.35  | 0.09 |

|     |      |     |     |      |     |      |     |      |      |      |      |      |      |
|-----|------|-----|-----|------|-----|------|-----|------|------|------|------|------|------|
| 8.0 | 1.2  | 8.2 | 3.3 | 0.88 | 3.4 | 0.48 | 3.3 | 0.60 | 2.2  | 0.27 | 1.8  | 0.24 | 0.05 |
| 6.8 | 1.6  | 9.4 | 3.6 | 1.1  | 4.4 | 0.62 | 4.3 | 0.85 | 2.3  | 0.29 | 2.0  | 0.31 | 0.08 |
| 4.6 | 1.0  | 5.9 | 2.1 | 0.68 | 2.8 | 0.41 | 2.9 | 0.67 | 2.0  | 0.26 | 1.8  | 0.23 | 0.13 |
| 5.2 | 1.2  | 6.4 | 2.4 | 0.73 | 2.9 | 0.43 | 3.2 | 0.61 | 1.7  | 0.20 | 1.4  | 0.21 | 0.10 |
| 4.4 | 0.86 | 4.7 | 1.7 | 0.54 | 2.0 | 0.29 | 1.6 | 0.30 | 0.91 | 0.10 | 0.70 | 0.10 | 0.05 |
| 8.7 | 1.8  | 11  | 4.2 | 1.2  | 4.6 | 0.77 | 4.8 | 0.98 | 2.9  | 0.40 | 2.5  | 0.35 | 0.13 |
| 5.8 | 1.2  | 7.1 | 2.7 | 0.79 | 3.2 | 0.47 | 3.1 | 0.61 | 1.8  | 0.23 | 1.6  | 0.21 | 0.07 |

**Table A.4.4-6. Cpx trace element data (ppm) sample 220620-3**

| Sample: 220620-3   Group: HKWest-BBA   Lithology: Basalt   Standard: 226500 29Si ppm |        |      |      |      |      |      |      |      |       |       |       |  |  |
|--------------------------------------------------------------------------------------|--------|------|------|------|------|------|------|------|-------|-------|-------|--|--|
|                                                                                      | Ca     | Sc   | Ti   | V    | Cr   | Mn   | Ni   | Sr   | Y     | Nb    | La    |  |  |
| Avg Detection limit (ppm)                                                            | 46.65  | 0.13 | 0.30 | 0.04 | 0.84 | 0.23 | 0.43 | 0.01 | 0.003 | 0.002 | 0.003 |  |  |
| Grain ID                                                                             |        |      |      |      |      |      |      |      |       |       |       |  |  |
| 20-3 cpx 1                                                                           | nd     | 80   | 1142 | 165  | 738  | nd   | 69   | 32   | 4.7   | 0.01  | 0.39  |  |  |
| 20-3 cpx 3                                                                           | nd     | 99   | 1310 | 230  | 1248 | nd   | 107  | 36   | 5.7   | 0.00  | 0.38  |  |  |
| 20-3 cpx 2                                                                           | 115359 | 91   | 1955 | 333  | 280  | 1445 | 59   | 24   | 7.3   | 0.01  | 0.65  |  |  |
| 20-3 cpx 3                                                                           | 157640 | 98   | 1494 | 229  | 4666 | 1089 | 126  | 45   | 8.6   | 0.00  | 0.87  |  |  |
| 20-3 cpx 4                                                                           | 142590 | 122  | 2807 | 408  | 351  | 1510 | 49   | 27   | 14    | 0.01  | 0.61  |  |  |
| 20-3 cpx 5                                                                           | 120720 | 77   | 1580 | 290  | 90   | 1215 | 50   | 25   | 7.7   | 0.01  | 0.62  |  |  |
| 20-3 cpx 6                                                                           | 95244  | 72   | 1505 | 238  | 289  | 719  | 54   | 18   | 4.5   | 0.00  | 0.29  |  |  |
| 20-3 cpx 7                                                                           | 136579 | 82   | 1516 | 213  | 267  | 1267 | 81   | 32   | 7.2   | 0.02  | 0.53  |  |  |
| 20-3 cpx 1                                                                           | 149146 | 118  | 1997 | 299  | 2326 | 1211 | 68   | 39   | 11    | 0.01  | 0.98  |  |  |
| min                                                                                  | 95244  | 72   | 1142 | 165  | 90   | 719  | 49   | 18   | 4.5   | 0.00  | 0.29  |  |  |
| max                                                                                  | 157640 | 122  | 2807 | 408  | 4666 | 1510 | 126  | 45   | 14    | 0.02  | 0.87  |  |  |
| average                                                                              | 131040 | 93   | 1700 | 267  | 1139 | 1208 | 74   | 31   | 7.8   | 0.01  | 0.59  |  |  |

**Table A4.4-6 continued**

| Ce   | Pr    | Nd   | Sm   | Eu    | Gd   | Tb    | Dy   | Ho    | Er   | Tm    | Yb   | Lu    | Pb   |
|------|-------|------|------|-------|------|-------|------|-------|------|-------|------|-------|------|
| 0.01 | 0.003 | 0.01 | 0.01 | 0.003 | 0.01 | 0.002 | 0.01 | 0.002 | 0.01 | 0.002 | 0.01 | 0.002 | 0.04 |
| 2.0  | 0.42  | 2.4  | 0.80 | 0.27  | 1.2  | 0.16  | 0.97 | 0.19  | 0.57 | 0.07  | 0.48 | 0.05  | 0.07 |

|     |      |     |      |      |     |      |      |      |      |      |      |      |      |
|-----|------|-----|------|------|-----|------|------|------|------|------|------|------|------|
| 2.2 | 0.44 | 2.9 | 1.0  | 0.35 | 1.1 | 0.15 | 1.1  | 0.20 | 0.57 | 0.09 | 0.48 | 0.05 | 0.01 |
| 3.4 | 0.63 | 3.6 | 1.0  | 0.45 | 1.5 | 0.22 | 1.3  | 0.37 | 1.2  | 0.14 | 1.1  | 0.12 | 0.08 |
| 3.6 | 0.77 | 5.3 | 1.8  | 0.53 | 1.9 | 0.28 | 1.7  | 0.29 | 0.87 | 0.12 | 0.57 | 0.10 | 0.04 |
| 3.5 | 0.89 | 6.2 | 2.5  | 0.77 | 2.8 | 0.43 | 2.8  | 0.60 | 1.8  | 0.19 | 1.2  | 0.15 | 0.05 |
| 3.7 | 0.86 | 4.4 | 1.9  | 0.61 | 1.7 | 0.29 | 2.3  | 0.44 | 1.3  | 0.17 | 1.0  | 0.14 | 0.11 |
| 1.7 | 0.41 | 2.2 | 1.1  | 0.38 | 1.2 | 0.17 | 1.1  | 0.22 | 0.76 | 0.10 | 0.64 | 0.06 | 0.03 |
| 2.8 | 0.64 | 3.4 | 1.5  | 0.46 | 1.3 | 0.25 | 1.4  | 0.32 | 0.95 | 0.13 | 0.74 | 0.10 | 0.08 |
| 4.7 | 0.97 | 6.0 | 1.9  | 0.71 | 2.3 | 0.33 | 2.1  | 0.45 | 1.2  | 0.18 | 0.96 | 0.14 | 0.04 |
| 1.7 | 0.41 | 2.2 | 0.80 | 0.27 | 1.1 | 0.15 | 0.97 | 0.19 | 0.57 | 0.07 | 0.48 | 0.05 | 0.01 |
| 3.7 | 0.89 | 6.2 | 2.5  | 0.77 | 2.8 | 0.43 | 2.8  | 0.60 | 1.8  | 0.19 | 1.2  | 0.15 | 0.11 |
| 3.1 | 0.67 | 4.0 | 1.5  | 0.50 | 1.7 | 0.25 | 1.6  | 0.34 | 1.0  | 0.13 | 0.80 | 0.10 | 0.06 |

