

Magmatism and related Au-Cu mineralization in the Hualgayoc mining district, northern Peru

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Abstract

The Hualgayoc district in the Cajamarca region in northern Peru hosts the Cerro Corona Au-Cu porphyry deposit, the Tantauatay high-sulfidation epithermal Au deposit, and the AntaKori skarn Cu-Au project, plus other Au, Cu, Ag and base metal prospects.

Herein the author presents a comprehensive geochemical study and U-Pb dating of igneous rocks associated with mineralization as well as barren intrusions and volcanic rocks in the Hualgayoc district. Bulk rock geochemistry, electron-probe analysis of amphibole grains, and laser ablation ICP-MS analysis of zircon were conducted in order to define the magmatic history of the district and characterize the magmas associated with Au-Cu mineralization.

Zircon U-Pb ages indicate that the magmatic activity in the district occurred in the Miocene from 14.8 to 9.7 Ma. The Cerro Corona porphyry Au-Cu deposit formed in a short period of time at around 14.5 Ma. Most igneous rocks hosting the Tantauatay high-sulfidation Au epithermal deposit formed later at around 13.7-11.5 Ma, and are contemporaneous to the high sulfidation epithermal mineralization. Several barren intrusions and volcanic rocks were emplaced contemporaneously.

Bulk rock, zircon and amphibole composition show that all magmas in the Hualgayoc district originate from an amphibole rich source, and are oxidized and water-rich regardless of the presence of mineralization. The magma conditions are conducive for the formation of porphyry and high-sulfidation epithermal deposits. The absence of mineralization in some intrusions suggests that other factors, such as intrusion shape and depth of emplacement, are required for the formation of a deposit.

It has been shown that zircon in igneous rocks associated with porphyry deposits have high positive Ce anomalies and low negative Eu anomalies reflecting the oxidized nature of their parental magmas. Igneous zircon from the Hualgayoc district show that the magnitude of Ce and Eu anomalies is independent of the association with mineralization. The result suggests that zircon composition cannot identify specific intrusions associated with mineralization. However, it remains useful in recognizing areas containing oxidized, hydrous magmas, some of which may be associated with porphyry or high-sulfidation epithermal deposits.

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CHAPTER 1.

Global Introduction

1.1 Preamble

Porphyry systems are the world's major source of Cu, Mo and Au. They constitute 60% of the world's Cu reserves, and more than 90% of the world's Mo reserves (Sinclair, 2007). Porphyry systems are found at convergent plate boundaries and are associated with continental and island arc magmatism and collisional orogen magmatism. Porphyry systems are commonly restricted to linear belts often hundreds of kilometers long, oriented parallel to the subduction trench, where they occur as dense clusters or aligned along major structures. Porphyry systems usually occur as vertically elongated stocks (> 3 km) emplaced at shallow crustal level (< 5 km) above large underlying plutons at depth of 5 km to 15 km. Magmatic hydrothermal fluids exsolved from the cooling magma at shallow depth are responsible for the formation of hydrothermal systems, which extracts metals from the melt and concentrate them to economic concentration within the intrusion. The interaction of the hydrothermal fluids with the intrusions and the country rocks produces various types of alteration. They include early, high temperature potassic alteration in the core of the intrusion, followed by intermediate chlorite-sericite at shallower depth, and a late-stage propylitic alteration occurring laterally on the margin of the intrusion and the surrounding country rocks. Most of the Cu mineralization, bornite and chalcopyrite, are found in the potassic and sericitic alteration zones (Sillitoe, 2010).

Research has been focusing on understanding the genesis and characteristics of magmas associated with the formation of porphyry systems. It is understood that porphyry systems are associated with highly oxidized and hydrous magmas (Ishihara, 1977; Richards, 2008; Richards, 2014). Oxidized magmas have a greater capacity to dissolve sulfur and metals and transport them to shallow crustal levels where the high-water content is required to form a hydrothermal system. Ballard et al. (2002) suggested that oxidation conditions of magma may be used in the

exploration for intrusions hosting porphyry-type mineralization. One approach, first proposed by Ballard et al. (2002) focuses on determining the oxidation condition of magmas using the Ce and Eu anomalies in magmatic zircon. Several studies show that porphyry Cu mineralization is associated with igneous rocks containing zircon grains with small negative anomalies of Eu and large positive Ce anomalies (Ballard et al., 2002; Shen et al., 2015; Lu et al., 2016). The main advantage of the use of zircon is robustness and resistance to alteration. They can be recovered from stream sediments or glacial till to assess the potential of a region and can be used as a vectoring tool toward areas containing oxidized intrusions.

The Andes of South America constitute one of the longest belts containing porphyry systems in the world and result from the active subduction of the Nazca plate under the South-American plate. The Andes of western South America contain a high concentration of porphyry-Cu systems of Cretaceous to Pleistocene age, including some of the world's largest known porphyry Cu deposits such as El Teniente (128 Mt Cu) and Chuquibambilla (126 Mt Cu) in Chile (Singer et al., 2008). They also contain the largest high-sulfidation epithermal Au district in the world at Yanacocha, Cajamarca region, northern Peru. The Hualgayoc district, located 30 km north of the Yanacocha district, contain two major mines: the Miocene Cerro Corona Au-Cu porphyry and the Miocene Tantaquata high-sulfidation epithermal Au deposit, as well as several barren intrusions of similar age. Thus, the Hualgayoc district provides an ideal location to study the magmas associated with porphyry-style mineralization and the applicability of zircon as an exploration tool. The authors visited the Hualgayoc district in July 2017 to collect samples and investigate the geology of the district. This thesis reports the analytical results of these 2017 samples and those collected earlier in the district by Keiko Hattori in 2016.

1.2 Previous work relevant to the thesis project

1.2.1 Previous study of the Cajamarca Region and Hualgayoc District

The geology, alteration and mineralization in the Cajamarca region in northern Peru have been described by several workers. Davies (2002) reported the tectonic, magmatic and metallogenic evolution of the region, excluding the Hualgayoc district, based on $^{40}\text{Ar}/^{39}\text{Ar}$ dating, petrography, bulk rock geochemistry and Rb-Sr and Nd-Sm isotope compositions of Paleogene to Miocene igneous rocks. The geology, mineralization, alteration and magmatic evolution of the Yanacocha high-sulfidation district have been studied by Gustafson (2004), Chiaradia (2009) and Longo (2005, 2010), among others.

The Hualgayoc district has been the focus of several studies. Macfarlane (1989) conducted Pb, Rb and Sr isotope analysis of Miocene igneous rocks and Cretaceous sedimentary rocks in the district, as well as nearby metasedimentary basement rocks in order to define the origin of Pb in mantos and vein deposits, and degree of assimilation of crustal rocks by parental magmas. Gustafson (2004) did a review of the geology, alteration and mineralization in the Hualgayoc district with a focus on the Tantahuatay high-sulfidation epithermal Au deposit. The geology, mineralization and alteration of the Cerro Corona Au-Cu porphyry deposit were described by James (1998) and Longridge (2016).

1.2.2 Previous study of zircon and oxidation conditions of magmas associated with porphyry-Cu deposits

Previous workers attempted to quantify the oxidation conditions of magmas (Spencer and Lindsley, 1981; Stormer, 1983; Andersen et al., 1993). Ballard et al. (2002) first proposed the use of zircon Ce and Eu anomalies to identify oxidized intrusions for the exploration of porphyry

systems. They proposed a method based on the lattice strain model to calculate Ce^{4+}/Ce^{3+} of magmatic zircon using whole rock composition as proxy for the parental melt.

Ballard et al. (2002) calculated Ce^{4+}/Ce^{3+} and Eu/Eu^* in zircon from 14 barren intrusions and 7 syn-mineralization intrusion from the Chuquicamata-El Abra Cu belt in northern Chile. It was found that zircon from syn-mineralization intrusions had higher Ce^{4+}/Ce^{3+} and higher Eu/Eu^* ratios than those from barren intrusions, reflecting higher oxidation conditions of parental magmas responsible for the mineralization.

Shen et al. (2015) compared the Ce and Eu anomalies of porphyry copper deposits in the Central Asian Orogenic belt. Their result shows that intrusive rocks associated with porphyry-Cu deposits of intermediate to high tonnage (1.5-4 Mt Cu to > 4 Mt Cu) have higher Ce^{4+}/Ce^{3+} in zircon than intrusive rocks associated with porphyry-Cu deposits of low tonnage (<1.5 Mt Cu), suggesting that the degree of magma oxidation condition may have a control on Cu tonnage.

Smythe & Brennan (2016) provided a method to estimate fO_2 values of magmas during zircon crystallization based on cerium redox equilibria in silicate melts. The calculation of fO_2 requires zircon REE, Hf, Th and U composition, zircon Ce^{4+}/Ce^{3+} and melt composition at the time of zircon crystallization. Smythe and Brennan (2016) calculated the fO_2 using their method for zircon from the Bishop tuff (California, USA), Toba tuff (Indonesia) and Umiakovik pluton (Labrador, Canada). The calculated fO_2 values agreed within one log unit to independent estimates of magma fO_2 for the same suits.

Loucks et al. (2020) provided a new zircon oximeter using trace element in zircon. The calculation of fO_2 simply requires Ce and U concentration in zircon. The Calculated fO_2 using zircon from rocks including the Bishop Tuff (California, USA), the Toba Tuff (Indonesia) and the Fish Canyon Tuff (Colorado, USA) agrees well with fO_2 values obtained from the same rock

using the amphibole oxybarometer of Ridolfi et al. (2010) and the Fe-Ti oxide oximeter of Ghiorso & Evans (2008).

Lu et al. (2016) showed that zircon from porphyry deposits from various terranes including Iran and Southeast Asia have higher Ce/Nd/Y and Eu/Eu* ratio than zircon from barren rocks in Australia and the USA. They concluded that zircon composition, Ce and Eu anomalies are useful fertility indicators for the exploration of porphyry deposits.

1.2.3 Factors controlling the trace elements concentrations in zircon

Zircon is a zirconium silicate of chemical formula ZrSiO_4 crystallizing in the tetragonal system. The crystal structure consists of chains in which Zr^{4+} cations in an 8-fold coordination alternate with Si^{4+} cations in a tetrahedral coordination. In silicate melt, Zr^{4+} and Si^{4+} are commonly substituted by other cations, such Hf^{4+} , U^{4+} or U^{6+} , Th^{4+} , Ti^{4+} , Rare Earth Elements (REE, La to Lu), and Y^{3+} .

Ti^{4+} can substitute Si^{4+} in zircon due to similar ionic radii in a tetrahedral coordination (0.56 Å, and 0.40 Å, respectively) (Tailby et al., 2011). This substitution of Si^{4+} by Ti^{4+} is controlled primarily by the temperature. High melt temperature expands the zircon lattice, allowing Ti^{4+} cations to substitute more easily to the slightly smaller Si^{4+} cations. Therefore, zircon that crystallize at high temperature usually contains higher Ti content than zircon crystallizing at lower temperature in a melt with similar Zr content. Natural zircon typically contains Ti below 30ppm). This substitution mechanism is the basis of the Ti-in-zircon thermometer developed by Watson et al. (2006). Ti content in zircon is also influenced by the activity of silica (a_{SiO_2}) and the activity of titanium oxide (a_{TiO_2}) of the melt. High a_{SiO_2} and high TiO_2 allows more Ti^{4+} to substitute to Si^{4+} (Watson et al., 2006). Therefore, a_{SiO_2} and TiO_2 of the parental melt must be known to obtain accurate results.

U^{4+} and Th^{4+} can substitute to Zr^{4+} due to similar ionic radii in an 8-fold coordination (1.14 Å, 1.19 Å, and 0.98 Å, respectively). The concentration of U and Th in zircon, usually a few hundred ppm, depends on the U and Th content of the parental melt. Both elements are incompatible in the structure of major rock-forming minerals, therefore their concentration in the melt usually increase with magma evolution, unless minerals with high distribution coefficients (D , concentration in mineral/concentration in melt) for U and Th such as monazite crystallize. U and Th content in zircon can be used as a proxy for melt U and Th content, which may give indications regarding the degree of magma evolution and the presence of co-crystallizing mineral phases. The concentration of U in zircon can also be controlled by the oxidation conditions of the parental melt. In oxidized magmas, some of the U are in the 6+ oxidation state, which cannot substitute for Zr^{4+} in zircon.

Hf^{4+} can substitute to Zr^{4+} in zircon due to nearly identical ionic radii in an 8-fold coordination (0.97 Å, and 0.98 Å, respectively). Due to nearly identical ionic radius, Hf is the most compatible trace element in zircon. Similar to U and Th, Hf is incompatible major rock-forming minerals, therefore its concentration in the melt usually increase with fractional crystallization of magma. Therefore, the concentration of Hf in zircon, usually a few thousand ppm, is controlled by the degree of evolution of the parental melts, and can be used to trace magma evolution (e.g. Claiborne et al., 2010). Rare instances of extremely evolved melt with elevated Hf concentration can crystallize the mineral hafnon of formula $(\text{Hf,Zr})\text{SiO}_4$, which contains several wt% Hf replacing Zr and forms a solid solution with zircon (Yin et al., 2013).

The REEs including Y are common trace elements in zircon. In magmas, the REEs+Y are at the 3+ oxidation state. This requires complex substitution mechanisms for the incorporation of REEs+Y to zircon lattice. The dominant mechanism is the “xenotime” substitution, which consists of a coupled substitution $(\text{Y, REE})^{3+} + \text{P}^{5+} = \text{Zr}^{4+} + \text{Si}^{4+}$, where $(\text{Y, REE})^{3+}$ substitute to

Zr^{4+} and P^{5+} substitute to Si^{4+} (Speer, 1982). Like U, Th and Hf, REEs+Y concentrations in zircon depend on their concentrations in the parental magma at the time of zircon crystallization. Heavy REEs have smaller ionic radii, closer in size to Zr^{4+} than light REEs ($\text{La}^{3+} = 1.30 \text{ \AA}$; $\text{Yb}^{3+} = 1.12 \text{ \AA}$; $\text{Zr}^{4+} = 0.98 \text{ \AA}$). Y^{3+} has the same ionic radius as Ho ($1.16 \text{ \AA}$). Therefore, heavy REEs+Y are more easily incorporated in zircon than light REEs. Lu concentration in zircon commonly reaches few tens of ppm whereas La concentration in zircon is nearly always below 1 ppm. Due to high concentration of Y in magmas compared to other REEs, Y concentration in zircon can range from a few hundred to a few thousand ppm. The REEs+Y concentration in magma can be affected by various factors including oxidation conditions. In oxidized magmas, some Ce exist in the $4+$ oxidation state, and in reduced magmas some Eu exist at the $2+$ oxidation state. Ce^{4+} substitute more readily to Zr^{4+} than Ce^{3+} due to identical oxidation state to Zr^{4+} . Therefore, zircon crystallizing in oxidized magmas display a high positive Ce anomaly compared to zircon crystallizing in reduced magmas. The zircon oximeter of Smythe & Brenan (2016) and Loucks et al. (2020) is based on this phenomenon, more Ce in zircon formed in oxidized magmas. Eu^{2+} is strongly incompatible in zircon compared to Eu^{3+} . Therefore, zircon crystallizing in reduced magmas display a profound negative Eu anomaly compared to zircon crystallizing in oxidized magmas. Co-crystallizing mineral phases may also affect the REE composition of zircon. REEs+Y are highly compatible in titanite, and titanite has slightly more affinity with the middle REEs than the light and heavy REEs. Therefore, the crystallization of titanite depletes REEs in the melt and causes a negative middle REEs anomaly. Titanite also preferentially incorporates Sm^{3+} and Gd^{3+} over Eu^{3+} , causing a positive Eu anomaly in the melt. This will be reflected in the composition of zircon crystallizing together or after titanite. Zircon crystallizing together or after titanite display overall low REEs, low middle REEs compared to heavy REEs and a very weak negative Eu anomaly (Loader et al., 2017). Amphibole crystallization will have a similar effect to

titanite on zircon composition although in a lesser degree due to lower D values of amphibole.

The crystallization of plagioclase depletes Eu in the melt because of high D value for Eu^{2+} and causes zircon to display profound Eu anomalies. Ionic radii of elements are from Shannon (1976).

1.3 Objectives of thesis project

- i. Establish the magmatic history of the Hualgayoc district through U-Pb zircon geochronology
- ii. Characterize the igneous rocks responsible for the formation of mineralized and barren intrusions in the Hualgayoc district using bulk rock, amphibole and zircon composition
- iii. Assess the applicability of Ce and Eu anomalies of magmatic zircon in evaluating the fertility of magmas

1.4 Scientific contributions of the thesis

The most significant contributions of this thesis are listed below:

- i. The magmatic history of the Hualgayoc district was previously not constrained well, with only a few intrusions dated by different workers using different dating techniques. Most dates were obtained from K-Ar on whole rock or alteration minerals. One intrusion in particular was wrongly thought to be of Eocene age based on Rb-Sr isochron. Our study provides new magmatic zircon U-Pb ages of numerous intrusion and extrusive rocks in the district, including igneous rocks associated with the Cerro Corona Au-Cu porphyry and Tantahuatay high-sulfidation epithermal Au deposit. This gives a better understanding of the magmatic history of the Hualgayoc district and of the Cajamarca region as a whole.

- ii. We provide the first extensive geochemical study of igneous rocks in the Hualgayoc district, including the compositions of bulk rock, zircon and amphibole. The data are compared with arc magmas associated with mineralization in the Cajamarca region. This may be helpful in the exploration for metal deposits in the Hualgayoc district and the Cajamarca region. On a larger scale, our findings also contribute to the general understanding of the genesis of magmas associated with porphyry and high-sulfidation epithermal type deposits in the Andes.
- iii. Our zircon composition data from the Hualgayoc district contribute to better constrain the applicability and limitations of the Ce and Eu anomalies in the exploration for porphyry and high-sulfidation epithermal type deposits. Previous studies mostly focused on comparing Ce and Eu anomalies in zircon from igneous rocks associated with mineralization to those from igneous rocks in different geographic location, of different ages, or from intrinsically barren suits. Our study compares zircon composition from mineralized and barren rocks of similar ages in the same geographic location.

1.5 Thesis outline

This thesis comprises five chapters. The first chapter, a global introduction, describes a preamble, previous studies related to the project, objectives of the thesis project, scientific contributions of the thesis, thesis outline, and statement of the author's original contributions.

Chapter 2 describes the analytical methods and procedures employed for data acquisition.

Chapter 3 is a manuscript in preparation for submission to the Society of Economic Geologists Special Publication, a tribute to Jeremy P. Richards (1960–2019). It presents the magmatic history and characteristics of magmas associated with porphyry-style mineralization and barren intrusion in the Hualgayoc district, and how they compare to other arc magmas of similar age in the Cajamarca region.

Chapter 4 is a manuscript submitted to the Journal of Geochemical Exploration in November 2019 from which we received reviews in July 2020 and started to address the comments from reviewers. It focuses on assessing the applicability of zircon Ce and Eu anomalies in evaluating the fertility of magmas for the exploration of porphyry-style mineralization. Since manuscripts include regional and local geology of the study area, several statements in this chapter are similar to those in Chapter 3.

Chapter 5 is the global conclusion of the thesis.

1.6 Statement of the author's contribution

This thesis constitutes the original research conducted by Martin Viala under the supervision of Professor Keiko Hattori at the University of Ottawa. The following outlines the contribution of the author.

Contributions:

- M. Viala wrote all chapters and produced all figures and tables
- Field work in July 2017 was assisted by K. Hattori
- Thin section preparation by Alain Mauviel at the University of Ottawa
- M. Viala conducted petrographic studies on thin sections and hand samples
- M. Viala prepared hand samples for bulk rock major and trace element analysis

- M. Viala processed hand samples to separate zircon grains, followed by mounting and polishing grains into epoxy resin
- M. Viala conducted scanning electron microscope (SEM) work on thin sections and mounted zircon grains at the University of Ottawa with the assistance of Glenn Poirier and David Diekrup
- M. Viala conducted Laser-Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS) work at the University of Ottawa with the assistance of Samuel Morfin.
M. Viala conducted data reduction
- M. Viala conducted electrons probe micro-analyzer (EPMA) work on thin sections at the University of Ottawa with the assistance of Glenn Poirier
- K. Hattori and J. Heddenquist provided useful comments on the manuscript

Several aspects of this manuscript were presented at conferences and published as meeting abstracts:

- Viala, M., Hattori, K., Baumgartner, R., Gomez, P., 2017. Characterization of igneous rocks in the Hualgayoc mining district, northern Peruvian Cordillera. SEG-PDAC Minerals Colloquium. (March 6, 2017, Toronto).
- Viala, M., Hattori, K., Gomez, P., 2018. Gold-copper fertile intrusions in the Hualgayoc mining district, Peru. SEG-PDAC Minerals Colloquium (March 5, 2018, Toronto)

Second Best Presentation Award
- Viala, M., Hattori, K., Gomez, P., 2018. Gold-copper fertile magmas in the Hualgayoc mining district, northern Peru. Advances in Earth Science Research Conference

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CHAPTER 2.

Analytical methods

2.1 Bulk-Rock Composition

Selected samples were stained using sodium cobaltinitrite to examine the occurrence of K-feldspar. Loss on ignition (LOI) was measured at the University of Ottawa using 1 g to 5 g of pulverized samples after heating the samples at 1050 °C for 2 h. Major elements, Sr and Zr were measured using a Rigaku Supermini 200 wavelength dispersive X-ray fluorescence spectrometer (XRF) on fused glass of pulverized samples mixed with lithium metaborate and lithium tetraborate at the University of Ottawa. Accuracy was calculated by comparing measured values to certified value GSP-2. Most elements show the accuracy better than 95%.

Trace element analyses, including REE, were performed at Actlabs (analytical code 4LITHOS) in Ancaster, Ontario, Canada. Pulverized samples were fused with sodium peroxide in a Zr crucible. The fused samples were dissolved in nitric and hydrochloric acids. The resulting solutions were diluted and analyzed using an Agilent 7900 inductively coupled plasma-mass spectrometer (ICP-MS) and a Varian 735ES Inductively coupled plasma-optical emission spectrometer (ICP-OES). Precision of the analysis was determined by comparing duplicate samples. Accuracy was calculated by comparing measured values to certified values NIST 696, NCS DC86303, NCS DC86314, OREAS 101a, OREAS 13b, OREAS 131a, GXR-1, GBW 07239, MP-1b and CCU-1e. Most elements show the accuracy better than 90%. Bulk rock composition data are given in Table A1-2.

2.2 Zircon analyses for compositions and U-Pb ages

Rock samples were crushed and separated into several size fractions using sieves of 500 µm, 210 µm, 125 µm and 53 µm mesh size. Zircon grains were concentrated from the 210-125µm and 125-53µm fractions using conventional magnetic and density techniques. Clear pink

grains were handpicked under a binocular microscope and mounted into an epoxy resin. Grains were examined under transmitted light microscope and cathodoluminescence detector attached to a scanning electron microscope (SEM-CL) at the University of Ottawa MicroAnalysis Laboratory. Transparent zircon grains without alteration, inclusions and fractures were selected for the analysis. Zircon grains showing sector zoning were rejected for trace element analysis as they have highly heterogeneous compositions (Hoffman and Long, 1984).

Trace element abundances were determined at the University of Ottawa using an Agilent 7700x ICP-MS coupled with a Photon Machines Analyte Excite 193 nm excimer laser. Reference materials NIST 612, BCR, GSEG1, BCR2G and GSD1G (Jochum et al., 2011) and 91500 zircon (Wiedenbeck et al., 1995) were analyzed for every seven unknown zircon samples. The presence of mineral inclusions was monitored using Ce, Ca, Sr, and Fe. Raw data were reduced using the GLITTER software (Griffin et al., 2008) with NIST612 reference material as the primary standard. Trace element concentrations were obtained based on the count ratios of the element to ^{29}Si and the composition of NIST612 (72.1 wt% SiO_2 , Jochum et al., 2011) and the stoichiometric zircon SiO_2 content (31.57 wt%). BCR and GSEG1 reference materials were used as secondary standards, and 91500 and Plešovice zircon were used to validate the analytical data. The instrument set-up and analytical method are essentially identical to those described in detail by Kobylinski et al. (2020). LA-ICP-MS trace elements in zircon data summary is given in Table A1-5 and A2-2. Detailed metadata for LA-ICPMS trace element analysis sessions are described in Table A1-6.

U-Pb ages of zircon from all samples except those from the Cerro Corona intrusive complex were obtained on separate runs using the same Agilent 7700x ICP-MS coupled with a Photon Machines Analyte Excite 193 nm excimer laser. Data reduction and correction for

instrument drift were processed using the GLITTER software, with 91500 zircon (1065 ± 0.3 Ma; Wiedenbeck et al., 1995) used as internal standard. Inclusions were monitored using Ce. Individual zircon ages were calculated from $^{206}\text{Pb}/^{238}\text{U}$ ratio using the IsoplotR software (Vermeesch, 2018), a modified program of the original *Isoplot* program by Ludwig (2003). 91500 zircon and Plešovice zircon (337.13 ± 0.37 Ma; Sláma et al., 2008) were used as external standard for validation of calculated ages. LA-ICP-MS zircon U/Pb data summary is given in table A1-3. Detailed metadata for LA-ICPMS U-Pb analysis sessions are described in Table A1-6.

Ages of zircon from intrusive phases 1, 4, 5 and 6 of the Cerro Corona intrusive complex were determined with the SHRIMP II at the Geochronological Laboratory of the Geological Survey of Canada. Selected zircons were mounted with standards FCT (Bachmann et al., 2007), Temora (Black et al., 2003), and GCS 6266 zircon (Whalen et al., 2017) with respective ages of 28.402 ± 0.023 , 416.5 ± 0.22 and 559 Ma. Zircon grains were mounted in epoxy, polished and coated with gold. Individual zircon ages were calculated from ^{207}Pb -corrected $^{206}\text{Pb}/^{238}\text{U}$ ratio using the IsoplotR software (Vermeesch, 2018). The instruments and analytical method are described in Boutonnet et al. (2012) and Whalen et al. (2017). SHRIMP zircon U/Pb data summary is given in Table A1-4

2.3 Amphibole composition

Igneous amphibole grains in thin sections made from sample SN from the San Nicolas intrusion and sample CD from the Coymolache Sill were examined by SEM to select suitable grains for analysis. Four different areas were examined in a total of four grains for sample CD, and three areas in each grain in a total of three grains in sample SN. The analyses of each areas in each grain were averaged. Quantitative analysis of their compositions was carried out using a

JEOL 8230 electron probe microanalyzer at the University of Ottawa. An accelerating voltage of 15 kV and a beam current of 20 nA using a beam size of 5 μm in diameter were used. Elements were acquired using analyzing crystals LIF for Fe k_{α} , Mn k_{α} , PETJ for K k_{α} , Ca k_{α} , PETL for Ti k_{α} , Cr k_{α} , Cl k_{α} , and TAP for Si k_{α} , Mg k_{α} , Al k_{α} , F k_{α} , Na k_{α} . The standards were Albite for Na k_{α} , Diopside #1 for Ca k_{α} , Mg k_{α} , Sanidine for Al k_{α} , Si k_{α} , K k_{α} , Hematite for Fe k_{α} , Rutile for Ti k_{α} , Tephroite for Mn k_{α} , Fluorite for F k_{α} , Tugtupite for Cl k_{α} , and Chromite for Cr k_{α} . The analytical procedure is essentially identical to that described in detail by Kobylinski et al. (2020). Amphibole data compositions and detailed metadata for analysis are given in Table A1-7.

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CHAPTER 3.

Magmatism and related Au-Cu mineralization in the Hualgayoc mining district, Northern Peru

Manuscript in preparation for submission to the Society of Economic Geologists Special
Publication, a tribute to Jeremy P. Richards (1960–2019).

3.1 Introduction

Porphyry-style Cu±Au and high-sulfidation Au deposits are important global suppliers of Cu and Au (Sillitoe, 2010). The Cajamarca region in the northern Peruvian Cordillera hosts numerous Miocene porphyry-related Cu±Au±Mo deposits and high-sulfidation Au epithermal deposits, including the Yanacocha deposit, the world's largest high-sulfidation Au deposit (Harvey et al., 1999; Longo et al., 2010), with >1200 t Au production.

The Hualgayoc district, located in the northern part of the Cajamarca region, was historically important producer of Ag in Peru (Gustafson, 2004). The district contains many Miocene igneous rocks, of dioritic to rhyolitic compositions, forming sills, plugs, domes and lava flows. Many of these rocks are barren, but some are associated with Au and Cu mineralization. Today, the Hualgayoc district hosts to major mines: the Cerro Corona Au±Cu porphyry deposit (James, 1998) and the Tantahuatay high-sulfidation Au deposit (Gustafson et al., 2004), plus the AntaKori Cu-Au-Ag skarn project (Eggleson et al., 2019) and other Au, Cu, Ag and base metals prospects. The tonnage of deposits is listed in Table 1.

This study examines both mineralized and barren igneous rocks in the Hualgayoc district to characterize the parental magmas and better understand the factors important for the formation of porphyry and high-sulfidation type deposits in the Northern Andes.

Previous studies show that highly oxidized and water-rich magmas are required for the formation of mineralized porphyry systems (e.g. Ishihara, 1977; Richards, 2008; Richards, 2014). We investigate the influence of these parameters on the formation of mineralization in the Hualgayoc district using EPMA analysis on amphibole and laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS) analysis on zircon from both barren and mineralized intrusions. We also perform U-Pb geochronology on zircon to define the magmatic history of the

district and evaluate the magmatic evolution in the Hualgayoc district over time and put it in context with other mineralized magmatic centers in the Cajamarca region.

3.2 Geological setting

3.2.1 Tectonic and magmatic history of the Cajamarca region

The Hualgayoc district is located in the northern part of the Cajamarca region, in the northern Peruvian Andes at 4000 m elevation (Fig. 1). The northern Peruvian Andes consist of four principal trench-parallel terranes oriented NW-SE: the Coastal belt, the Western Cordillera, the Marañon Fold Thrust Belt and the Eastern Cordillera. The Coastal belt consists of barren coastal batholiths of Upper Cretaceous to Paleocene ages (Mukasa and Tilton 1984; Cobbing 1999). The Western Cordillera is composed of Precambrian to Paleozoic metasedimentary rocks, which are overlain by Ordovician to Upper Cretaceous siliciclastic and carbonate sedimentary rocks (Scherrenberg et al., 2012). The Eastern Cordillera is separated from the Western Cordillera by the Marañon Fold Thrust Belt and consists of Paleozoic metasedimentary rocks intruded by Ordovician to Triassic rocks (Chew et al., 2016).

The Cajamarca region is located in the northern part of the Western Cordillera (Fig. 1). The crystalline basement of Precambrian age is overlain by a thick (> 2 km) Upper Jurassic to Lower Cretaceous siliciclastic sedimentary rocks in the base and ~1500 m thick Upper Cretaceous limestone beds and shales (Benavides-Caceres, 1956; Wilson, 1984). They are overlain by Eocene to Miocene intermediate to felsic volcanic rocks of the Llama-Calipuy Group and are intruded by numerous mafic to felsic intrusive bodies of similar ages. The igneous rocks formed in response to the easterly subduction of the Farallon and Nazca Plate. The sedimentary rocks were deformed during two periods of Tertiary tectonism in the northern Peruvian Andes:

the Inca Orogeny and the Quechua Orogeny (Mégard, 1984; Benavides-Cáceres, 1999). The Inca Orogeny involved four pulses of crustal shortening during Paleocene to Miocene time: Inca I (59-55 Ma), Inca II (44-43 Ma), Inca III (26 Ma) and Inca IV (22 Ma). Pulse I and II of the Inca orogeny are due to a change in subduction direction from NNE to NE and an increase in the subduction rate of the subducting Farallon plate below the South American continent (Pardo-Casas and Molnar, 1987). Pulse III of the Inca orogeny coincide with the break-up of the Farallon plate into the Nazca and Coco plates followed by rapid convergence and clockwise rotation of the Nazca plate (Padro-Casas and Molnar, 1987). The Quechua orogeny corresponds to crustal thickening events in three pulses during Pliocene-Miocene time: Quechua I (17 Ma), Quechua II (8-7 Ma) and Quechua III (7-4 Ma) (Benavides-Cáceres, 1999), which coincide with the rapid subduction of the Nazca plate (Padro-Casas and Molnar, 1987).