**Table A4.4-7. Cpx trace element data (ppm) sample 220620-4**

| Sample: 220620-4   Group: HKWest-BBA   Lithology: Basalt   Standard: 231200 29Si ppm |        |      |      |      |      |      |      |      |       |       |       |  |  |
|--------------------------------------------------------------------------------------|--------|------|------|------|------|------|------|------|-------|-------|-------|--|--|
|                                                                                      | Ca     | Sc   | Ti   | V    | Cr   | Mn   | Ni   | Sr   | Y     | Nb    | La    |  |  |
| Avg Detection limit (ppm)                                                            | 45.75  | 0.13 | 0.30 | 0.03 | 0.76 | 0.22 | 0.40 | 0.01 | 0.003 | 0.001 | 0.003 |  |  |
| Grain ID                                                                             |        |      |      |      |      |      |      |      |       |       |       |  |  |
| 20-4 cpx 3                                                                           | nd     | 62   | 838  | 175  | 2595 | nd   | 165  | 33   | 4.3   | 0.00  | 0.19  |  |  |
| 20-4 cpx 1                                                                           | nd     | 95   | 1890 | 308  | 1605 | nd   | 116  | 28   | 8.5   | 0.01  | 0.38  |  |  |
| 20-4 cpx 1                                                                           | 103811 | 56   | 1227 | 252  | 756  | 1035 | 60   | 20   | 6.3   | 0.02  | 0.35  |  |  |
| 20-4 cpx 2                                                                           | 128587 | 75   | 1892 | 287  | 683  | 1138 | 116  | 22   | 7.8   | 0.01  | 0.41  |  |  |
| 20-4 cpx 3                                                                           | 120204 | 90   | 2156 | 370  | 426  | 1940 | 73   | 16   | 10.3  | 0.01  | 0.43  |  |  |
| 20-4 cpx 5                                                                           | 152724 | 91   | 1759 | 324  | 2549 | 1073 | 103  | 33   | 8.9   | 0.01  | 0.62  |  |  |
| 20-4 cpx 6                                                                           | 118632 | 79   | 1808 | 276  | 598  | 1190 | 74   | 22   | 9.7   | 0.05  | 0.54  |  |  |
| 20-4 cpx 7                                                                           | 148935 | 89   | 1741 | 319  | 1221 | 1377 | 75   | 31   | 8.8   | 0.01  | 0.55  |  |  |
| min                                                                                  | 103811 | 56   | 838  | 175  | 426  | 1035 | 60   | 16   | 4.3   | 0.00  | 0.19  |  |  |
| max                                                                                  | 152724 | 95   | 2156 | 370  | 2595 | 1940 | 165  | 33   | 10.3  | 0.05  | 0.62  |  |  |
| average                                                                              | 128816 | 80   | 1664 | 289  | 1304 | 1292 | 98   | 26   | 8.1   | 0.01  | 0.43  |  |  |

**Table A4.4-7 continued**

| Ce | Pr | Nd | Sm | Eu | Gd | Tb | Dy | Ho | Er | Tm | Yb | Lu | Pb |
|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
|----|----|----|----|----|----|----|----|----|----|----|----|----|----|



|             |              |             |             |              |             |              |             |              |             |              |             |              |             |
|-------------|--------------|-------------|-------------|--------------|-------------|--------------|-------------|--------------|-------------|--------------|-------------|--------------|-------------|
| <i>0.01</i> | <i>0.002</i> | <i>0.01</i> | <i>0.01</i> | <i>0.003</i> | <i>0.01</i> | <i>0.002</i> | <i>0.01</i> | <i>0.002</i> | <i>0.01</i> | <i>0.002</i> | <i>0.01</i> | <i>0.002</i> | <i>0.03</i> |
| 1.0         | 0.22         | 1.2         | 0.58        | 0.22         | 0.94        | 0.12         | 0.80        | 0.20         | 0.52        | 0.06         | 0.40        | 0.06         | 0.03        |
| 1.8         | 0.39         | 2.9         | 1.3         | 0.39         | 1.7         | 0.25         | 1.8         | 0.35         | 0.83        | 0.11         | 0.93        | 0.11         | 0.04        |
| 1.7         | 0.40         | 2.4         | 0.88        | 0.35         | 1.3         | 0.21         | 1.4         | 0.32         | 1.1         | 0.12         | 0.79        | 0.10         | 0.03        |
| 2.2         | 0.49         | 3.2         | 1.4         | 0.58         | 1.8         | 0.26         | 1.5         | 0.35         | 0.94        | 0.13         | 1.0         | 0.13         | 0.05        |
| 2.5         | 0.54         | 3.3         | 1.5         | 0.52         | 1.9         | 0.32         | 2.0         | 0.46         | 1.6         | 0.19         | 1.2         | 0.16         | 0.05        |
| 3.2         | 0.69         | 3.9         | 1.6         | 0.62         | 2.0         | 0.27         | 1.8         | 0.41         | 1.3         | 0.16         | 0.98        | 0.11         | 0.04        |
| 2.4         | 0.51         | 3.5         | 1.3         | 0.53         | 2.0         | 0.35         | 2.5         | 0.51         | 1.7         | 0.22         | 1.3         | 0.15         | 0.11        |
| 2.8         | 0.59         | 3.3         | 1.1         | 0.42         | 1.5         | 0.22         | 1.6         | 0.32         | 0.95        | 0.12         | 0.82        | 0.12         | 0.04        |
| <i>1.0</i>  | <i>0.22</i>  | <i>1.2</i>  | <i>0.58</i> | <i>0.22</i>  | <i>0.94</i> | <i>0.12</i>  | <i>0.80</i> | <i>0.20</i>  | <i>0.52</i> | <i>0.06</i>  | <i>0.40</i> | <i>0.06</i>  | <i>0.03</i> |
| <i>3.2</i>  | <i>0.69</i>  | <i>3.9</i>  | <i>1.6</i>  | <i>0.62</i>  | <i>2.0</i>  | <i>0.35</i>  | <i>2.5</i>  | <i>0.51</i>  | <i>1.7</i>  | <i>0.22</i>  | <i>1.3</i>  | <i>0.16</i>  | <i>0.11</i> |
| <i>2.2</i>  | <i>0.48</i>  | <i>3.0</i>  | <i>1.2</i>  | <i>0.45</i>  | <i>1.6</i>  | <i>0.25</i>  | <i>1.7</i>  | <i>0.36</i>  | <i>1.1</i>  | <i>0.14</i>  | <i>0.93</i> | <i>0.12</i>  | <i>0.05</i> |

**Table A4.4-8. Cpx trace element data (ppm) sample YAM002**

| Sample: YAM002   Group: YAM-BA   Lithology: Basaltic Andesite   Standard: 230000 29Si ppm |        |      |      |      |      |      |      |      |       |       |       |  |
|-------------------------------------------------------------------------------------------|--------|------|------|------|------|------|------|------|-------|-------|-------|--|
|                                                                                           | Ca     | Sc   | Ti   | V    | Cr   | Mn   | Ni   | Sr   | Y     | Nb    | La    |  |
| Avg Detection limit (ppm)                                                                 | 44.69  | 0.12 | 0.32 | 0.03 | 0.77 | 0.21 | 0.40 | 0.01 | 0.002 | 0.002 | 0.003 |  |
| Grain ID                                                                                  |        |      |      |      |      |      |      |      |       |       |       |  |
| yam cpx 4                                                                                 | 142941 | 160  | 4056 | 371  | 87   | 2170 | 20   | 31   | 37    | 0.04  | 2.1   |  |
| yam cpx 3a                                                                                | 136484 | 149  | 3063 | 282  | 13   | 2560 | 12   | 24   | 32    | 0.02  | 1.5   |  |
| yam cpx 3b                                                                                | 137667 | 144  | 3215 | 314  | 16   | 2379 | 13   | 53   | 33    | 0.05  | 1.7   |  |
| yam cpx 2                                                                                 | 132805 | 149  | 2969 | 336  | 42   | 2315 | 32   | 22   | 29    | 0.02  | 1.2   |  |
| yam cpx 1                                                                                 | 123824 | 152  | 2796 | 279  | 15   | 2470 | 28   | 22   | 35    | 0.03  | 1.3   |  |
| yam cpx 5                                                                                 | 130914 | 133  | 3374 | 289  | 13   | 2308 | 13   | 31   | 31    | 0.18  | 2.1   |  |
| yam cpx 6                                                                                 | 148567 | 177  | 2225 | 236  | 26   | 2697 | 20   | 24   | 65    | 0.05  | 5.6   |  |
| yam cpx 7                                                                                 | 136756 | 161  | 2556 | 265  | 21   | 2587 | 35   | 23   | 68    | 0.04  | 4.6   |  |
| yam cpx 8                                                                                 | 134564 | 137  | 2409 | 255  | 19   | 2243 | 35   | 23   | 29    | 0.02  | 1.4   |  |
| <i>min</i>                                                                                | 123824 | 133  | 2225 | 236  | 13   | 2170 | 12   | 22   | 29    | 0.02  | 1.2   |  |
| <i>max</i>                                                                                | 148567 | 177  | 4056 | 371  | 87   | 2697 | 35   | 53   | 68    | 0.18  | 5.6   |  |
| <i>average</i>                                                                            | 136058 | 151  | 2963 | 292  | 28   | 2414 | 23   | 28   | 40    | 0.05  | 2.4   |  |

*Table A4.4-8 continued*

| Ce   | Pr    | Nd   | Sm   | Eu    | Gd   | Tb    | Dy   | Ho    | Er    | Tm    | Yb   | Lu    | Pb   |
|------|-------|------|------|-------|------|-------|------|-------|-------|-------|------|-------|------|
| 0.01 | 0.003 | 0.01 | 0.01 | 0.003 | 0.01 | 0.002 | 0.01 | 0.002 | 0.005 | 0.002 | 0.01 | 0.002 | 0.03 |
| 8.8  | 2.1   | 13   | 4.9  | 1.5   | 6.7  | 1.0   | 6.7  | 1.5   | 4.3   | 0.50  | 3.3  | 0.49  | 0.06 |
| 6.4  | 1.6   | 9.9  | 3.6  | 1.2   | 4.9  | 0.8   | 5.7  | 1.3   | 3.7   | 0.41  | 3.0  | 0.41  | 0.05 |
| 6.9  | 1.5   | 10.3 | 4.2  | 1.2   | 5.4  | 0.9   | 5.9  | 1.3   | 3.6   | 0.48  | 3.1  | 0.43  | 0.11 |
| 5.5  | 1.3   | 8.4  | 3.9  | 0.99  | 4.6  | 0.7   | 5.7  | 1.3   | 3.6   | 0.42  | 2.7  | 0.43  | 0.04 |
| 6.0  | 1.3   | 8.8  | 3.6  | 1.1   | 5.1  | 0.9   | 5.9  | 1.2   | 4.0   | 0.47  | 3.3  | 0.51  | 0.10 |
| 8.3  | 1.7   | 11   | 4.7  | 1.1   | 5.7  | 0.8   | 5.7  | 1.1   | 3.6   | 0.40  | 3.1  | 0.44  | 0.19 |
| 24   | 4.6   | 28   | 9.9  | 1.6   | 11   | 1.8   | 12   | 2.4   | 7.5   | 0.96  | 6.4  | 0.90  | 0.30 |
| 21   | 4.3   | 27   | 9.4  | 1.5   | 11   | 1.7   | 12   | 2.5   | 8.1   | 1.1   | 6.6  | 0.93  | 0.27 |
| 5.8  | 1.3   | 8.7  | 3.7  | 0.97  | 4.6  | 0.8   | 5.1  | 1.1   | 3.6   | 0.43  | 2.8  | 0.44  | 0.06 |
| 5.5  | 1.3   | 8.4  | 3.6  | 0.97  | 4.6  | 0.7   | 5.1  | 1.1   | 3.6   | 0.40  | 2.7  | 0.41  | 0.04 |
| 24   | 4.6   | 28   | 9.9  | 1.6   | 11   | 1.8   | 12   | 2.5   | 8.1   | 1.1   | 6.6  | 0.93  | 0.30 |

## APPENDIX 4.5: Pyroxene Composition and Texture Description

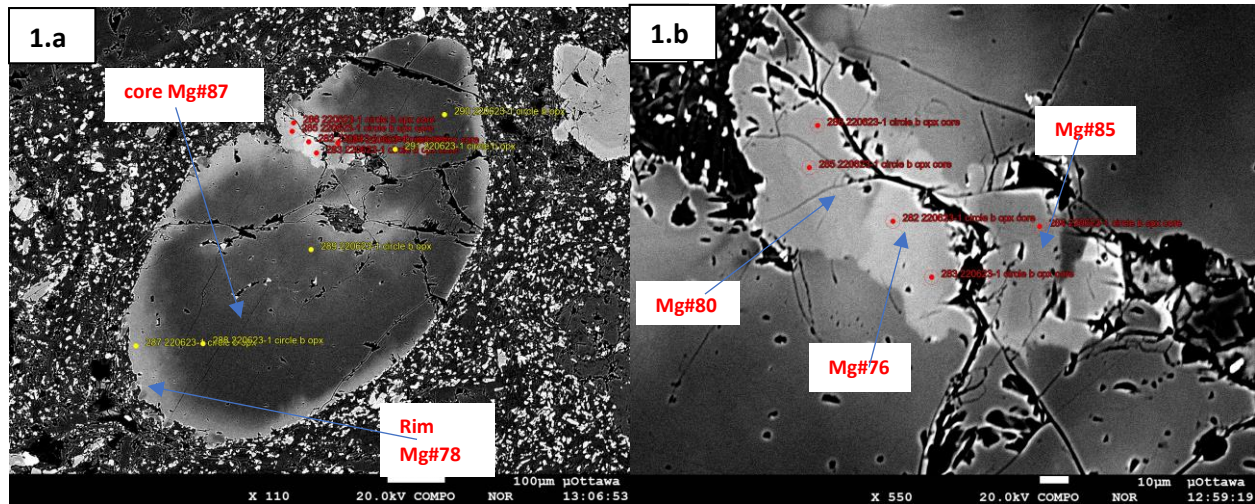
### Sample 220623-1 Hishikari Basaltic Andesite

There are 2 types of Cpx in sample 220623-1:

- 1) **oscillatory zoned Cpx** between Mg poor (Mg#78) and Mg rich (Mg#82) bands (>10 micron meters in thickness).
- 2) **Cpx inclusions in Opx grains which are commonly patchy zoned** with Mg poor areas (Mg#75) and Mg rich areas (Mg#80). One Cpx inclusion is reverse zoned, with an Mg rich rim, and Mg poor core.

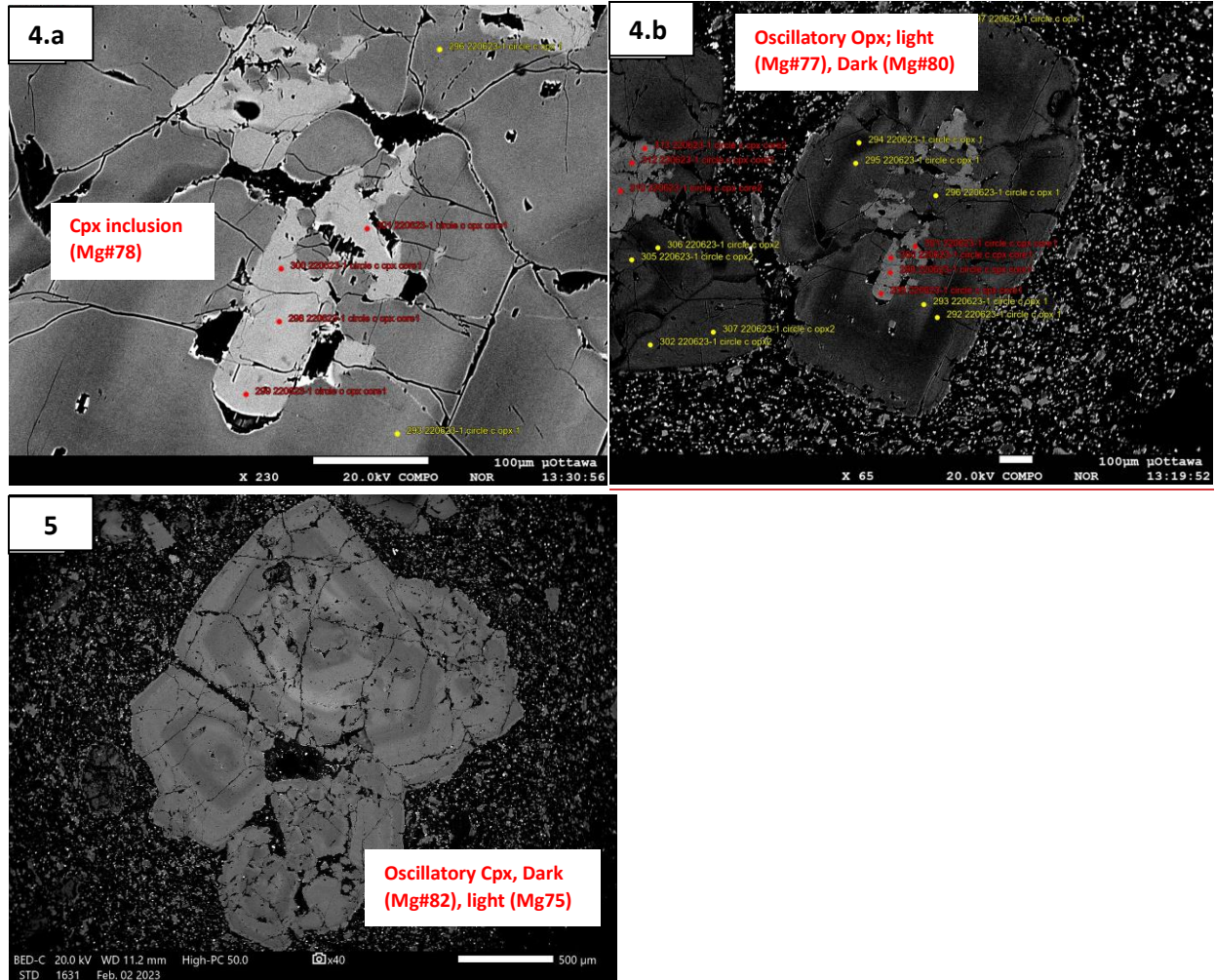
There are 2 types of Opx in sample 220623-1:

- 1) **normally zoned Opx** with an Mg rich core (Mg#87) and Mg poor rim (Mg#78).
- 2) **Oscillatory zoned Opx** between Mg rich (Mg#80) and Mg poor (Mg#77) bands (>10 micrometers in thickness).









**Figure A4.5-1:** 1.a and b) Normally zoned Opx with Mg rich core (1.a) and its reverse zoned Cpx inclusion (1.b). This grain is different from the rest of the population. 2.a and b) patchy zoned Cpx inclusion (2.a) hosted by an oscillatory zoned Opx with thick rings. 3.a and b) Patchy zoned Cpx inclusion (3.a) hosted by an oscillatory zoned Opx (3.b) with thin rings. 4.a and b) homogenous Cpx inclusion (4.a) hosted by an oscillatory zoned Opx. 5) oscillatory zoned Cpx.



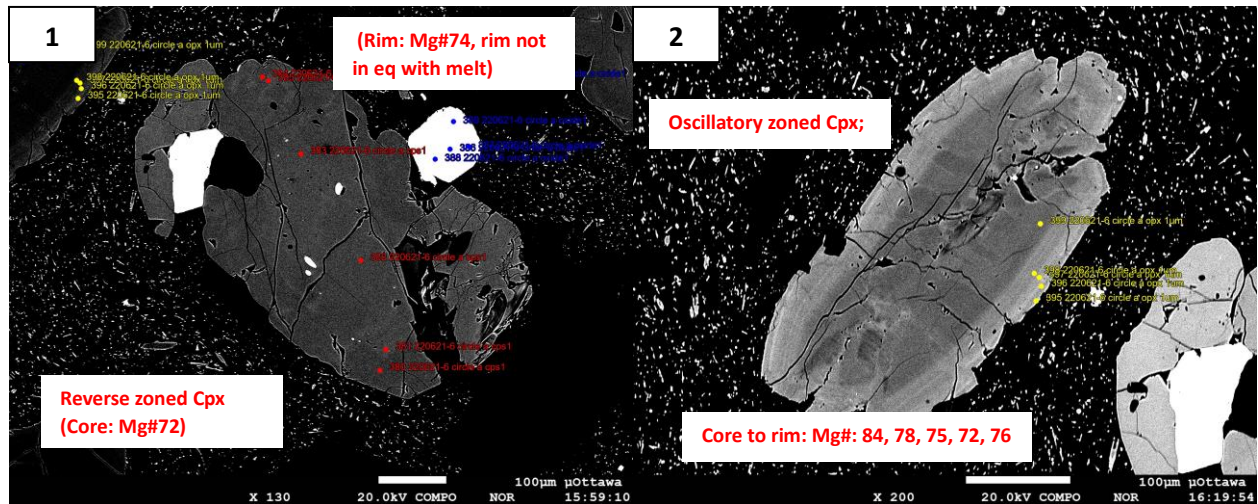
## 220621-6 Hishikari Two-Pyx Andesite

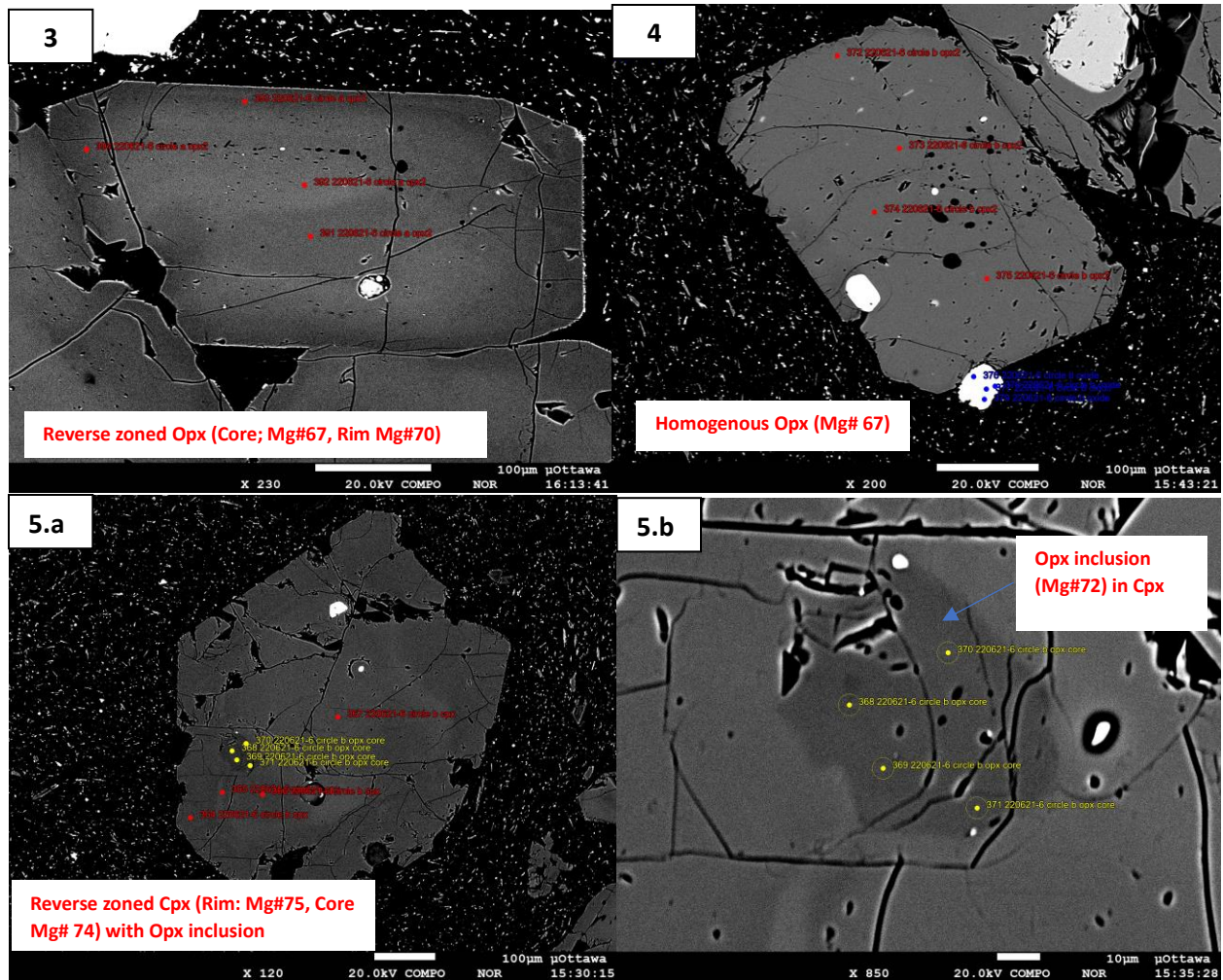
There are two populations of Cpx in this sample:

- 1) **Oscillatory zoned** Alternating between Mg rich and Mg poor with an Mg rich core. For example, fig. 2 shows an oscillatory zoned Cpx with an mg rich core (Mg#84) followed by oscillating rings that alternate between Mg poor (Mg#72) and Mg rich (Mg#77). These rings are thin (~1micron thick)
- 2) **reverse zoned** with an Mg poor core and Mg rich rim (Core: Mg#72, Rim: Mg#74). Several of these reverse zoned Cpx grains have an Opx inclusion (Mg#72).