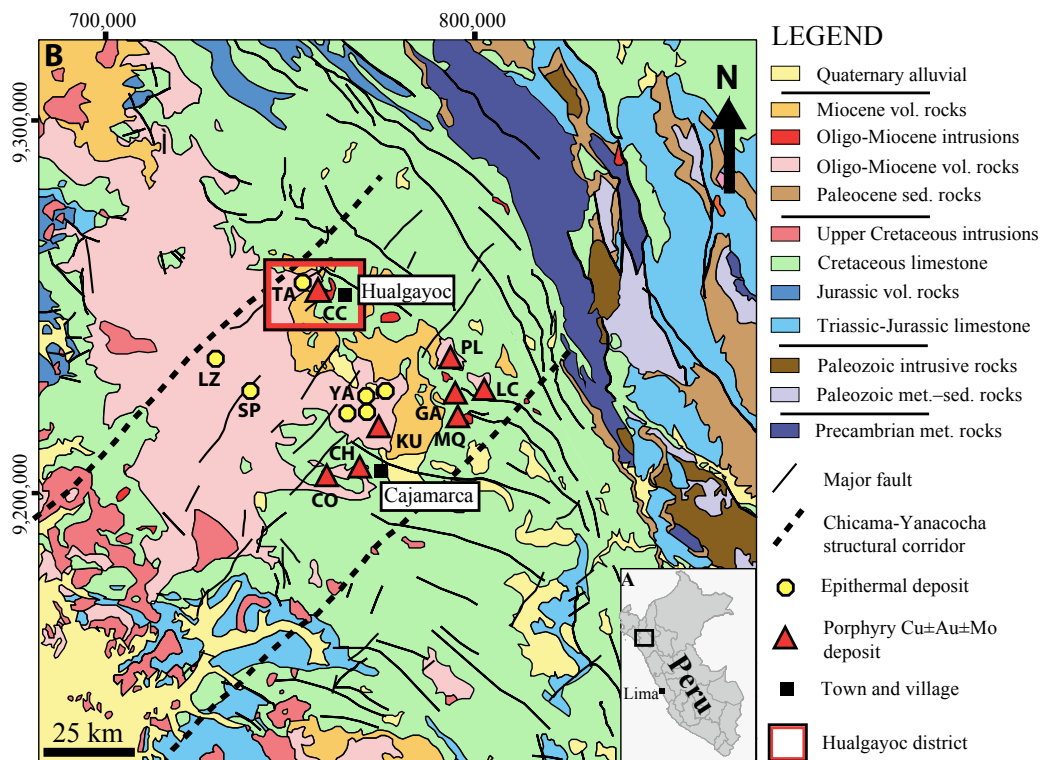


Figure 3.1 (A) Location of the Cajamarca Region (black square) within Peru. (B) Geological map of the Cajamarca region showing the locations of major porphyry Cu±Au and high-sulfidation Au deposits. The Hualgayoc District is located 30 km north of the Yanacocha district.

CC= Cerro Corona, CH= Chamis, CO= Colpayoc, GA= El Galeno, KU=Kupfertal, LC= La Carpa, LZ= La Zanja, MQ= Michiquillay, PL= Perol, SP= Sipan, TA= Tantahuatay, YA= Yanacocha. Modified after Brewer and Davis (2004). UTM coordinates are WGS84 Zone 17.

Two major magmatic episodes are recorded in the Cajamarca region. The oldest episode occurred during the Paleogene (57-35 Ma) and produced the basaltic to andesitic Llama-Calipuy volcanic sequence (Noble et al., 1990; Davies, 2002), and the intermediate barren intrusions of Cocanes East (43.6 Ma; Llosa et al., 1996), Cerro Montana (47 Ma), La Carpa (42.55 Ma), and Cerro Perol East (57 Ma) (Davies, 2002). This magmatism coincides with high convergence rate of the Farallon plate associated with pulses I and II of the Inca orogeny. Magmatic activity decreased from 36 to 24 Ma due to slow convergence rate (Pardo-Casas and Molnar, 1987). Mafic dykes at 29.5 Ma (Davies, 2002) mark the onset of pulse III of the Inca orogeny.

Pulse IV of the Inca orogeny at 22 Ma marks the onset of the second episode of major magmatic activity in the Cajamarca region during the Miocene (23 Ma-7Ma). Early-Miocene to Middle-Miocene magmatic activity from 23 Ma to 16 Ma occurred during the formation of several porphyry Cu±Au deposits in the southeastern part of the Cajamarca region. They include Minas Congas (23.2-17.1 Ma), Michiquillay (19.8 Ma) and El Galeno (17.5-16.5 Ma), and Minas Carpa (~17 Ma) (Davies, 2002). The tonnage of these deposits is listed in Table 1. Several barren intrusions were emplaced during the same period. They include the Aurora Patricia (21.3 Ma), Michiquillay north (20.6 Ma) and La Carpa (17.9 Ma) intrusions (Davies, 2002). Pulse I of the Quechua orogeny at 17 Ma marks the start of magmatic-hydrothermal activity in the Hualgayoc district, which lasts until around 9 Ma. Magmatic-hydrothermal activity in the Yanacocha district, located 30 km south of the Hualgayoc district, started at ~16 Ma and formed the first deposit of the Yanacocha high-sulfidation district at 13.5 Ma, with the largest deposit forming later at 9-8

Ma (Longo et al., 2010). Cessation of major magmatic activity in the Cajamarca region coincides with pulse II of the Quechua orogeny at 7–8 Ma.

Deposit name ¹	Deposit type	Tonnage (Mt)	Grade		Comment
			Cu (wt%)	Au (g/t)	
Hualgayoc district					
Cerro Corona	Porphyry Au-Cu	110 [1]	0.5 [1]	0.9 [1]	54.4 t Au, 0.37 Mt Cu produced, 2009-2019 [4]
Tantahuatay	High-Sulfidation Au-Ag	225 [1]	–	0.33 [1]	23.8 t Au produced, 2014-2018 [6]
AntaKori project	Skarn Cu-Au	517 [5]	–	–	Indicated and inferred resources consist of 2.3 Mt Cu and 140 t Au (2019) [5]
Cajamarca region					
Minas Conga	Porphyry Au-Cu	641 [1]	0.28 [1]	0.75 [1]	
El Galeno	Porphyry Cu-Au	661 [1]	0.5 [1]	0.12 [1]	
Michiquillay	Porphyry Cu	1150 [1]	0.63 [1]	–	
Sipan	High-Sulfidation Au-Ag	16 [1]	–	2 [1]	~30 t Au in oxide zone mined before 2001 [1]
La Zanja	High-Sulfidation Au-Ag	33 [1]	–	0.69 [1]	19.4 t Au produced, 2014-2018 [6]
Yanacocha district	High-Sulfidation Au-Ag	–	0.63 [1]	0.98 [1]	1225 t Au produced, 1993–2010 [2]; 81.2 t 2015-2019; proven and probable reserves (2019): 216 t Au (oxide and sulfide), 0.66 Mt Cu (sulfide) [7]

La Carpa, Chamis and Colpayoc are porphyry prospects with no available values of reserves

References: [1] M. Cardozo, pers. comm. (2020); [2] Longo et al. (2010); [3] Candiotti and Guerrero (1997); [4] <https://www.goldfields.com>; [5] <https://regulusresources.com/projects/resource/>; [6] www.buenaventura.com [7] www.miningdataonline.com

¹Locations are shown in Figure 1

Table 3.1: Tonnage and grade data of deposits from the Cajamarca region

3.2.2 Geology of the Hualgayoc district

The Hualgayoc district is largely underlain by weakly folded Cretaceous limestone and minor sandstone. The stratigraphy of the district is described in detail by Benavides-Cáceres

(1956) and Wilson (1963). The district was cut by several NW—SE and NE—SW trending faults during pulse I of the Inca orogeny at 59-55 Ma under compressional regime (Benavides-Cáceres, 1999). These faults were later reactivated during pulse I of the Quechua orogeny at ~17 Ma, in the Middle Miocene, again under regional compression (Benavides-Cáceres, 1999).

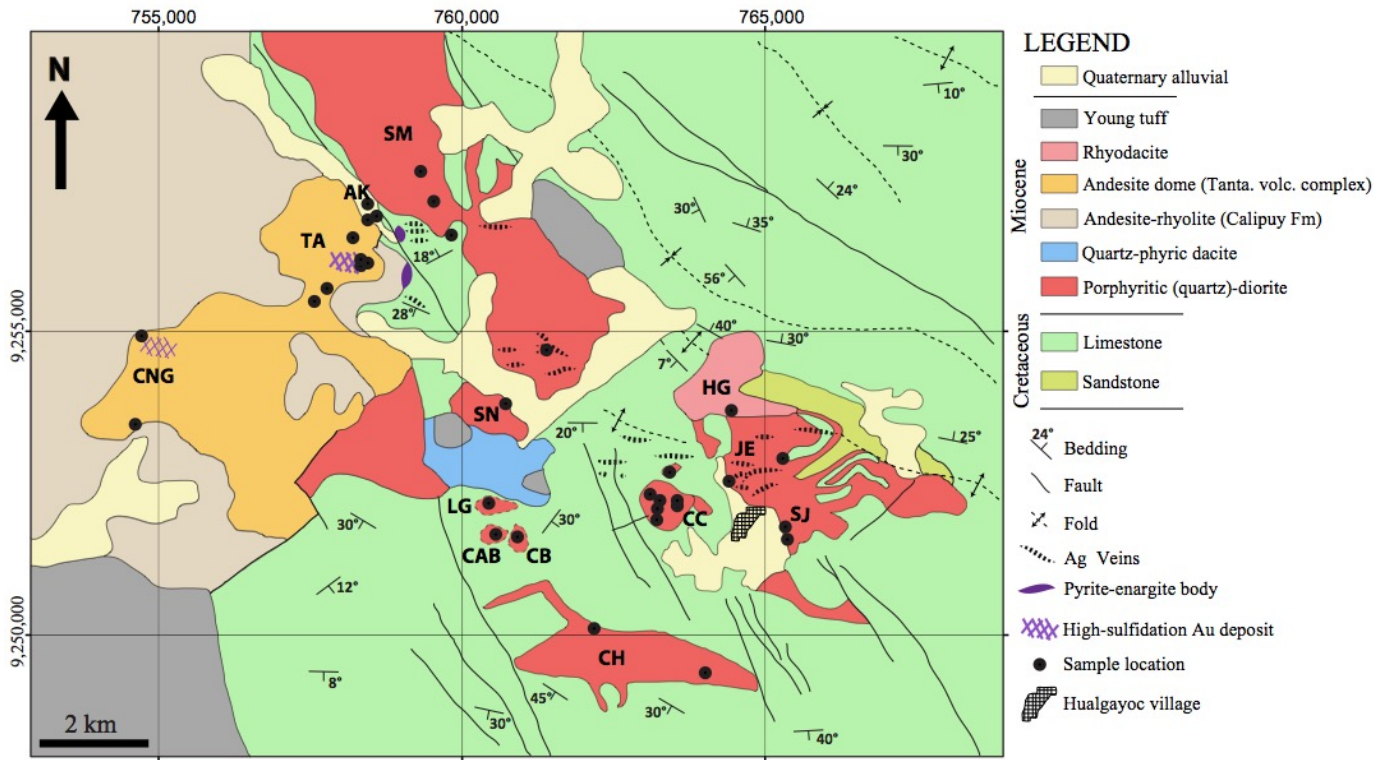


Figure 3.2. Simplified geological map of the Hualgayoc District showing sample locations and igneous units. Abbreviations: AK= AntaKori, CAB= Caballerisa, CB= Choro Blanco, CC= Cerro Corona, CH = Coymolache, HG= Hualgayoc, JE = Cerro Jesus, LG= Las Gordas, SJ = San Jose, SM= San Miguel, SN= San Nicolas, TA= Tantahuatay 2, CNG= Cerro Cienaga. Modified after S. Canchaya, J. Paredes and R. Tosdal (1996), cited by Gustafson et al. (2004). UTM coordinates are WGS84 Zone 17.

Igneous units in the Hualgayoc district are listed in Table 2. In the western part of the Hualgayoc District, the Cretaceous sedimentary rocks are overlain by andesitic to rhyolitic flows, domes and tuffs of the Calipuy Formation and intruded by several porphyritic necks and dykes of similar composition of the Tantahuatay volcanic complex (Orange on Fig. 2).

The eastern and northwestern parts of the district are dominated by amphibole $\pm$ biotite porphyritic quartz-diorite including the Cerro Corona intrusive complex, the Coymolache sill, the Cerro Jesus, Cerro San Jose, Cerro Las Gordas, Cerro Caballerisa, Cerro Choro Blanco, San Nicolas and the San Miguel intrusions, plus the Hualgayoc rhyodacite dome north of Cerro Jesus.

Igneous unit	Abbreviations in the map	Lithology	Primary minerals
Cerro Corona (phase 1 to 6)	CC	Qz-diorite porphyry	Bt. Hbl. Pl. Qz. Ap. Mag. Ilm. Zrn
San Jose	SJ	Qz-diorite porphyry	Bt. Hbl. Pl. Qz. Mag. Ilm. Ap. Zrn
Tantahuatay – Tantahuatay 2 center	TA	Altered igneous rock	Qz (residual). Zrn.
Tantahuatay – Cerro Cienaga center	CNG	Altered porphyry	Pl. Qz. . Zrn.
AntaKori PK	AK	Altered Pl-Qz porphyry	Pl. Qz. Zrn.
AntaKori PF		Altered Pl-Qz-Bt porphyry	Pl. Qz. Bt. Zrn.
Cerro Jesus	JE	Qz-diorite porphyry	Pl. Hbl. Qz. Ap. Zrn.
Cerro Choro Blanco	CB	Diorite porphyry	Pl. Hbl. Qz. Zrn.
Cerro Caballerisa	CAB	Diorite porphyry	Pl. Hbl. Qz. Zrn.
Las Gordas	LG	Silicified intrusive rock	Qz (residual). Zrn.
Coymolache	CO	Qz-diorite porphyry	Pl. Hbl. Bt. Qz. Kfs. Mag. Zrn.
San Miguel	SM	Qz-diorite porphyry	Pl. Hbl. Bt. Qz. Kfs. Mag. Ilm. Zrn.
San Nicolas	SN	Qz-diorite porphyry	Pl. Hbl. Bt. Mag. Zrn.
Calipuy volcanic formation		Andesite	Bt. Pl. Qz. Hbl. Zrn.
		Rhyolite	Bt. Pl. Qz. Kfs. Hbl. Zrn.
Hualgayoc	HG	Rhyodacite	Bt. Pl. Kfs. Qz. Zrn.

Table 3.2: Igneous units in the Hualgayoc district. Abbreviations: Ap: apatite; Bt: biotite; Hbl: hornblende; Ilm: ilmenite; Kfs: potassic feldspar; Mag: magnetite; Pl: plagioclase; Qz: quartz; Zrn: zircon

The Hualgayoc district hosts various styles of mineralization emplaced between 15 and 11 Ma (Macfarlane and Petersen, 1990; Macfarlane *et al.*, 1994; Noble and McKee, 1999). They include porphyry Au-Cu mineralization at Cerro Corona, high-sulfidation epithermal Au mineralization at Tantahuatay skarn Cu-Au-Ag mineralization at the AntaKori area. Minor

occurrences of Pb-Zn-Cu-Ag veins and mantos are reported near the Hualgayoc village by Macfarlane (1989).

The Cerro Corona porphyry Au-Cu deposit (CC on Fig. 2) is located 2 km west of the Hualgayoc village in the western part of the district. This porphyry deposit is hosted by multiple quartz-diorite intrusions emplaced in Cretaceous limestone. At least six separate intrusive phases are identified. Au and Cu Tonnage are listed in table 1.

The Tantahuatay volcanic complex hosts high-sulfidation Au deposits (Gustafson et al., 2004); enargite and pyrite are associated with pervasive silicification and pyrophyllite $\pm$ alunite alteration. K/Ar age of hypogene alunite (12.4 ± 0.4 ; Macfarlane et al., 1994) indicates the alteration at Tantahuatay occurred nearly 2 m.y. after formation of the Cerro Corona intrusive complex. Au mineralization is localized in two centers, Tantahuatay 2 (TA on Fig. 2), and Cerro Cienaga (CNG on Fig. 2) (Gustafson et al., 2004). Au tonnage is listed in table 1.

The AntaKori Project located north the Tantahuatay 2 mine (AK in Fig. 2) contains several porphyritic intrusive units emplaced in Cretaceous limestone and overlain by volcanic and volcanoclastic rocks of the Calipuy formation. The mineralization includes Cu-Au-Ag skarn mineralization hosted in the limestone, and Cu-Au-Ag $\pm$ Mo porphyry mineralization. Fragments of brecciated porphyritic rocks in a drill core display secondary K-feldspar and biotite (Stewart Redwood, Pers. Comm., 2017) indicating high-temperature potassic alteration at depth. Cu and Au tonnages are listed in table 1.

3.3 Results

3.3.1 Samples and alteration

Most samples were collected from outcrops (description and locations listed in Table A1-1 in the Appendix, and photographs of representative hand specimens are presented in Fig. 3).

Two samples from the San Jose intrusion were obtained from drill cores provided by Gold Fields La Cima S.A. Samples from Cerro Corona were collected from the mine open pit. All samples from the Tantahuatay area were obtained from drill cores in the Tantahuatay mine, with access provided by Compañía de Minas Buenaventura S.A.A, except sample CNG-1, which was collected from an outcrop. Samples from the AntaKori area were obtained from drill cores of Regulus Resources Inc.