There are two populations of Opx:

- 1) **reverse zoned Opx** (Core: Mg#67, Rim: Mg#70)
- 2) **unzoned/homogenous Opx** (Mg#67).





**Figure A4.5-2:** 1) reverse zoned Cpx with corroded edges, 2) oscillatory zoned Cpx with an Mg rich core (Mg: 84) followed by thin (~1 micron) oscillatory rings alternating between Mg poor (Mg#77) to Mg rich (Mg#72), 3) reverse zoned (Patchy zoned??) Opx, 4) Homogenous euhedral Opx (analysis is labelled wrong), 5.a and b) reverse zoned Cpx (5.a) with a homogenous Opx inclusion (5.b).



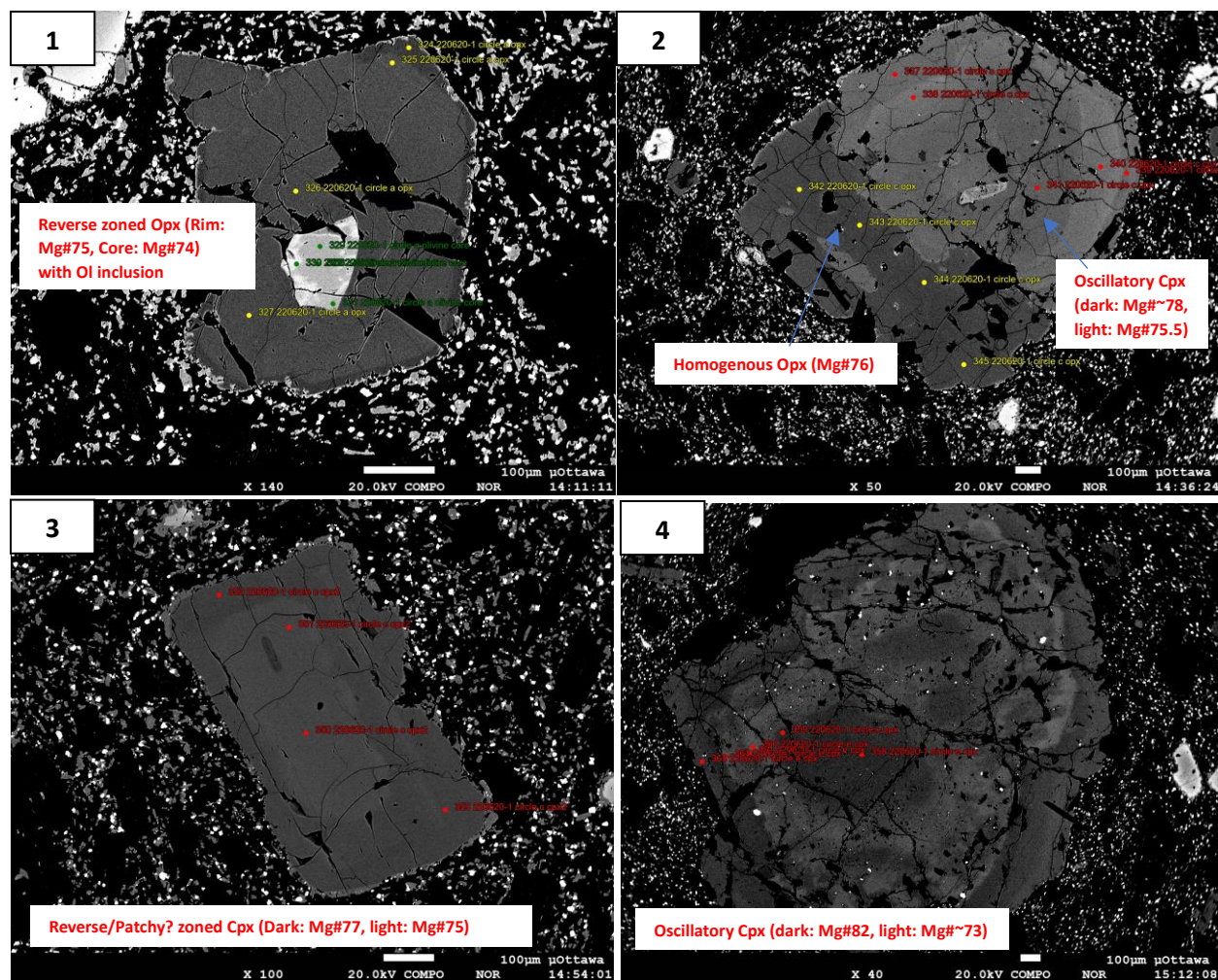
### Sample 220620-1 Ol Basalt (West of Isa)

There are 2 populations of Opx in this sample:

- 1) **reverse/Patchy? zoned** with a Mg rich rim (Mg#75) areas and Mg poor areas (Mg#74). Core of these grains are Mg poor and Mg rich towards the rim but also include patches of Mg poor areas distributed across the grain. Several of these grains have Ol inclusions.
- 2) **Homogenous Opx** (Mg#76) which is usually amalgamated with Cpx

There are 2 populations of Cpx in this sample:

- 1) **oscillatory zoned Cpx** that have oscillating rings that alternate between Mg rich (Mg#82) and Mg poor (Mg#73).
- 2) **reverse zoned Cpx** with an Mg rich rim (Mg#77) and a Mg poor core (Mg#75)



**Figure A4.5-3:** 1) Reverse/Patchy? zoned Opx with an Ol inclusion, 2) homogenous Opx amalgamated with oscillatory zoned Cpx, 3) reverse zoned Cpx, 4) oscillatory zoned Cpx

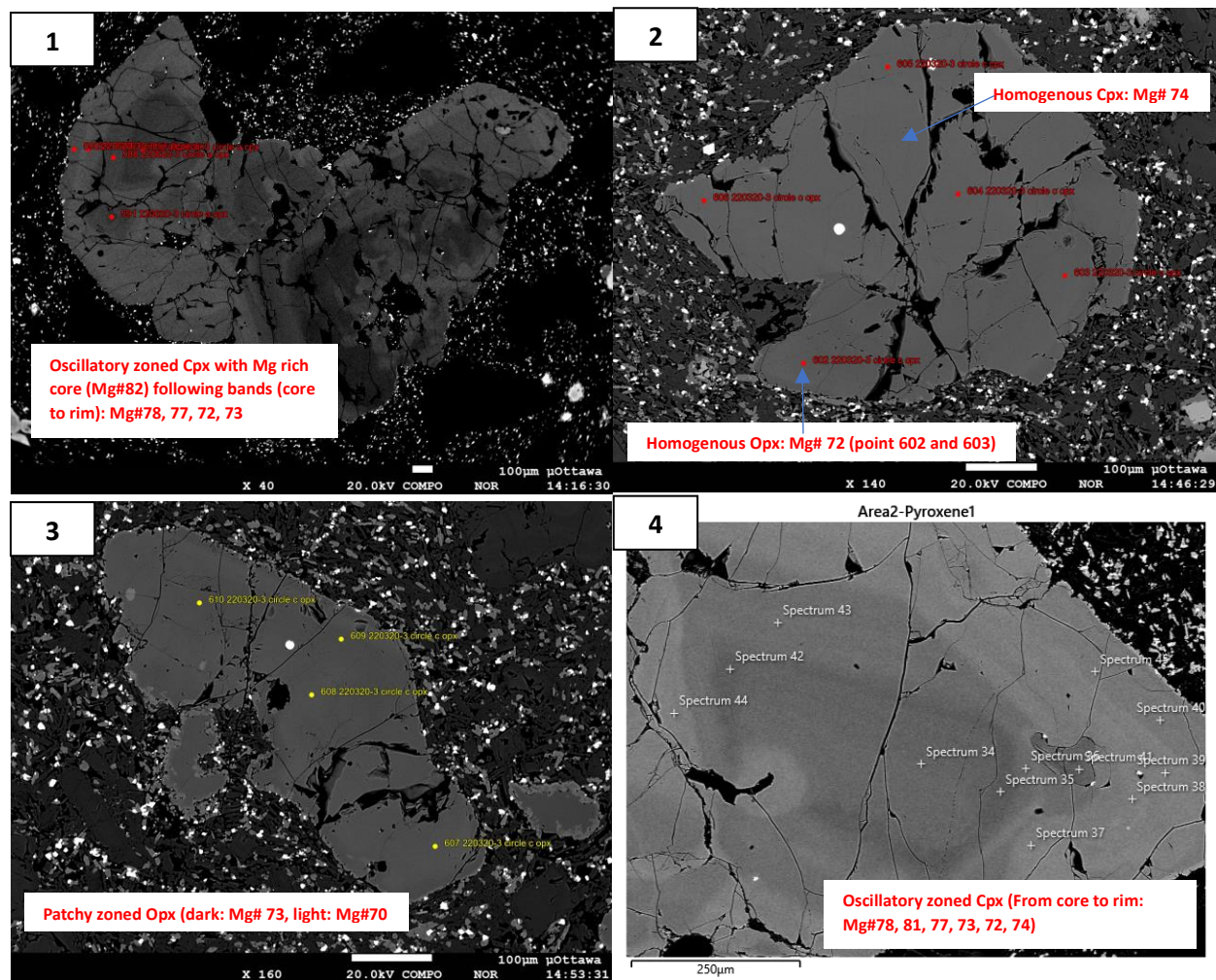
## Sample 220620-3 Ol Basalt (West of Isa)