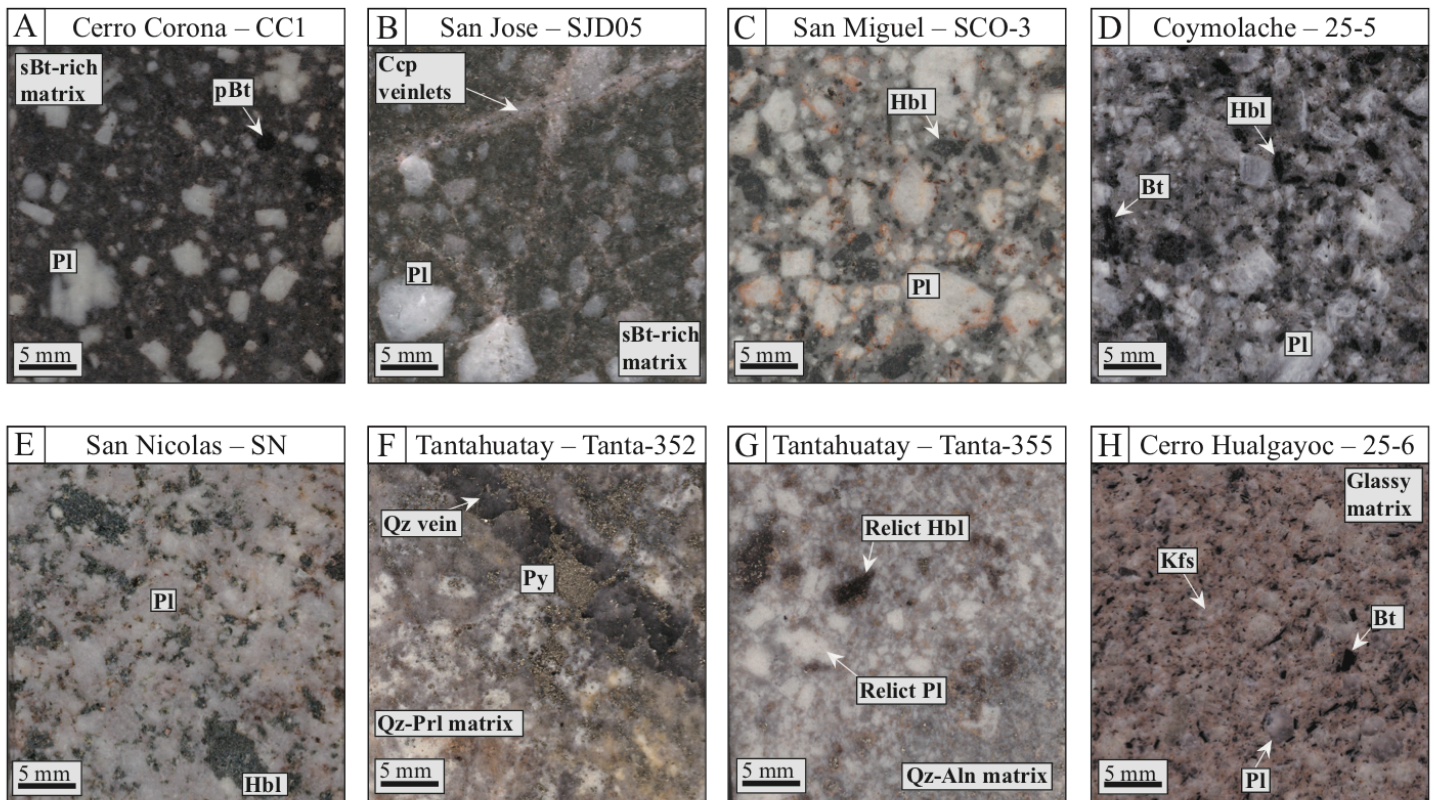


Figure 3.3. Slab photos of samples from igneous rocks in the Hualgayoc district. (A) Sample CC-2 from phase #2 of the Cerro Corona intrusive complex. The sample is affected by potassic alteration forming secondary biotite after amphibole and primary biotite. (B) Sample SJD-05 from the San Nicolas intrusion showing visual similarities with sample CC-2 from the Cerro Corona intrusive complex. The sample is affected by potassic alteration forming secondary biotite in the matrix and chalcopyrite veinlets with pinkish K-feldspar halo. (C)

Sample SCO-3 from the San Miguel intrusion rich in amphibole phenocrysts, the totality of which are replaced by chlorite. (D) Sample 25-5 from the Coymolache sill. Biotite and amphibole phenocrysts are affected by minor chloritization. (E) Sample SN from the San Nicolas intrusion showing an equigranular texture, which contrasts with the porphyritic texture seen in other intrusions. Most amphibole crystals are replaced by chlorite. (F, G) Sample Tanta-352 and Tanta-355 from the Tantauatay Volcanic Complex. All primary minerals have been replaced by quartz and pyrophyllite and/or alunite due to intense acid alteration. Sulfides including pyrite and enargite are found disseminated and in quartz veins. (H) Sample 25-6 from the Hualgayoc rhyodacite dome shows no trace of alteration and has quartz, biotite, K-feldspar and plagioclase phenocrysts floating in a glassy matrix. Abbreviations: Aln: alunite; Bt/pBt: primary biotite; sBt: secondary biotite; Ccp: chalcopyrite; Hbl: hornblende; Kfs: potassic feldspar; Pl: plagioclase; Prl: pyrophyllite; Py: pyrite; Qz: quartz.

All samples collected in the Hualgayoc district are hydrothermally altered except for the Coymolache sill and San Nicolas intrusion. Alteration includes weak to moderate alteration of ferromagnesian minerals by chlorite $\pm$ epidote in the San Miguel, Cerro Choro Blanco, Cerro Caballerisa and Cerro Jesus intrusions. Moderate to intense alteration of white mica is present in the Cerro San Jose and Cerro Jesus intrusions. Silicification and quartz stockwork veinlets occur in the Cerro Las Gordas intrusion.

Porphyry-style mineralization of chalcopyrite in veinlets and/or dissemination, in rocks with K-feldspar + biotite alteration is present in samples of all intrusive phases (CC1, 4, 5, 6) of the Cerro Corona complex. They are porphyritic quartz-diorite with phenocrysts of plagioclase, amphibole, quartz and biotite, with accessory microphenocrysts of magnetite, zircon and apatite and minor ilmenite. Moderate to strong alteration of K-feldspar + biotite $\pm$ illite affects all samples. Sample CC6 was affected by chlorite + epidote alteration replacing primary and secondary biotite and primary amphibole. All samples contain a minor amount of disseminated pyrite and chalcopyrite with traces of bornite.

One drill core sample from the San Jose intrusion (sample SJD-05) is similar in lithology and alteration to Cerro Corona samples. It is a quartz-diorite porphyry containing phenocrysts of

quartz, plagioclase, biotite and amphibole with minor magnetite and minor ilmenite. The alteration consists of K-feldspar and white mica locally replacing plagioclase, the formation of secondary biotite after primary biotite and amphibole, and minor chlorite after secondary biotite. Minor chalcopyrite containing trace bornite inclusions occurs disseminated and in pyrite + K-feldspar + quartz veinlets.

All drill core samples from the Tantauatay volcanic complex (samples Tanta-352, 355, 356, 357, 358) and sample CNG-1 are medium to fine-grained porphyritic rocks that were affected by moderate to very strong pervasive alunite $\pm$ pyrophyllite alteration, which replaced all primary minerals except quartz. All samples contain small amount of pyrite, disseminated or as narrow (<10 mm wide) veinlets with quartz.

3.3.2 Bulk rock composition

Bulk rock major and trace element data are presented in Table A1-2 in the Appendix. Most samples in this study have SiO₂ content that range from 59 to 61 wt%; some samples from Cerro Corona, Cerro Jesus and Cerro San Jose have SiO₂ up to 67 wt% due to silicification. Sample SG from the Las Gordas intrusion, which consist mostly of residual quartz with minor clay minerals, contains a high SiO₂ concentration (75%).

Samples from unmineralized and weakly to moderately altered San Miguel, Coymolache, San Nicolas, Choro Blanco and Caballerisa intrusions have similar K₂O content, ranging from 1.4 wt% to 2.5 wt%. Samples from the Cerro Corona, Cerro Jesus and Cerro San Jose intrusion contain variable K₂O contents, up to 6.9 wt%, consistent with the alteration of K-rich minerals such as K-feldspar, biotite and white mica.

All samples contain moderate REE concentrations, with total REE (Σ REE) ranging from 36 to 110 ppm except Sample 25-4 from the altered San Jose intrusion, which has 17 ppm. All

samples except for SG, CNG-1, Tanta-352, Tanta-355, Tanta-357 and Anta-6 intrusions have similar convex-downward chondrite-normalized REE patterns, sloping from La_{cn} to Yb_{cn} (9-18 $\text{La}_{\text{cn}}/\text{Yb}_{\text{cn}}$) with nearly flat Dy_{cn} to Yb_{cn} (1.1-1.4 $\text{Dy}_{\text{cn}}/\text{Yb}_{\text{cn}}$) (Fig. 4A). Younger rocks such as the Hualgayoc rhyodacite and Tantahuatay igneous rocks have overall lower total REE contents (83-54 ppm) than the older intrusions (120-66 ppm).

Samples SG, CNG-1, Tanta-352, Tanta-355, Tanta-357 and Anta-6 are intensely altered with residual quartz±alunite±pyrophyllite and show a clear convex-downward REE pattern with low heavy REE (HREE), middle REE (MREE) and Y (1.3-0.5 ppm Dy, 0.5-0.3 ppm Yb, 5-2 ppm Y) (Fig. 4B). The convex-downward REE pattern likely reflects preferential HREE and MREE removal by acidic hydrothermal fluids, which can mobilize REE and Y (Fulignati et al., 1999; Van Dongen et al., 2010). This is consistent with alteration mineralogy of alunite and pyrophyllite. Retention of light REE (LREE) in these rocks is explained by their preferential incorporation in alteration minerals such as sulfates (e.g. alunite) (Terakado and Fujitani, 1998). Sample 25-4 from the San Jose intrusion also shows low LREE values, attributed to intense weathering after acidic alteration.

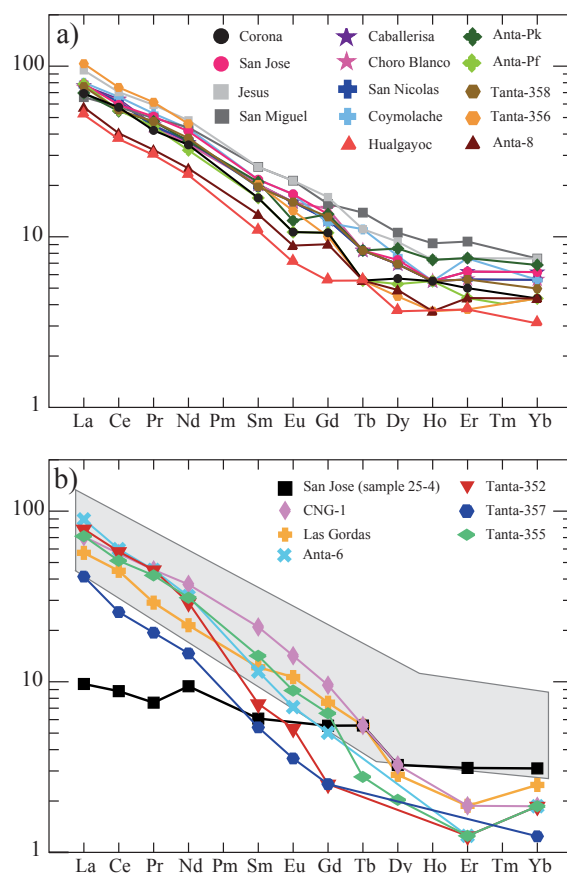


Figure 3.1. Chondrite-normalized REE patterns of intrusions and volcanic rocks in the Hualgayoc district. Chondrite values are from McDonough and Sun (1995). (A) REE patterns of weakly to moderately altered samples. All samples show similar concave-upward patterns with high LREE and relatively flat MREE to HREE. (B) REE patterns of intensely altered samples, all from the western part of the study area except highly weathered sample 25-4 from the San Jose intrusion and strongly silicified sample SG from the Las Gordas intrusion. All samples have low values of HREE. The weathered sample 25-4 from the San Jose intrusion also has low LREE values. Gray field corresponds to the range of values of least-altered samples (A).

All samples except those with intense alteration have weak Eu anomalies ($Eu/Eu^* = [Eu_{cn}] / [(Sm_{cn} * Gd_{cn})^{0.5}]$), ranging from 0.7 to 1.2, which may reflect late plagioclase crystallization in the parental magmas or oxidized conditions, where Eu is mostly +3. Most samples have low Th content below 7ppm, except sample Tanta-355 and Tanta-356 from the Tantauatay area, with 11 and 10 ppm Th, respectively, and all have a Th/U ratio in bulk rocks

<5, except sample CC5-s from Cerro Corona and sample Tanta-355. All samples have low Nb content, below 8 ppm.

3.3.3 Zircon optical properties and internal textures

All zircon grains are clear, pink, and range from 50 μm to 200 μm in size. Most grains have euhedral prismatic crystals with length/width ratios that range from 1.5 to 3. Grains show fine, well developed oscillatory growth zoning in SEM-CL images (Figs. 5A, B, C). Inherited cores are rare, and were observed in zircon from the Cerro Corona intrusive complex and the Hualgayoc rhyodacite (Fig. 5C). There is no major difference in texture, crystal habit and shape of zircon grains among different intrusions and volcanic rocks. Several zircon grains from the Tantauatay volcanic complex are corroded and show patchy to feathery bright areas that overprint oscillatory growth zoning, suggesting sub-solidus alteration. The corrosion of zircon may have been caused by acidic hydrothermal fluids forming alunite $\pm$ pyrophyllite in these samples.

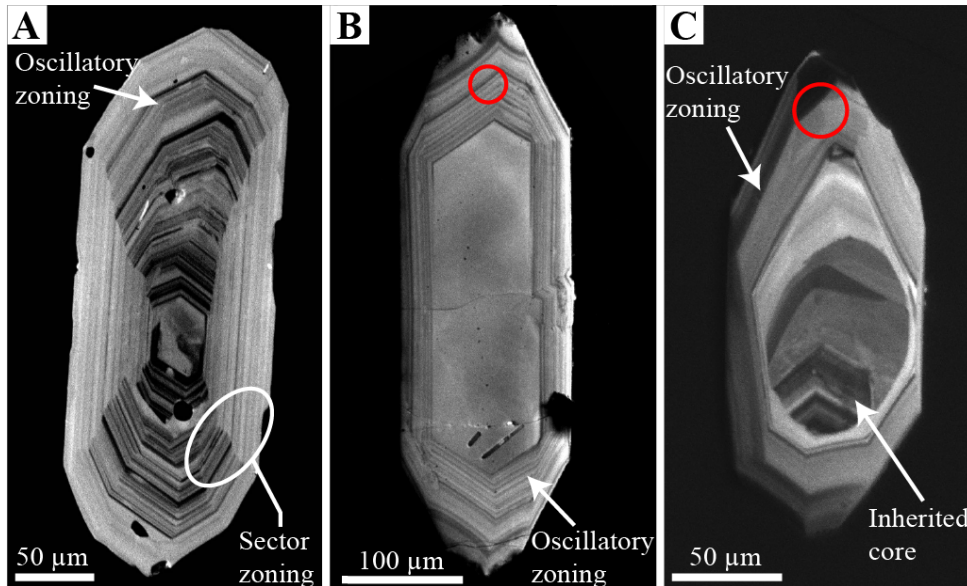


Figure 3.2: Cathodoluminescence images of representative zircon grains. (A) Zircon from phase 1 of the Cerro Corona Complex with oscillatory and sector zoning (sample CC1). (B) Zircon from the San Jose intrusion with oscillatory zoning (sample 25-4). (C) Zircon from the Cerro Corona intrusive complex with oscillatory zoning and an inherited core (sample CC1).

Hualgayoc rhyodacite with resorbed core of inherited zircon with coarse oscillatory-zoned overgrowth (sample 25-6). Red circles indicate areas of trace element analyses in B and C.

3.3.4 U-Pb zircon ages

Zircon U-Pb data are presented in Table A1-3 and Table A1-4 in the Appendix. Zircon U-Pb ages of samples are presented in Table 3 and Fig. 6. Magmatic activity in the district was suggested to have begun in the Paleocene at about 40 Ma, based on a Rb-Sr isochron age of the San Miguel intrusion (Macfarlane, 1989). This study shows that U-Pb zircon ages of the San Miguel intrusion is Middle Miocene, 14.52 ± 0.14 Ma. Our dating of intrusions in the district indicate nearly continuous magmatism, from 14.8 to 9.7 Ma. SHRIMP U-Pb dates of zircon of the Cerro Corona intrusive phases 1, 4, 5 and 6 yielded very similar ages between 14.59 and 14.40 with overlapping 2 sigma uncertainties, indicates the Cerro Corona intrusive complex formed in a short period of time.