There are 2 populations of Cpx in this sample:

- 1) **Oscillatory zoned Cpx** that have oscillating rings that alternate between Mg rich to Mg poor. Although Mg composition alternates between Mg rich to Mg poor, the Mg composition gradually decreases from core to rim.
- 2) **Homogenous/unzoned Cpx** (Mg#74). Several of these grains have a partial Opx rim (Mg#72).

The are 2 populations of Opx in this sample:

- 1) **Patchy zoned Opx** with Mg rich areas (Mg#73) and Mg poor areas (Mg#70)
- 2) **Unzoned/homogenous Opx** (Mg#72). Many of these grains occurs as partial rims to Cpx.



**Figure A4.5-4:** 1) Oscillatory zoned Cpx, 2) homogenous Cpx with an Opx partial rim, 3) patchy zoned Opx, 4) oscillatory zoned Cpx (SEM data)

### **Sample 220620-4 Ol Basaltic Andesite (West of Isa)**

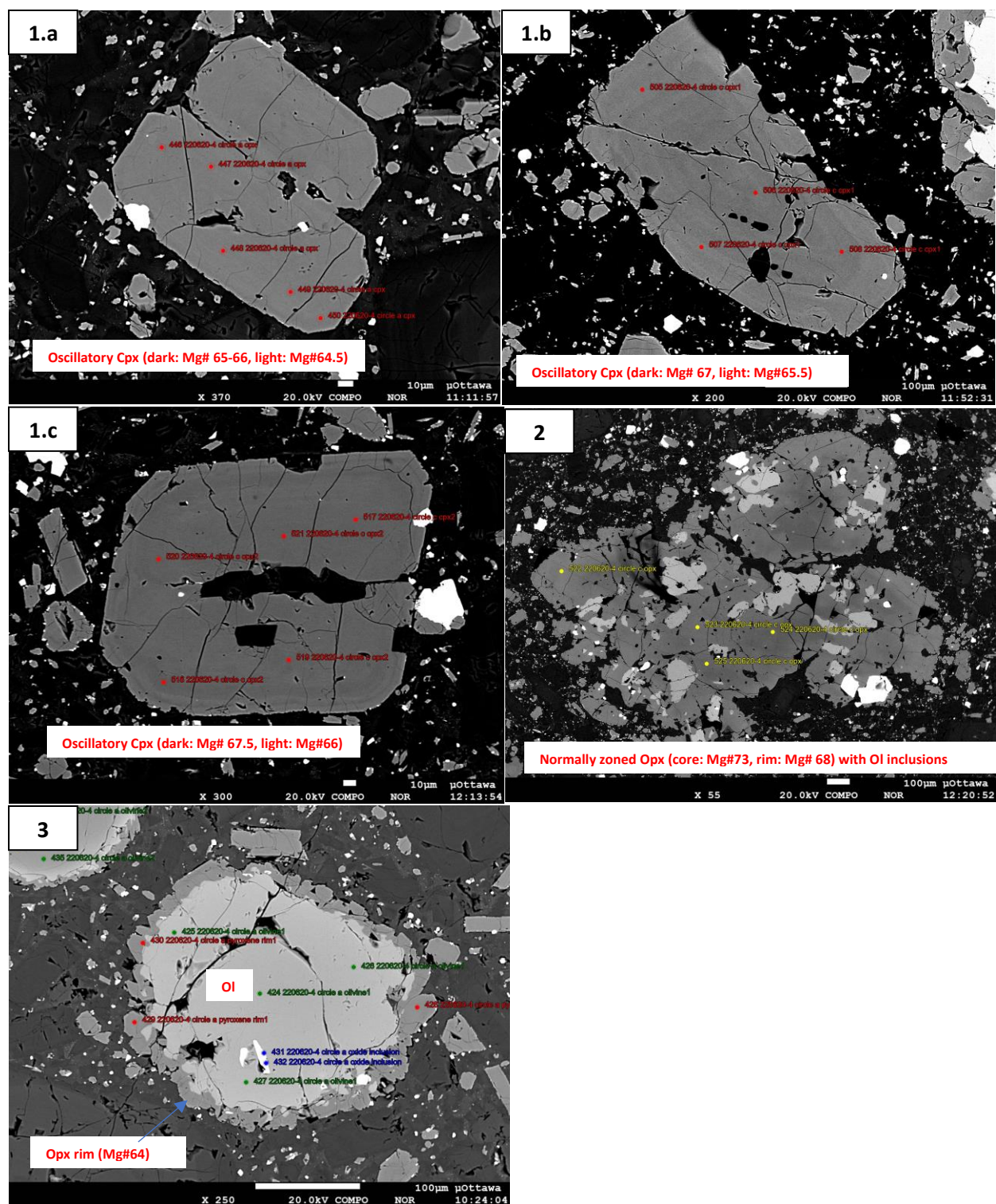
There is 1 population of Cpx in this sample:

- 1) **Oscillatory zoned Cpx** with oscillating rings that alternate between Mg rich (Mg#~67) and Mg poor (Mg#66).

There are 2 populations of Opx in this sample:

- 1) **Normally zoned Opx** with a Mg rich core (Mg#73) and Mg poor rim (Mg#68). Opx grains commonly have Ol inclusions.
- 2) **Opx rims (Mg#64)** around olivine (olivine reacting with melt to form Opx? These rims only form around olivine)





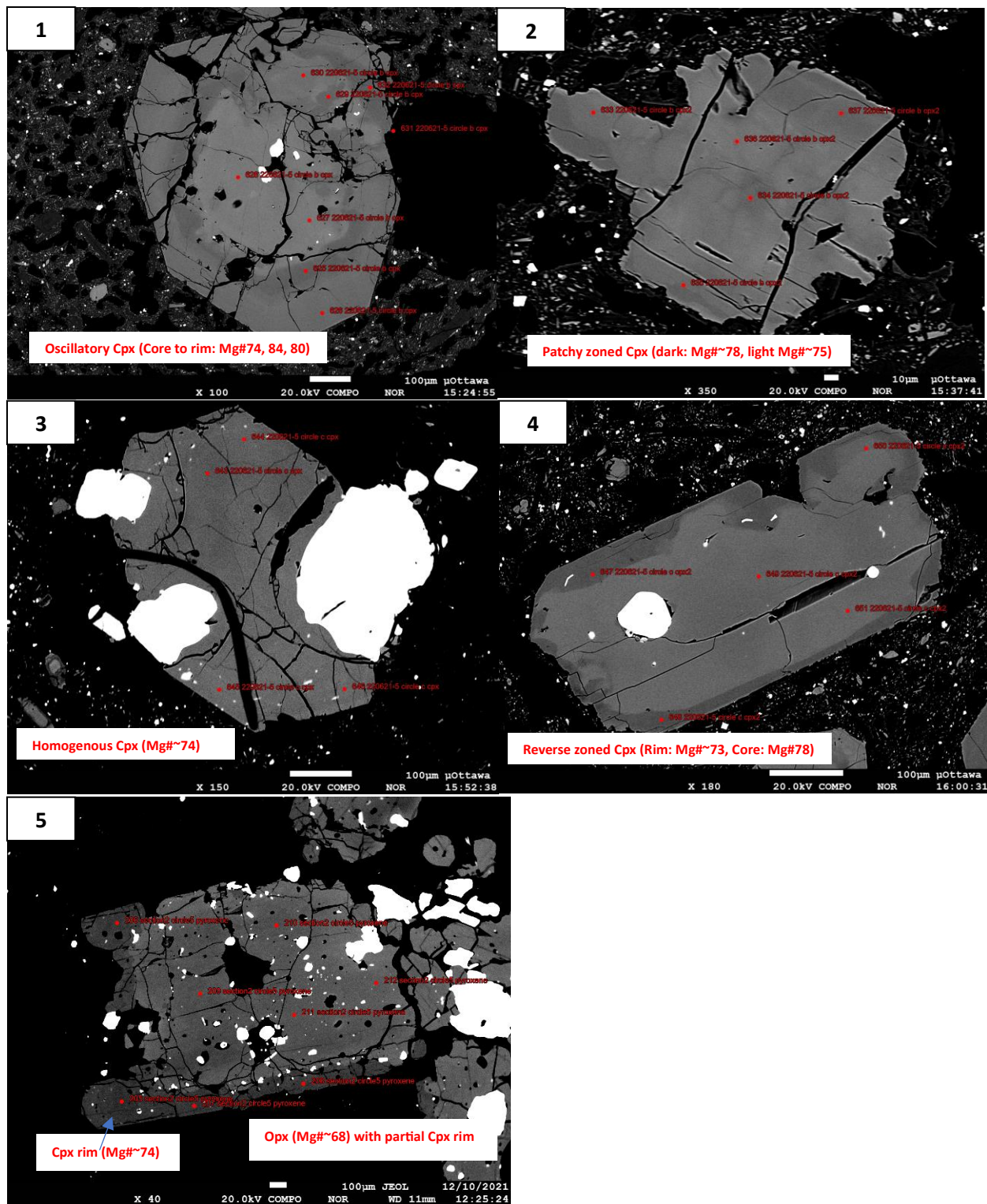
**Figure A4.5-5:** 1.a, b and c) oscillatory zoned Cpx, 2) Normally zoned Opx, 3) Opx rim around olivine

### **Sample 220621-5 Pyroclastic Ol Basaltic Andesite (Hishikari)**

There are 3 populations of Cpx in this sample:

- 1) **Reverse zoned Cpx** with Mg rich rim (Mg#78) and Mg poor core (Mg#73)
- 2) **Patchy zoned Cpx** with Mg rich areas (Mg#~78) and Mg poor areas (Mg#75)
- 3) **Oscillatory zoned Cpx** with oscillating rings alternating between Mg rich and Mg poor. For example, core to rim: Mg#74, 84, 80.
- 4) **Unzoned/Homogenous Cpx** (Mg#74)

Opx is homogenous (Mg#67) where several grains have partial Cpx rims (Mg#74)



**Figure A4.5-6:** 1) oscillatory zoned Cpx, 2) patchy zoned Cpx, 3) homogenous/unzoned Cpx, 4) reverse zoned Cpx, 5) homogenous Opx with Cpx partial rim



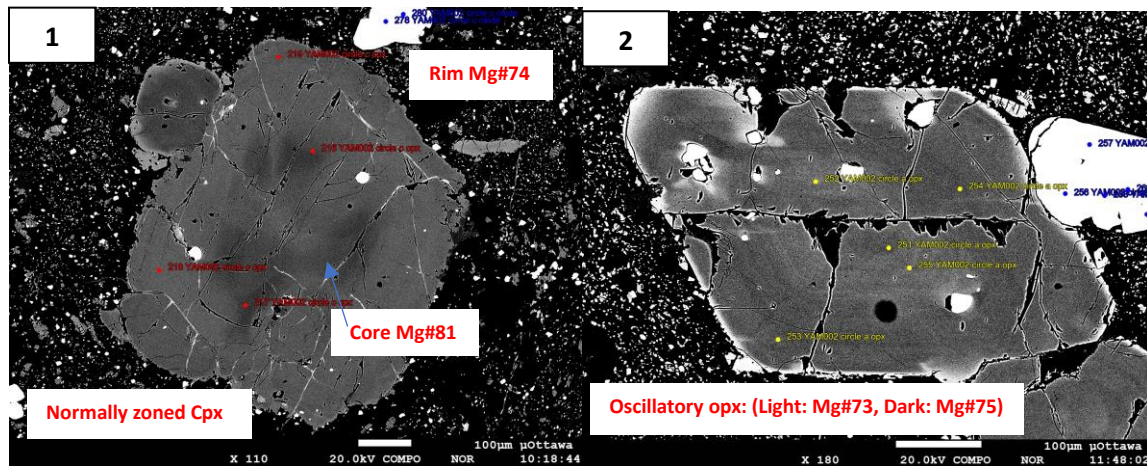
## Sample YAM002 Basaltic Andesite from Yamgano deposit