Igneous rocks hosting high-sulfidation Au mineralization at the Tantauatay 2 center of the Tantauatay deposit (samples Tanta-352, 355, 356 and 357) were emplaced between 13.09 Ma and 12.46 Ma, contemporaneously with the formation of epithermal mineralization, as indicated by hypogene K-Ar alunite ages of 12.4 ± 0.4 Ma (Macfarlane et al., 1994). Igneous rocks from the Cerro Cienaga center of the Tantauatay deposit (sample CNG-1 and Tanta-358) formed earlier at 14.52 ± 0.49 Ma and 14.06 ± 0.49 Ma, respectively.

The youngest zircon age of intrusions in the district, 12.01 ± 0.26 Ma, was obtained from Anta-PF in the AntaKori area. This is close to the age of the rhyolite unit of the Calipuy Formation, 11.49 ± 0.37 Ma, which represents the youngest volcanic rock in the Tantauatay and AntaKori area. One sample from the Calipuy rhyolite is altered to pervasive white-mica and

contains minute chalcopyrite grains, indicating that hydrothermal activity continued in the Tantauatay and AntaKori area until after the eruption of the Calipuy Formation.

After a ~1.5 m.y. hiatus, the barren Cerro Hualgayoc rhyodacite dome was emplaced north of the Cerro Corona deposit, at 9.74 ± 0.31 Ma. This represents the final magmatic activity in the Hualgayoc district.

Sample	Abbreviations in the map	Igneous unit	Zircon age (Ma)
CC1	CC	Cerro Corona Phase 1	14.57±0.16
CC4		Cerro Corona Phase 4	14.40±0.28
CC4b			14.51±0.21
CC5		Cerro Corona Phase 5	14.42±0.20
CC5n			14.40±0.12
CC6		Cerro Corona Phase 6	14.59±0.13
SJD-02	SJ	San Jose	14.73±0.13
25-4			
Tanta-352	TA	Tantauatay – Tantauatay 2 center	13.09±0.27
Tanta-355			12.91±0.56
Tanta-356			12.64±0.56
Tanta-357			12.46±0.49
Tanta-358	CNG	Tantauatay – Cerro Cienaga center	14.06±0.49
CNG-1			14.52±0.49
Anta-PK	AK	AntaKori PK	14.44±0.25
Anta-PF		AntaKori PF	12.01±0.26
25-7	CJ	Cerro Jesus	14.83±0.36
CB	CB	Cerro Choro Blanco	14.22±0.25
CAB	CAB	Cerro Caballerisa	14.11±0.18
LG	LG	Las Gordas	14.35±0.28
25-5	CO	Coymolache	14.32±0.28
SCO-1	SM	San Miguel	14.52±0.14
SCO-2			
SCO-3			
SN	SN	San Nicolas	13.67±0.28
Anta-6		Calipuy	13.18±0.37

Anta-8			11.51±0.37
25-6	HG	Hualgayoc	9.74±0.31

Table 3.3: U-Pb zircon ages of samples from the Hualgayoc district. Uncertainties represent 2σ . Ages of the San Jose and San Miguel intrusion were calculated by combining zircon from several samples, SJD-02 and 24-4 for the San Jose intrusion and SCO-1, SCO-2 and SCO-3 for the San Miguel intrusion.

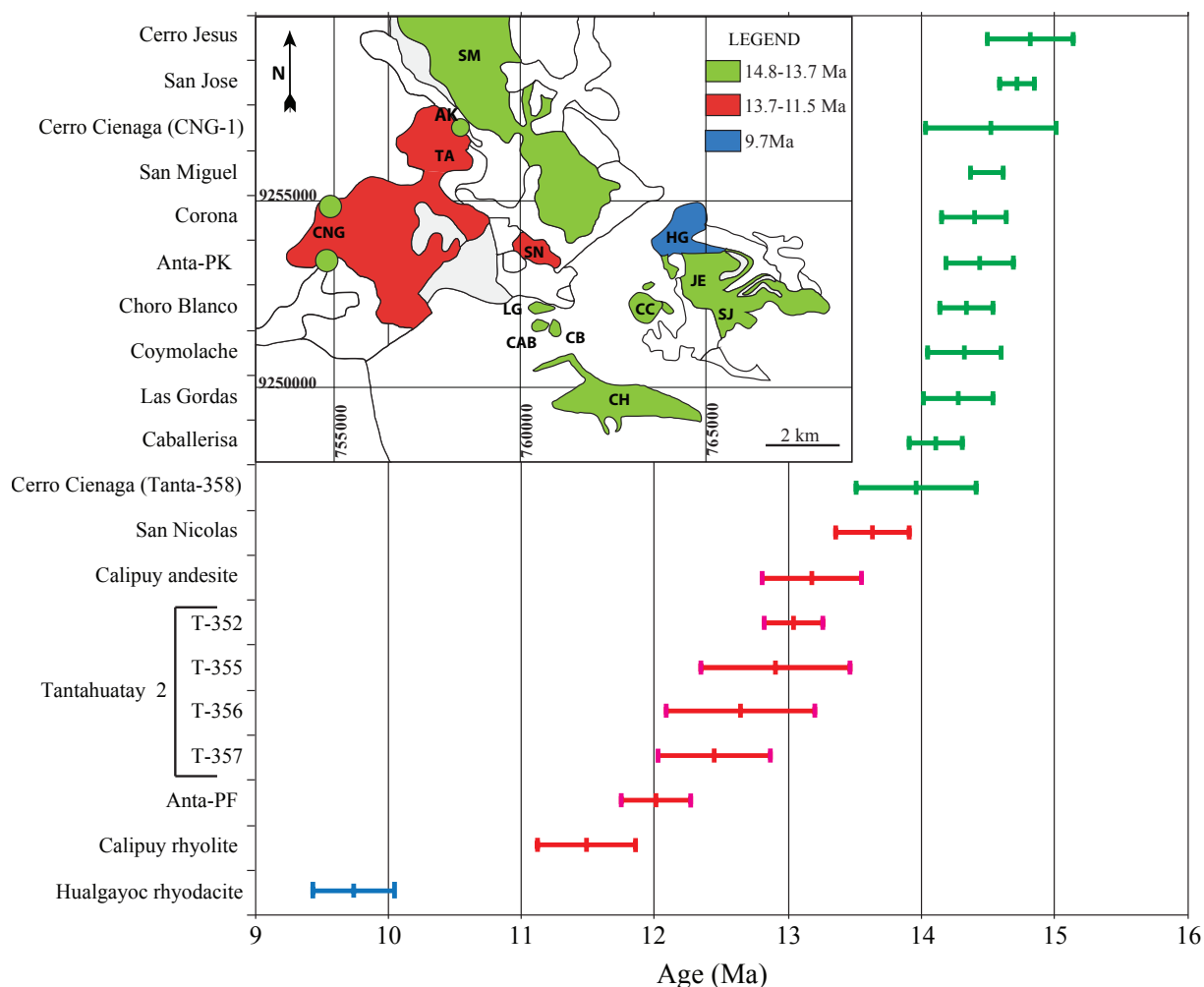


Figure 3.6. $^{206}\text{Pb}/^{238}\text{U}$ zircon ages of igneous rocks in the Hualgayoc district. Error bars represent 2σ uncertainties. The age bar of the Cerro Corona intrusive complex correspond to the range of ages of intrusive phases 1, 4, 5 and 6. Colors are the same as in Fig. 8.

3.3.5 Trace element abundance in zircon

Zircon trace element data are presented in Table A1-5 in the Appendix. All zircon grains (n=473) have similar chondrite-normalized REE patterns, with pronounced positive Ce anomalies and weak to moderate negative Eu anomalies ($Eu/Eu^* = [Eu_{cn}]/[(Sm_{cn} * Gd_{cn})^{0.5}] = 0.3-0.8$) (Fig. 7). Zircon compositions form two groups. Group A consists of zircon from old intrusions (14.8-13.7Ma, green in Fig. 6), including the mineralized Cerro Corona and Cerro San Jose intrusion, and the apparently barren Cerro Caballerisa, Cerro Choro Blanco, the Cerro Cienaga center of the Tantahuatay deposit, Anta-PF, San Miguel and Cerro Las Gordas intrusions. Zircon in this group A is characterized by a large range in ΣREE abundance, from 170 to 1000 ppm (Fig. 8C) and low Th/U, mostly between 0.5 and 0.1 (Fig. 8A). Hf is compatible in zircon but highly incompatible in many other rock-forming minerals, which leads an increase in a magma during fractional crystallization. Therefore, Hf content in zircon can be used as an indicator for the degree of fractional crystallization (e.g. Claiborne et al., 2010). Group A zircon shows no significant change in the contents of total REE, Th and U with increasing Hf.

Group B consists of zircon from younger igneous rocks in the district (13.7-11.5 Ma, red in Fig. 8), including the Tantahuatay 2 center of the Tantahuatay deposit, the San Nicolas intrusion and volcanic rocks from the Calipuy Formation. This group is characterized by lower ΣREE , < 550 ppm (Fig. 8C) and a wide range in Th/U ratios, between 1 and 0.2 (Fig. 8A).

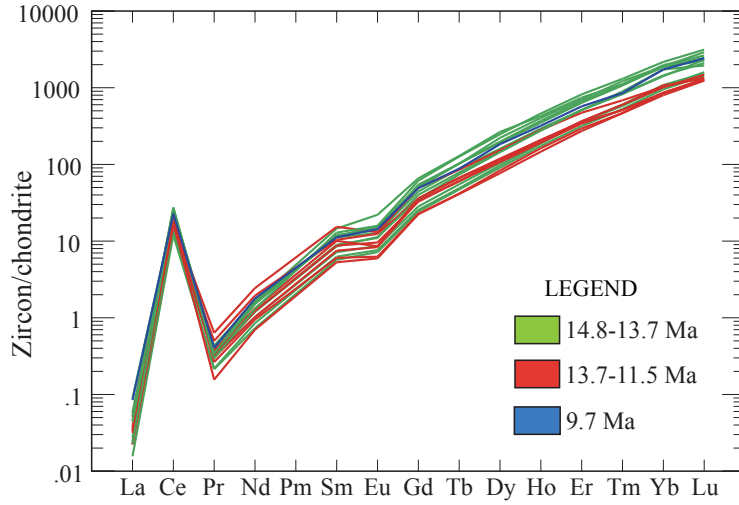


Figure 3.7. Chondrite-normalized REE patterns for zircon of igneous rocks from the Hualgayoc district. Median values for individual igneous units plotted. Colors are the same as in Fig. 6.

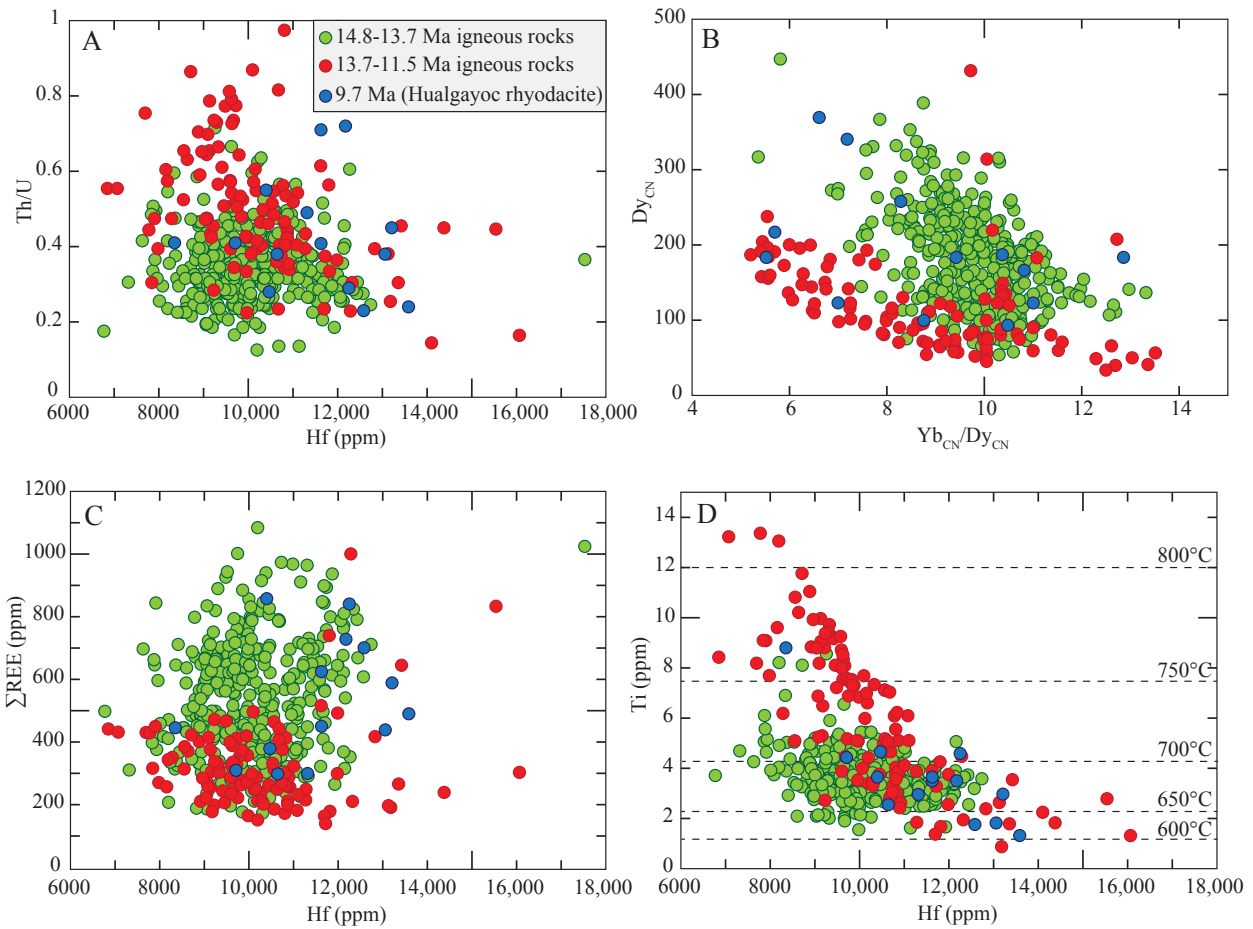


Figure 3.8. Trace element composition of zircon (n = 473) from the Hualgayoc district. Symbol colors are the same as in Fig. 6. The compositions of zircon from 14.8-13.7 Ma igneous rocks

(green) are distinctly different from 13.7-11.5 Ma igneous rocks (red). Zircon from the Hualgayoc rhyodacite (9.74 ± 0.31 Ma) are in blue. Temperature values in (D) corresponds to zircon crystallization temperatures using Ti contents in zircon calculated from Ferry and Watson (2007) assuming $a_{\text{SiO}_2} = 1$ and $a_{\text{TiO}_2} = 0.7$.

3.3.6 Zircon crystallization temperatures

Zircon crystallization temperatures are calculated using Ti-in-zircon geothermometry of Ferry & Watson (2007) assuming activities of SiO_2 (a_{SiO_2}) and TiO_2 (a_{TiO_2}) are 1 and 0.7, respectively. The value for a_{SiO_2} is 1 is justified because of the presence of quartz phenocrysts and quartz in the matrix. Activity of TiO_2 is lower than 1 because rutile is not an igneous mineral. Ilmenite microphenocrysts are recognized in several samples from the Cerro Corona, San Jose and San Miguel-intrusions, indicating that a_{TiO_2} for these magmas was above 0.6 (Watson et al. 2006; Fu et al., 2008). We therefore assign a value of 0.7 for a_{TiO_2} , which has been used for granitic to dioritic melt of similar bulk compositions and mineralogy (Chelle-Michou et al., 2014; Buret et al., 2016). Changing the a_{TiO_2} by ± 0.2 results in a change in zircon crystallization temperature by ± 30 °C. The majority of Group A zircon grains yield crystallization temperatures of 710 °C to 640 °C, with only minor decrease with increasing Hf content (Fig. 8D). Zircons from Group B have a wider spread of crystallization temperature, decreasing from 800 °C to 600 °C with increasing Hf content (Fig. 8D).

3.3.7 Amphibole composition

Composition of four amphibole phenocrysts from the Coymolache sill and three from the San Nicolas intrusion are listed in Table A1-7 in the Appendix. All amphibole phenocrysts from the Coymolache Sill are euhedral to sub-euhedral with homogenous in back-scattered electron images (Figure A1-26 in the Appendix). Amphiboles from the San Nicolas intrusion are sub-euhedral to anhedral and show fractures and altered rims (Figure A1-27 in the Appendix).

Regardless, all areas of analysis of all 3 grains from the San Nicolas intrusion have nearly identical composition indicating primary, homogenous composition. Amphibole grains from both the San Nicolas intrusion and Coymolache sill have similar composition and are classified as magnesio-hornblende of the calcic amphibole group, according to the nomenclature of Hawthorne et al. (2012).

Amphiboles from the Coymolache sill have a Mg# ($Mg\# = 100 * [(MgO/40.3) / ((MgO/40.3) + (FeO/71.8))]$) of 65 to 60, and a Cl and F content of 0.11 to 0.17 and 0.10 to 0.19 wt%, respectively. Amphibole from the San Nicolas intrusion have slightly higher Mg#, 75 to 76, and a Cl and F content of 0.12 to 0.14 and 0.75 to 0.78 wt%, respectively. Amphibole oxy-thermo-hydro-barometry (Ridolfi et al., 2010) indicates 862 °C to 830 °C (± 22 °C σ_{est}) and a pressure of 191 Mpa to 139 Mpa (with ± 20 Mpa maximum uncertainty) for the emplacement of the Coymolache sill. The pressure corresponds approximately to 7 km to 5 km depth, assuming a crustal density of 2.7 g/cm³. Amphiboles from the San Nicolas intrusion crystallized at slightly lower temperature, 810 °C to 795 °C (± 22 °C σ_{est}), and at a lower pressure of 77 to 70 Mpa (with ± 8 MPa maximum uncertainty), which correspond approximately to 3 km to 2.5 km depth. Amphibole from the Coymolache sill records an oxygen fugacity of the parental magma FMQ+1.5 to +2.0 (1.5 to 2 logarithmic units above the FMQ buffer). Amphibole from the younger San Nicolas intrusion indicates higher oxidation conditions, with values about FMQ+3.0, indicating that the parental magma was oxidized, suggesting a minor increase of magmatic oxidation condition over time. Amphiboles from the Coymolache sill record a water content in the melt of 5.1 to 5.5 wt% H₂O (± 0.4 wt% σ_{est}), whereas amphibole from the San Nicolas intrusion record a lower water content of 2.8-2.9 wt% H₂O (± 0.4 wt% σ_{est}).

3.4 Discussion

3.4.1 Characteristics of Hualgayoc magmas

3.4.1.1 Water content and oxidation state of parental magmas recorded in amphibole:

Crystallization of amphibole in andesitic magma requires relatively high H₂O contents ($\geq$ 3-4 wt%) (Naney, 1983; Ridolfi et al., 2010). This is consistent with the melt water content calculated from amphibole composition from the Coymolache sill and San Nicolas intrusions (Fig. 9C), nearly 3 wt% (San Nicolas), up to >5 wt% (Coymolache).

Amphiboles from the San Nicolas intrusion plot close to the stability curve of amphibole (Fig. 9C), which may explain their partially resorbed rims (Figure A1-27 in the Appendix). On the other hand, amphiboles from the Coymolache sill, which plot inside the stability field, have well-defined euhedral crystal habits (Figure A1-26 in the Appendix). Amphibole grains from the San Nicolas intrusion appear to have crystallized relatively late, based on the estimate of a low temperature ($\sim$ 800 °C) and shallow depth (about 3 km) (Fig. 9A).

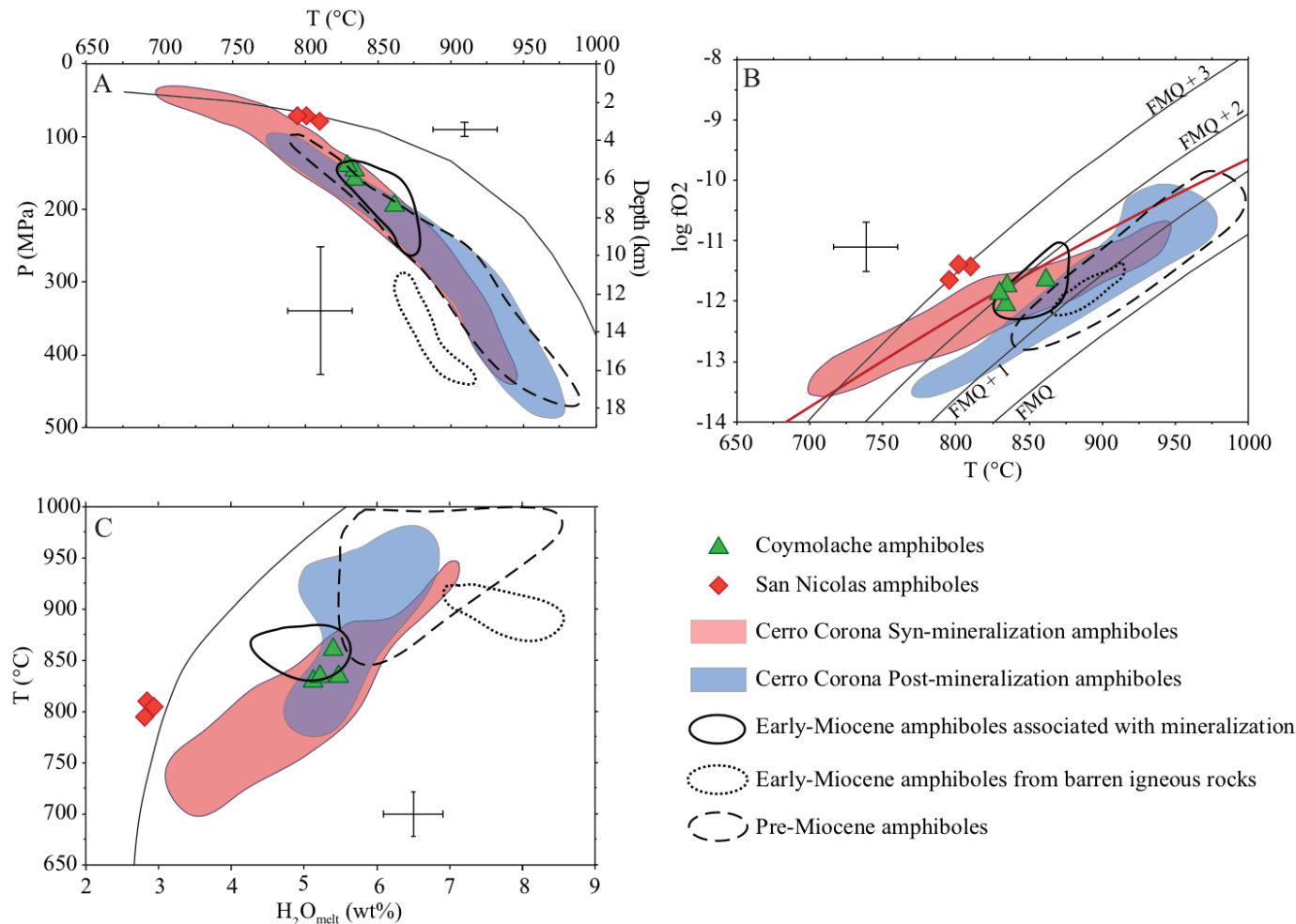


Figure 3.9. Pressure, temperature, fO_2 and H_2O content of melt, based on the amphibole composition from Coymolache sill ($n=4$), San Nicolas intrusion ($n=3$), the Cerro Corona intrusive complex ($n=34$), pre-Miocene igneous rocks (57-29.5 Ma) ($n=26$) and early to middle-Miocene (23-16 Ma) igneous rocks ($n=16$) in the Cajamarca region using the geothermobarometry of Ridolfi et al. (2010). Amphibole compositions from pre-, early and middle Miocene used data reported by Davies (2002). Temperature, fO_2 and water contents for the Cerro Corona complex were calculated using the amphibole composition data reported by Longridge (2016). Thermal stability of amphibole is shown by the solid curve in (A) and (C). (A) Error bars represent the uncertainties of P , and the standard error estimate of T . The depth and maximum depth uncertainties are calculated using the rock density of 2.7 g/cm^3 . (B) FMQ, FMQ+1, FMQ+2 and FMQ+3 buffer curves are represented by solid black curves. The thick red line represents the SO_2 - H_2S gas buffer curve (Einaudi et al., 2003). Error bars represent the maximum $\log fO_2$ error and the standard error estimate of T . (C) Error bars represent the standard error estimate of T and variation in accuracy with H_2O_{melt} .

Magma water contents calculated with the method of Ridolfi et al. (2010) using amphibole composition data reported by Longridge (2016) are high, 3–6 wt% H_2O , for the Cerro

Corona intrusive complex. Water content in melt decreases with decreasing temperature and crystallization depth (Fig. 9C), suggesting release of magmatic fluids during cooling and ascent of the intrusion. Amphiboles from post-mineralization bodies in the Cerro Corona intrusive complex also record a high melt water content (4.5-7 wt%) and high crystallization temperature (775–975°C), suggesting post-mineralization dykes also formed from hot, hydrous magma.

Amphibole from syn-mineralization intrusions of the Cerro Corona intrusive complex record an increasing oxidation conditions during cooling, from FMQ+1 at 950 °C to slightly above FMQ+3 at about 700 °C. This trend of increasing oxidation state with decreasing temperature crosscuts the rock buffer curve and follows the SO₂-H₂S gas buffer (Fig. 9B), (Einaudi et al., 2003). Amphibole from post-mineralization dykes from the Cerro Corona intrusive complex records a similar oxidation state at high temperature to that of syn-mineralization intrusions. However, on cooling the trend followed the rock buffer curve at ~ FMQ+1, resulting in lower oxidation conditions in the melt at lower temperature. Amphibole compositions from the barren Coymolache sill and San Nicolas intrusion indicate a high oxidation state, about FMQ+2 and FQM+3, respectively (Fig. 9B). These are similar to and higher than the oxidation state of syn-mineralization intrusions of the Cerro Corona intrusive complex at a given temperature.

3.4.1.2 Oxidation conditions and temperature recorded in zircon

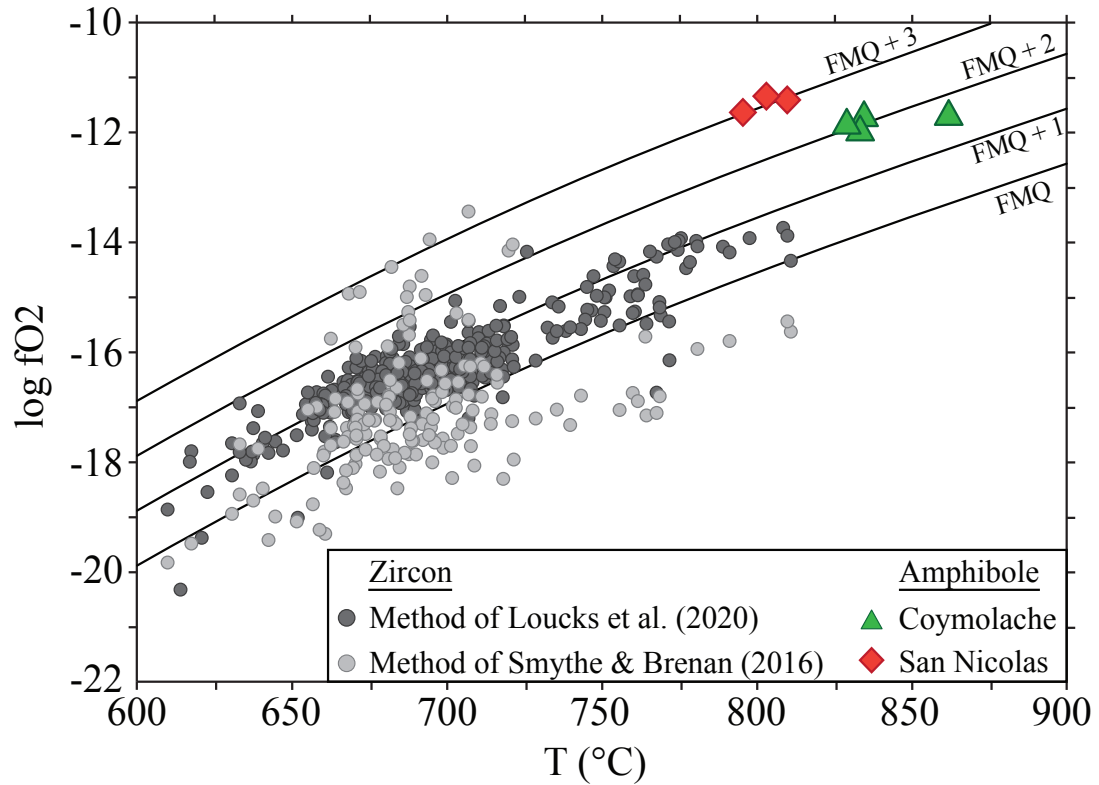


Figure 3.10: fO_2 of melt based on zircon composition using the method of Loucks et al., (2020), and the method of Smythe & Brenan (2016) using hydrous NBO/T values. Circles represent individual zircon. Zircon crystallization temperature data are from Fig. 8D. Amphibole data are from Fig. 9B. FMQ, FMQ+1, FMQ+2 and FMQ+3 buffer curves are represented by solid black line. Standard errors for the method of Loucks et al. (2020) are of ± 0.6 log unit fO_2 . Standard errors for the method of Smythe & Brenan (2016) are of ± 1 log unit fO_2 .

Due to the intense hydrothermal alteration affecting most rocks in the Hualgayoc district and alteration of amphibole grains, we also calculated oxidation condition of magmas using the zircon oximeters. Previous workers proposed a variety of oximeters using zircon compositions (e.g., Trail et al., 2012). This paper calculated fO_2 using the recently proposed oximeter by Smythe & Brenan (2016) and Loucks et al. (2020). The zircon oximeter of Smythe & Brenan (2016) requires parental melt composition and water content at the time of zircon crystallization. We used bulk rock composition of weakly altered samples from the Cerro Corona, San Miguel,

Choro Blanco, Caballerisa and San Nicolas intrusions and the Coymolache sill as proxy for melts composition, and LOI as proxy for melt water content. fO_2 was calculated using hydrous NBO/T values, as anhydrous values yielded unrealistically low fO_2 values, below FMQ, for each sample. fO_2 values calculated from zircon using this method range from around FMQ -1 up to FMQ +3, with most ranging from FMQ -1 to FMQ +1 (Fig 10, light gray). The zircon oximeter of Smythe & Brenan (2016) is sensitive to water content in the melt, therefore the range in fO_2 values is likely caused by the wide variation in LOI of samples (1.51-6.28 wt%). The zircon oximeter of Loucks et al. (2020) requires only the trace element abundances of zircon. All zircon grains yield slightly higher fO_2 values slightly those obtained using the method of Smythe & Brenan (2016). Most values range between FMQ and FMQ +1.5 (Fig. 10, dark gray), with no apparent variation with decreasing crystallization temperature. The data also suggest oxidation conditions at the time of zircon crystallization remained similar from 14.8 to 9.7 Ma.

Both zircon oximeters yield lower overall fO_2 values than the amphibole oximeter of Ridolfi et al. (2010). The low calculated fO_2 values below FMQ using the zircon oximeter of Smythe & Brenan (2016) is possibly due to difference between bulk composition and LOI of samples compared to composition and water contents of the melt, causing an underestimation of calculated fO_2 . Regardless, the data suggest all magmas in the district were oxidized, between FMQ and FMQ +3, independent of the association with mineralization, with minimum change over time.

3.4.2 Evolution of parental magmas in the Hualgayoc district

3.4.2.1 Evolution in bulk-rock composition:

Amphibole preferentially incorporates HREE and MREE over LREE, and MREE over HREE (Sisson, 1994, Tiepolo et al., 2007). Partition coefficients between amphibole and melt, $D_{\text{amph/melt}}$ values, for La, Dy and Yb in andesitic melt are around 0.5, 4.4 and 2.7 respectively (Sisson, 1994). The convex-downward chondrite-normalized REE profile with nearly flat Dy_{cn} to Yb_{cn} of bulk rock compositions of igneous rocks in the Hualgayoc district suggests preferential fractionation of MREE over HREE (Fig. 4A). This suggests parental magmas in the Hualgayoc district originate from partial melting of an amphibole-rich source.

Igneous rocks with ages of 14.8-13.7 Ma (Fig. 6, green) are diorites to quartz-diorites, with similar mineralogy and major element composition. Felsic rocks, such as the Calipuy rhyolite and the Hualgayoc rhyodacite dome, are younger, formed between 13.7 and 9.7 Ma. The evolution over time is reflected by a gradual change in major and trace element composition: a steady decrease in FeO_t , MgO , TiO_2 , CaO and V , and a steady increase in K_2O and SiO_2 , and a steady decrease in REE content and slight increase in $La_{\text{cn}}/Yb_{\text{cn}}$ ratio (9-17) from 14.8 Ma to 9.7 Ma. The temporal change in bulk rock composition may be explained by fractional crystallization of magmas, more assimilation of crustal rocks by younger magmas, smaller degrees of partial melting of the source for younger rocks and a change in the magma source composition.