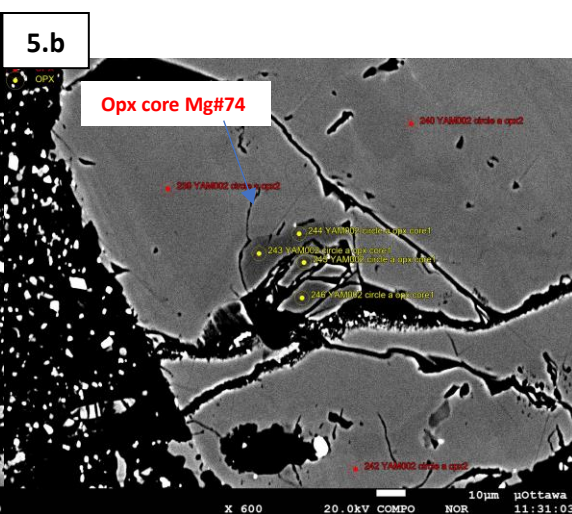
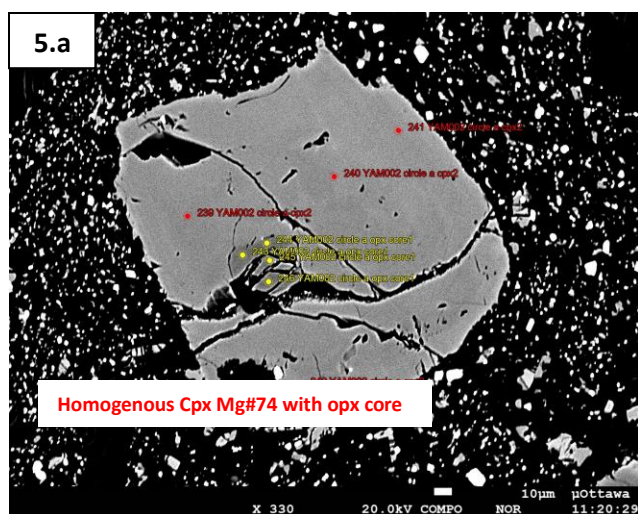
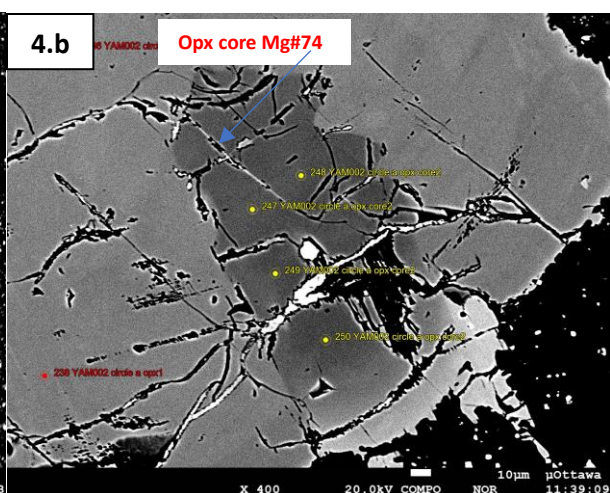
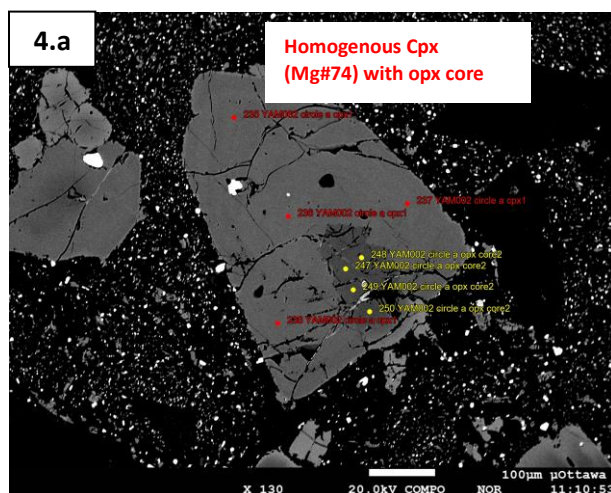
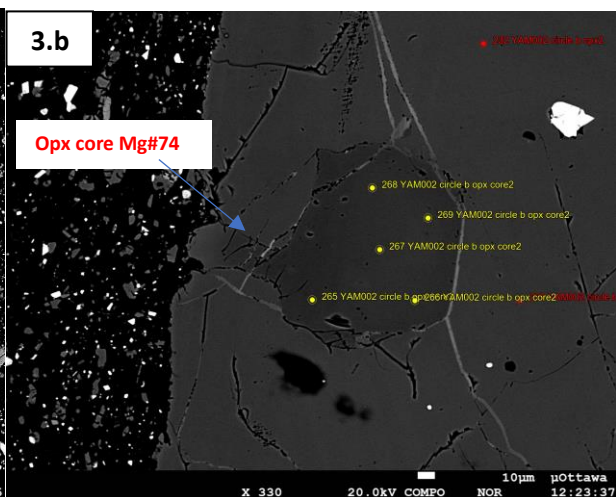
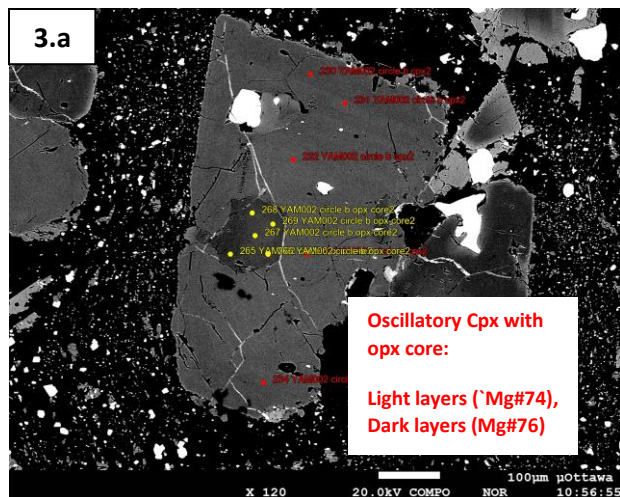
There are 3 different populations of Cpx in sample YAM002:

- 1) **Homogenous/unzoned Cpx (Mg#74)** where many of these grains have an Opx inclusions
- 2) **Oscillatory zoned Cpx** that have thin oscillating rings that alternate between Mg rich (Mg#76) and Mg poor (Mg#74). Several of these grains have Opx inclusions.
- 3) **Normally zoned Cpx** where these grains do not contain an opx inclusions (Core: Mg#81, Rim: Mg#74)

There are 3 different population of Opx in sample YAM002:

- 1) **oscillatory zoned Opx** between Mg rich (Mg#75) and Mg poor (Mg#73).
- 2) **normally zoned Opx** (Core: Mg#74, Rim: Mg#~68)
- 3) **Opx occurring as inclusions** within Cpx grains (Mg#74)







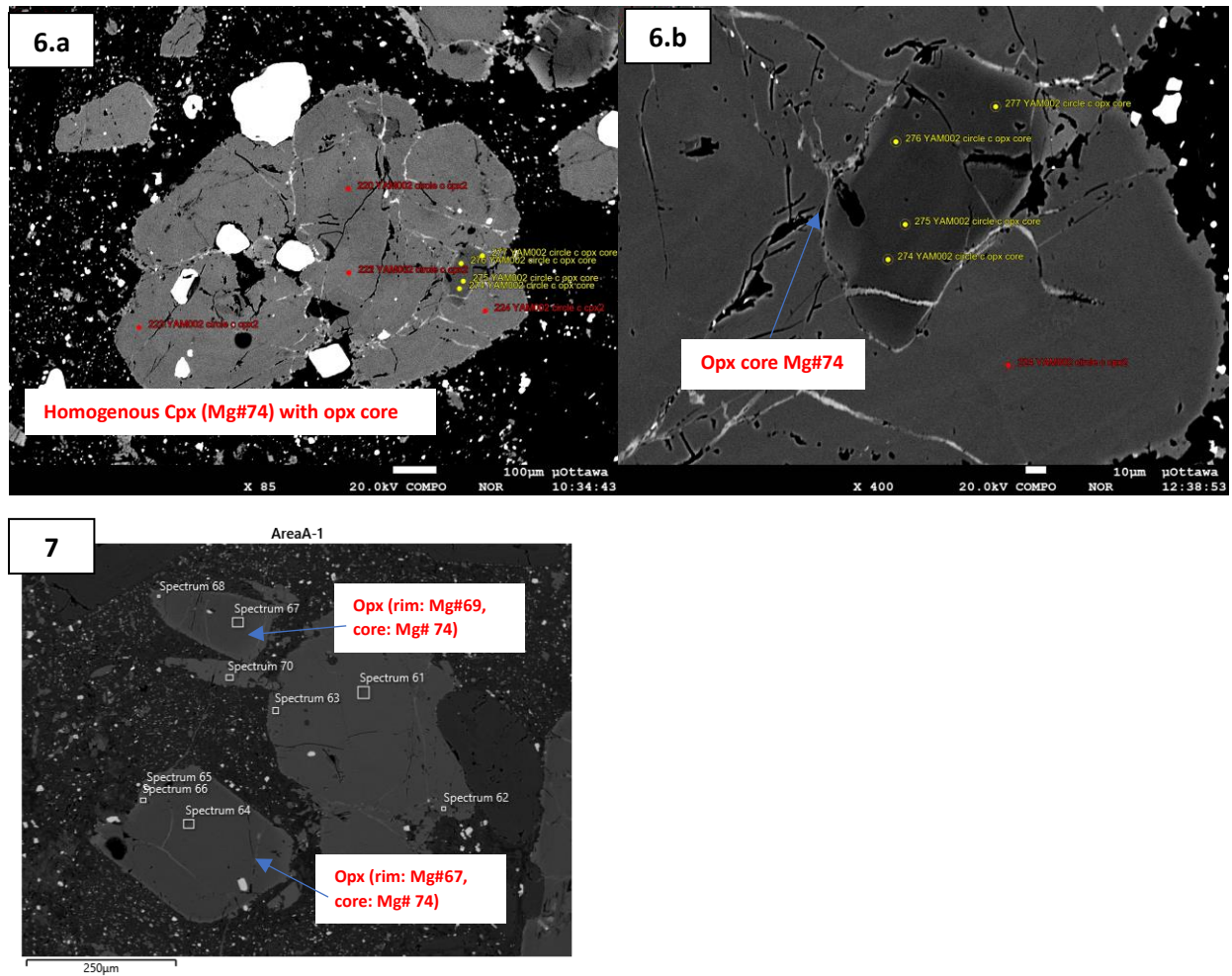


Figure A4.5-7 Normally zoned Cpx, 2) oscillatory zoned Opx with thin bands, 3.a and b) oscillatory zoned Opx (3.a) with an Opx core (3.b). Figures 4.a, 5.a and 6.a show a homogenous Cpx with an Opx core (figures 4.b, 5.b, and 6.b). Fig.7) normally zoned Opx.