Assimilation of crustal material appears minimal, based on bulk rock strontium isotopic data reported by Macfarlane (1989). The San Miguel and Cerro Jesus intrusions, the Coymolache sill and the Hualgayoc rhyodacite have a narrow range in initial ratios of $^{87}\text{Sr}/^{86}\text{Sr}$, $(^{87}\text{Sr}/^{86}\text{Sr})_i$, between 0.70439-0.70494 (Macfarlane, 1989). Cerro Corona intrusions show slightly higher values of 0.70559, probably due to the incorporation of Sr with high ^{87}Sr from limestone during hydrothermal alteration (Macfarlane, 1989). Limestone country rocks and the meta-sedimentary

basement had a high $^{87}\text{Sr}/^{86}\text{Sr}$ at the time of magmatism, ranging from 0.7078 to 0.7246, and 0.7217 to 0.7400, respectively (Macfarlane, 1989). The rarity of inherited cores in zircon supports a minimal assimilation of meta-sedimentary basement rocks.

A decreasing degree of partial melting of the source would produce melts with increasing incompatible elements. The young Hualgayoc rhyodacite has a Mg# of 40, similar to those of older, weakly altered intermediate rocks in the district (36–48 Mg#). The Hualgayoc rhyodacite and Calipuy rhyolite rocks have low La content (12 and 14 ppm, respectively) compared to older intermediate rocks in the district (12–23 ppm). If the degree of partial melting decreased over time, we would expect higher Mg# and higher La content in the Hualgayoc rhyodacite and Calipuy rhyolite compared to older rocks. Therefore, the data indicate that the degree of partial melting of the source cannot explain the compositional change of magma over time.

Decreasing HREE and increasing $\text{La}_{\text{cn}}/\text{Yb}_{\text{cn}}$ ratio over time in igneous rocks from the Hualgayoc district suggests increasing fractional crystallization of amphibole in the melt. The presence of amphibole phenocrysts in most rocks supports that amphibole was a fractionating phase in magmas. This is also supported by the gradual depletion in MgO, FeO, CaO and V in magmas over time in the Hualgayoc district. Therefore, it is likely that amphibole fractionation was controlling the change in magma composition over time in the Hualgayoc district.

3.4.2.2 Evolution in zircon composition:

The composition of zircon reflects that of the melt at the time of crystallization (Cherniak et al., 1997; Claiborne et al., 2010). In contrast to the gradual change in major and trace element contents of bulk rock composition of igneous rocks from 14.8 Ma to 11.5 Ma, zircon reveals a sharp compositional difference between the 14.8–14 Ma and 13.7–11.5 Ma. Since the bulk rock

compositions do not indicate any sharp change, the compositional variation of zircon between the two groups is most likely explained by co-crystallizing phases.

The crystallization of minerals with high D values such as titanite affects the abundance of REE in melt. Titanite crystallization causes depletion in MREE in the melt due to its greater affinity for MREE, over LREE and HREE ($D_{\text{Titanite/melt}}$ values for La, Dy and Yb are 113, 935 and 393, respectively; Bachmann et al., 2005). Titanite crystallization also causes an increase in Eu/Eu* in the melt because of its slightly greater affinity for Sm and Gd over Eu (Bachmann et al., 2005; Loader et al., 2017). Amphibole crystallization has a similar effect as titanite but to a lesser degree, due to smaller REE partition coefficient, D values < 10 (Sisson, 1994), than those for titanite. Plagioclase crystallization causes a decrease in Eu/Eu* in the melt due to its greater affinity for Eu²⁺ (Dunn and Sen, 1994).

Group B zircon show decreasing Dy/Yb ratios with increasing Dy content (Fig. 8B, red), and low content of total REE content < 550 ppm (Fig. 8C, red). The increase in Dy/Yb is also accompanied by a slight increase in Eu/Eu*, from ~0.4 to ~0.8, which may be due to co-crystallization of titanite. This is supported by the presence of pseudomorphic replacement of titanite by rutile in Sample Anta-PK from the AntaKori-PF intrusion. In contrast, Group A zircon have higher REE and Dy content than group B zircons, and do not show a clear relationship between Dy content and Dy/Yb ratios (Fig. 8C, green). In addition, Eu/Eu* does not vary with Dy/Yb. These data indicate that titanite did not crystallize before and during Group A zircon crystallization. All samples associated with Group A zircon contain amphibole and plagioclase. The lack of strong geochemical evidence in zircon for the co-crystallization of these major minerals suggests that zircon crystallized relatively late, which is supported by low crystallization temperature (<750 °C) of most Group A zircon grains (Fig. 8D, green) and the absence of zircon inclusion in plagioclase and amphibole phenocrysts.

Group A zircons are characterized by relatively cool and constant crystallization temperature, between 720 °C and 640 °C for most grains (Fig. 8D, green), independent of the Hf concentration, suggesting the parental magmas maintained a relatively constant temperature during zircon crystallization. By contrast, the younger Group B zircons indicate a large decrease in crystallization temperature, from about 800 °C to about 620 °C with increasing Hf content (Fig. 8D, red), indicating that the magmas were saturated with zircon at high temperatures.

Zircon crystallization temperature of Group A are similar to zircon saturation temperature based on bulk rock compositions following Watson and Harrison (1983). Samples associated with group A zircon yield zircon saturation temperature between 775 °C and 700 °C. Most of these saturation temperatures are higher than all zircon crystallization temperatures for each individual sample.

Due to intense alteration of most samples associate with Group B zircon, zircon saturation temperature was calculated only for sample SN of the unaltered San Nicolas intrusion. Sample SN has very similar bulk composition to samples associated with Group A zircon, and therefore has a similar zircon saturation temperature of 720 °C (Fig. 10). This temperature is lower than most crystallization temperatures of zircon from this sample, which range from ~810 °C to ~670 °C, which is higher than the saturation temperature.

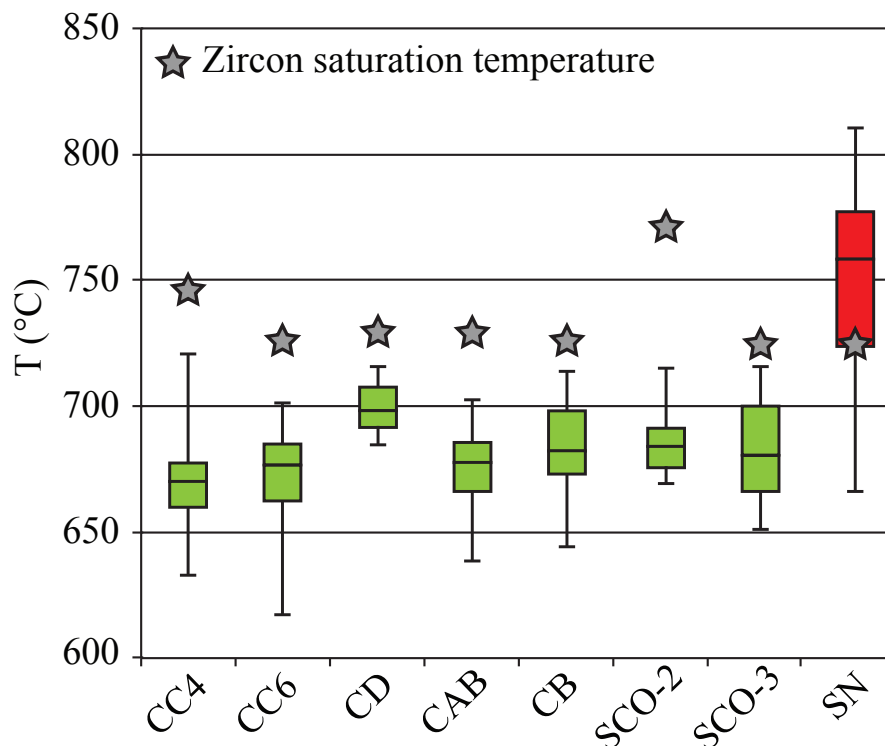


Figure 3.3. Zircon crystallization temperature of weakly to moderately altered samples shown in box-whisker plots compared to zircon saturation temperatures (gray stars) from intrusions in the Hualgayoc district. CC4: Cerro Corona phase 4; CC6: Cerro Corona phase 6; CD: Coymolache Sill; CAB: Caballerisa; CB: Choro Blanco; SCO-2 and SCO-3: San Miguel; SN: San Nicolas. The colors of symbols are the same as in Fig. 6. Zircon saturation temperatures are calculated with the method of Watson and Harrison (1983). The upper and lower box values correspond to quartile values, and upper and lower lines correspond to min and max values.

Discrepancy between zircon saturation temperature and zircon crystallization temperatures in sample SN may be attributed to under or overestimation of $a\text{TiO}_2$, or that zircon crystallized in a melt that has different composition from the observed bulk rock. Calculation of zircon crystallization temperature requires activity of TiO_2 of the melt. An increase in $a\text{TiO}_2$ from 0.7 to 1 would decrease the calculated zircon crystallization temperature by about 35 °C, which is not sufficient to explain the discrepancy of this sample.

The calculation of zircon saturation temperatures requires the cation ratios of $(\text{Na} + \text{K} + 2\text{Ca})/(\text{Al} - \text{Si})$ and Zr content of the melt at the time of zircon crystallization. Our calculation uses

bulk composition of rock samples as a proxy for melt composition. Therefore, any discrepancies between melt and bulk rock composition would yield erroneous saturation temperature. Hydrothermal alteration is unlikely to have been the cause of the discrepancy observed in sample SN, as the sample is only affected by very weak chloritization. The data may suggest an early crystallization of zircon in a magma at high temperatures, followed by composition change of melt due to fractionation, contamination, or mixing with another melt of different composition. Most zircon grains from sample SN of the San Nicolas intrusion are sub-euhedral, with only very few euhedral grains compared to other intrusions in the district, suggesting they weren't in equilibrium with their final host melt, which supports this interpretation.

3.4.3 Comparison of the Hualgayoc district with other igneous rocks in the Cajamarca region

3.4.3.1 Change in magma composition from early to late Miocene period in the Cajamarca region: barren Pre-Miocene magmas in the Cajamarca region originate from the active subduction of the Farallon plate under the South American plate. They are characterized by higher compatible elements concentration compared to Miocene magmas (Davies, 2002), and have high Yb and low La/Yb (Fig 12A).

Igneous rocks from Miocene igneous rocks in the Cajamarca region formed in response to the subduction of the Nazca plate below the South American plate. They include early Miocene intrusions (23-16 Ma) associated with the Michiquillay, El Galeno and Minas Congas porphyry Cu-Au deposits and contemporaneous barren intrusions, and late Miocene (12-8 Ma) igneous rocks from the Yanacocha high-sulfidation Au district (Fig. 1). The intrusions are dioritic to granodioritic, and volcanic rocks are andesitic to rhyolitic, with amphibole $\pm$ biotite phenocrysts in the intrusions and amphibole $\pm$ biotite $\pm$ clinopyroxene $\pm$ K-feldspar in the volcanic rocks

(Davies, 2002, Chiaradia et al., 2009; Longo et al., 2010). All igneous rocks are similar in lithology, mineralogy and bulk rock composition to those in the Hualgayoc district, reflecting a similar origin of the parental magmas. The mineralogy suggests that all parental magmas were hydrous.

All Miocene igneous rocks contain between 58 and 70 wt% SiO₂, low MgO (<4wt%) and low TiO₂ (<0.7 wt%) and are depleted in compatible elements compared to Pre-Miocene magmas (Chiaradia et al., 2009; Davies 2002). Mineralized early Miocene intrusions in the Cajamarca region have slightly higher SiO₂, > 63 wt%, than most barren intrusions of similar ages and intrusion from the Hualgayoc district. All have low HREE, with Yb <1.6ppm and high La/Yb, ranging from 13 to 37 (Fig. 12A).

Early Miocene intrusions in the region have a nearly straight, negatively sloped normalized pattern of REE, with minimal MREE depletion relative to HREE (Dy_{cn}/Yb_{cn} ranging from 1.6 to 2.2). In contrast, igneous rocks in the Yanacocha and Hualgayoc district show a convex-downward chondrite-normalized REE pattern with Dy_{cn}/Yb_{cn} ranging from 1 to 1.5 except for one sample from Yanacocha with a value of 2 (Fig. 12B). This suggests greater degrees of amphibole crystallization in middle to late Miocene magmas of the Hualgayoc and Yanacocha district compared to early Miocene magmas. We observe an overall increase in La/Yb ratios with decreasing Yb over time in all rocks in Cajamarca (Fig. 12A), reflecting depletion of HREE in magma over time. This is interpreted by Chiaradia et al. (2009) and Longo et al. (2010) as an increase in garnet content in the source over time due to crustal thickening associated with pulse I and II of the Quechua orogeny. Older igneous rocks (14.8-13.7 Ma) in the Hualgayoc district have La/Yb ratio similar to early Miocene intrusions, < 35, with most plotting in the normal arc rock field (Fig. 12B) whereas younger igneous rocks in the Hualgayoc district (13.7-9.7 Ma) have higher La/Yb ratio similar to those of igneous rocks from Yanacocha, above 20,

plotting within the “adakitic” geochemistry field (Fig. 12B). This may indicate garnet started appearing in the source at the time of magmatism in the Hualgayoc district.

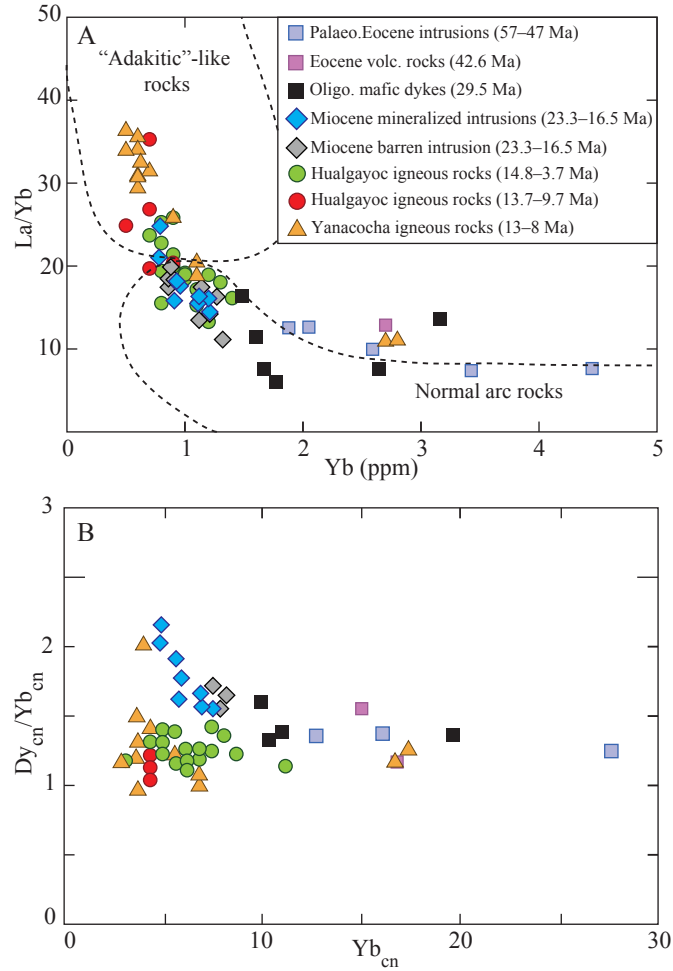


Figure 3.12. Whole rock Dy_{cn}/Yb_{cn} vs Yb_{cn} (A) and La/Yb vs Yb (ppm) (B) diagrams of pre-Miocene, early Miocene, Yanacocha middle to late Miocene and Hualgayoc igneous rocks from the Cajamarca region. Fields for adakite-like and normal arc rocks from Castillo et al. (1999). Data from pre-Miocene and early Miocene igneous rocks are from Davies (2002), and data from Yanacocha igneous rocks are from Chiaradia et al. (2009). The values Dy_{cn} pre-and early Miocene rocks were calculated using the formula $Dy_{cn} = (Tb_{cn} * Ho_{cn})^{0.5}$.

3.4.3.2 Characteristics of fertile and barren igneous rocks in the Cajamarca Region:

The magmas associated with porphyry and high-sulfidation style mineralization are oxidized and water rich (Ishihara, 1977; Richards, 2014). The oxidation state of magmas responsible for the formation of porphyry-style mineralization is usually greater than FMQ+2

(Wang et al., 2014; Sun et al., 2015; Hattori, 2018). High-water content in magma promotes exsolution of an aqueous phase for magmatic hydrothermal system.

Data from the Hualgayoc district indicate that all magmas were oxidized ($\geq$ FMQ) and water rich ($\geq$ 3wt% H₂O), regardless of the presence of mineralization in the intrusions. Oxidation conditions and water content of Pre-Miocene and Early to Middle Miocene magmas calculated from amphibole data reported by Davies (2002) using the method of Ridolfi et al. (2010) shows that the mineralized and barren intrusions in the Cajamarca region were all oxidized and water rich, similar to magmas from Hualgayoc (Fig. 9B, C). The data indicate that a high-water content and high magma oxidation state are not the only requirement to generate porphyry and high-sulfidation style of ore deposits in the Cajamarca region.

The shape of the intrusion is of great importance. Narrow, cylindrical to plug-like intrusions, such as comprising the Cerro Corona intrusive complex, allow the hydrothermal system to be focused in a localized area, leading to precipitation of metals in high concentration to form economic mineralization (Richards, 2005; Sillitoe, 2010). In contrast, sills, such as that of Coymolache, are not able to focus exsolved fluids. The depth of emplacement is also of importance. Since the solubility of water in magma decreases sharply at shallow depth (<5 km, Moore et al., 1995), the ascent to a shallow depth results in saturation and exsolution of magmatic aqueous fluids. By contrast, intrusions emplaced at very shallow depth (<1 km) largely degass magmatic vapors with low capacity to transport metals (Hedenquist, 1995). Other factors that may also exert a role in the formation of hydrothermal mineralization include the intrinsic metal content of the melt, rate of fluid exsolution (Richards, 2018), and interaction of fluids with wall rock (Einaudi et al., 2003).

High-sulfidation epithermal deposits such as Tantahuatay and those in the Yanacocha district form at shallow depth <500 m below the surface (Arribas, 1995; Sillitoe and Hedenquist,

2003). High-sulfidation epithermal deposits are spatially and temporally associated with porphyry deposits, and represent the shallow part of the magmatic hydrothermal system (Hedenquist et al., 1998; Sillitoe, 2010). We observe an apparent shift from porphyry-type deposits, dominant from 22 Ma to 14 Ma, to shallower, high-sulfidation deposits that have dominated from 12 Ma to 8 Ma in the Cajamarca region. This change in deposit type may simply be due to different levels of erosion, i.e., the younger, epithermal style deposits have yet to be eroded to the level necessary to expose deeper porphyry deposits. In the Hualgayoc district there are several faults trending NW—SE and NE—SW (Fig.2), which separates rocks of the Tantauatay volcanic complex from other intrusions located to the east, suggesting that the eastern part of the district exposes deeper section of the upper crust. It is possible that the 14.5 Ma Cerro Corona porphyry deposit was accompanied by high-sulphidation mineralization at a shallower level, which has since been eroded. Equally, porphyry-type mineralization appears to be present at depth below the Tantauatay deposit (Gustafson, 2004).

Contrary to Miocene igneous rocks, Pre-Miocene equivalents in the Cajamarca region are not known to be associated with porphyry and high-sulfidation style mineralization. The oxidation conditions and water content of pre-Miocene magmas (calculated from amphibole data; Davies, 2002) indicate that pre-Miocene magmas were hydrous (>5 wt% H_2O) and also oxidized, between FMQ +1 and +2. This was similar to post-mineralization magma from the Cerro Corona intrusive complex and magmas from barren early to middle Miocene intrusions. Pre-Miocene intrusions were also emplaced in Cretaceous limestone at shallow crustal levels, similar to Miocene intrusions (Davies, 2002). The apparent absence of mineralization in Pre-Miocene igneous rocks may simply be due to other requirements to form a deposit not being satisfied.

3.5 Conclusions

Magmatic activity in the Hualgayoc district was continuous from 14.8 to 11.5 Ma, and ended at around 9.7 Ma with the emplacement of the Hualgayoc rhyodacite dome. The Cerro Corona porphyry Au-Cu deposit formed in a short period of time at around 14.5 Ma. Most igneous rocks hosting the Tantauatay high-sulfidation Au epithermal deposit formed later at around 13.7-11.5 Ma, and are contemporaneous to the high sulfidation epithermal mineralization. Multiple barren intrusions were contemporaneous during the whole duration of magmatic activity in the district.

Amphibole and zircon geochemistry reveals that the parental magmas of all igneous rocks in the Hualgayoc district were water-rich and oxidized, above FMQ, regardless of the presence of mineralization. The evidence suggests factors other than magmatic oxidation conditions and water content are required for the mineralization. This may also apply to other igneous rocks in the Cajamarca region.

Bulk rock compositions suggest parental magmas in the Hualgayoc district originate from an amphibole-rich source in the lower-crust or lithospheric mantle, similar to other Miocene magmas in the Cajamarca region. The rocks in the Hualgayoc district also appear to record the transition from a near garnet-free source in Early- to Middle-Miocene, to a garnet-bearing source in Late-Miocene period, and also increasing fractional crystallization of amphibole during the period from 14.8 to 9.7 Ma.

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CHAPTER 4.

Hualgayoc mining district, northern Peru: Testing the use of zircon composition in exploration for porphyry-type deposits

Abstract

The Hualgayoc district in the Cajamarca region, northern Peru, hosts several mines, including the Cerro Corona Au+Cu porphyry deposit (0.55 Mt Cu, 99 t Au) and the Tantahuatay high-sulfidation epithermal Au deposit (74 t Au), plus other Au, Cu, Ag and base metal prospects. Previous studies have documented that zircon in igneous rocks associated with porphyry systems elsewhere in the world have large positive Ce anomalies and small negative Eu anomalies, characteristics that reflect both the oxidized and hydrous nature of their parental magmas. This study presents data on the trace element compositions of magmatic zircon from igneous rocks associated with porphyry-style mineralization, as well as barren stocks, sills and volcanic rocks in the district, in order to investigate the usefulness of zircon composition in exploration for porphyry-type deposits. The compositions of the zircon suggest that all parental magmas in the Hualgayoc district are oxidized, and that the magnitude of Ce and Eu anomalies is independent of the spatial and/or temporal association of igneous rocks with mineralization. Although zircon composition is not sufficient to recognize specific intrusions as fertile to generate hydrothermal ore deposits, the method, properly used, may be useful to target areas containing oxidized igneous rocks for further detailed exploration.

4.1. Introduction

Porphyry-style Cu±Au and high-sulfidation epithermal Au mineralization are important sources of Cu and Au. These deposits are typically associated with oxidized and hydrous arc magmas of intermediate to felsic composition (Ishihara, 1977; Streck and Dilles, 1998; Richards et al., 2012). The oxidation conditions of the metal-fertile magmas thought to be responsible for mineralization are believed to have an fO_2 greater than 1 logarithmic units above the fayalite-

magnetite-quartz (FMQ) buffer (Wang et al., 2014; Shen et al., 2015; Hattori, 2018). This apparent association of mineralization with relatively oxidized magmas is attributed to the high capacity of oxidized magmas to extract metals and S from their magma source region and to transport these elements to shallow crustal levels, and avoiding the immiscible separation of sulfides that may sequester metals from partitioning to a magmatic-hydrothermal fluid (Botcharnikov et al., 2011; Zajacz et al., 2012).

Rare earth elements (REE) occur mostly as trivalent cations, but Ce can be +4 in oxidized magmas and Eu can be +2 in reduced magmas. Ce^{4+} is easily incorporated into the Zr^{4+} site of zircon whereas Eu^{2+} is not readily included into the crystal structure. Thus, the magnitude of Ce and Eu anomalies in zircon reflects magmatic redox conditions (Burnham and Berry, 2012; Smythe and Brenan, 2016). Previous studies of porphyry Cu deposits have noted an association with igneous rocks that contain zircon with small negative anomalies of Eu and large positive Ce anomalies (Ballard et al., 2002; Liang et al., 2006), indicating a relatively oxidized parental magmas. Therefore, it has been proposed to use this characteristic of zircon in exploration (Ballard et al., 2002; Lu et al., 2016; Cooke et al., 2017).

The Hualgayoc mining district (~100 km²) in the northern Peruvian Cordillera contains many Miocene igneous rocks of dioritic composition. The district hosts two major deposits, the Cerro Corona Au+Cu porphyry deposit (99 t Au, 0.55 Mt Cu, Table 1), and the Tantauatay high-sulfidation Au deposit (74 t Au, Table 1). Therefore, the area provides an opportunity to compare the composition of zircon from igneous rocks spatially and temporally related to ore deposits, and those that are unaltered and not known to have any nearby ores, in order to assess the usefulness of zircon composition for exploration.

4.2. Study area

4.2.1. Regional geology and ore deposits

The Hualgayoc mining district is located in the northern part of the Cajamarca region in the Western Cordillera of the northern Peruvian Andes (Fig. 1). The Western Cordillera consists of a basement of Neoproterozoic to Lower Paleozoic metasedimentary rocks overlaid by sedimentary rocks of Ordovician to Upper Cretaceous ages (Scherrenberg et al., 2012). The Cajamarca region consists of a thick (> 4 km) sequence of weakly deformed Upper Jurassic to Upper Cretaceous siliciclastic and carbonate sedimentary rocks overlying the metasedimentary basement. The base of the sequence is dominated by a >2 km-thick package of Upper Jurassic to Lower Cretaceous turbiditic to deltaic sedimentary rocks, mainly sandstone, shale and quartzite. The upper part of the sequence is dominated by a thick, > 2 km, carbonate platform sedimentary rocks, mainly limestone with minor shale, marl and sandstone. The detailed stratigraphy of the area is described by Wilson (1984) and Benavides-Cáceres (1999).

The basement rocks and overlying Cretaceous sedimentary rocks were affected by several crustal shortening events, from the Eocene to Miocene, resulting in the formation of E–W to NW–SE thrust faults and NE–SW trending structures (Fig. 1) (Benavides-Cáceres, 1999; Davies, 2002). Intense magmatic activity in the region during the Eocene to Miocene was associated with these tectonic events (McKee and Noble, 1990; Noble et al., 1990). A ~2 km-thick sequence of intermediate to felsic volcanic and volcanoclastic rocks of the Calipuy Formation, including pumiceous pyroclastic rocks, ignimbrites and lava flows, were deposited above the Cretaceous sedimentary sequences (Wilson, 1984). The sedimentary and volcanic rocks were intruded by dioritic to granodioritic plugs, stocks, sills and volcanic domes (Wilson, 1984). Extensive porphyry- and high-sulfidation epithermal-style mineralization in the Cajamarca region is

associated with these Miocene intrusions along the intersection of NW and NE-trending structures (Vidal et al., 1997; Gustafson et al., 2004).

The Cajamarca province hosts numerous porphyry Cu±Au and high-sulfidation epithermal Au±Ag deposits of early to late Miocene age, which includes the Minas Congas and Cerro Corona Au+Cu porphyry deposit, the Michiquillay Cu porphyry deposit and the El Galeno Cu+Au porphyry deposit, and the Yanacocha and Tantahuatay high-sulfidation Au±Ag deposits (Fig. 1). The tonnage of deposits are listed in Table 1.

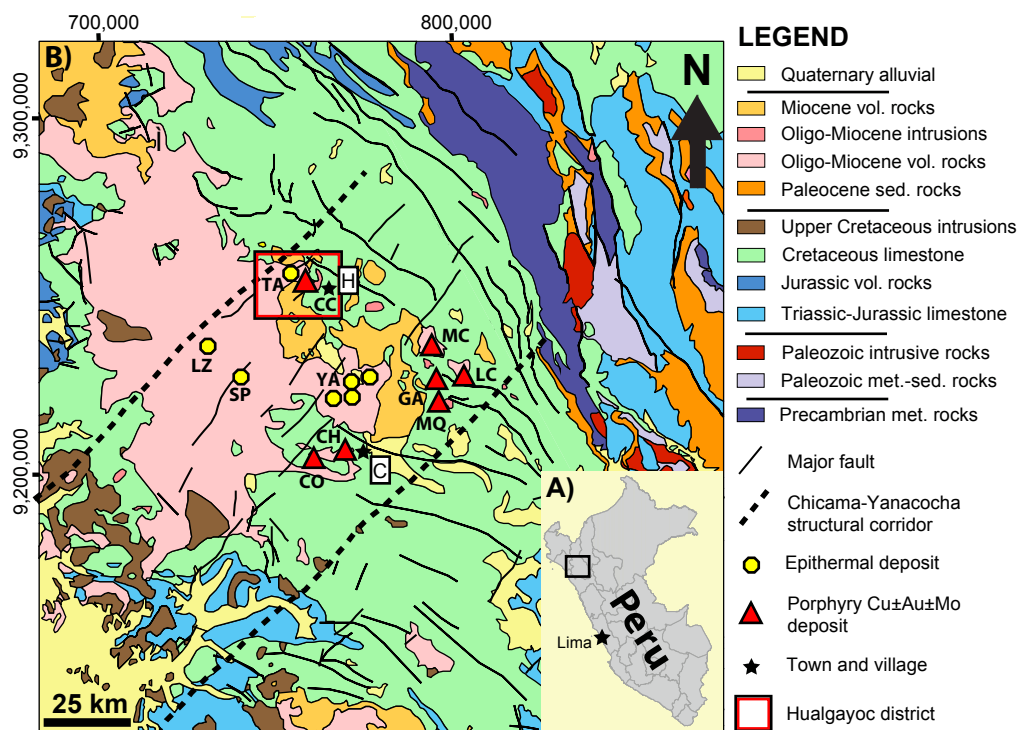


Figure 4.1: (A) Location of the Cajamarca region (black square) within Peru. (B) Geological map of the Cajamarca region showing the locations of major porphyry Cu±Au and high-sulfidation Au deposits. The Hualgayoc district is located 30 km north of the Yanacocha district. CC = Cerro Corona, CH = Chamis, CO = Colpayoc, GA = El Galeno, LC = La Carpa, LZ = La Zanja, MC = Minas Conga, MQ = Michiquillay, SP= Sipan, TA = Tantahuatay, YA = Yanacocha. Modified after Brewer and Davis (2004). UTM coordinates in metres are WGS84 Zone 17.

Deposit name ¹	Deposit type	Tonnage (Mt)	Grade		Contained metal		Comment
			Cu (wt%)	Au (g/t)	Cu (Mt)	Au (t)	
Cerro Corona	Porphyry Au-Cu	110 [1]	0.5 [1]	0.9 [1]	0.55 [1]	99 [1]	54.4 t Au, 0.37 Mt Cu produced, 2009-2019 [4]
Minas Conga	Porphyry Au-Cu	641 [1]	0.28 [1]	0.75 [1]	1.8 [1]	480 [1]	
El Galeno	Porphyry Cu-Au	661 [1]	0.5 [1]	0.12 [1]	3.3 [1]	79 [1]	
Michiquillay	Porphyry Cu	1150 [1]	0.63 [1]	–	7.2 [1]	–	
Sipan	High-Sulfidation Au-Ag	16 [1]	–	2 [1]	–	32 [1]	~30 t Au in oxide zone mined before 2001 [1]
Tantahuatay	High-Sulfidation Au-Ag	225 [1]	–	0.33 [1]	–	74 [1]	23.8 t Au produced, 2014-2018 [6]
La Zanja	High-Sulfidation Au-Ag	33 [1]	–	0.69 [1]	–	23 [1]	19.4 t Au produced, 2014-2018 [6]
Yanacocha district	High-Sulfidation Au-Ag	–	0.63 [1]	0.98 [1]	–	–	1225 t Au produced, 1993–2010 [2]; 81.2 t 2015-2019; proven and probable reserves (2019): 216 t Au (oxide and sulfide), 0.66 Mt Cu (sulfide) [7]
AntaKori project	Skarn Cu-Au	517 [5]	–	–	2.3 [5]	140 [5]	Indicated and inferred resources (2019) [5]

La Carpa, Chamis and Colpayoc are porphyry prospects with no available values of reserves

References: [1] M. Cardozo, pers. comm. (2020); [2] Longo et al. (2010); [3] Candiotti and Guerrero (1997); [4] <https://www.goldfields.com>;

[5] <https://regulusresources.com/projects/resource/>; [6] www.buenaventura.com [7] www.miningdataonline.com

¹Locations are shown in Figure 1

Table 4.1: Tonnage and grade data of deposits from the Cajamarca region

4.2.2. Geology of the Hualgayoc district

The basement rocks of the Hualgayoc district are mainly composed of weakly folded Upper Cretaceous limestone and minor sandstone. The district was affected by several NW—SE and NE—SW trending faults during the Incaic Orogeny event at 59-55 Ma under compressional

regime (Benavides-Cáceres, 1999). These faults were reactivated during the Quechua orogenic event at ~ 17 Ma, in the early Miocene, again under regional compression (Benavides-Cáceres, 1999).

In the western part of the Hualgayoc district, the Cretaceous sedimentary rocks were intruded by several porphyritic necks, dykes and volcanic domes of similar composition to the Tantahuatay volcanic complex (Fig. 2), the latter being the host of the Tantahuatay high-sulfidation epithermal Au deposit. U/Pb dating of zircon from a dacitic rock of the Tantahuatay complex yielded an age of 13.4 ± 0.2 Ma (James, 1998). The Cretaceous sedimentary rocks and rocks of the Tantahuatay volcanic complex are locally overlain by andesitic to rhyolitic flows, domes and tuffs of the Calipuy Formation, which also partially hosts the Tantahuatay deposit, and the Negrito Formation.

The eastern and northwestern parts of the district are dominated by amphibole $\pm$ biotite porphyritic diorite to quartz-diorite, including the Cerro Corona intrusive complex, the Coymolache sill, and the Cerro Jesus, Cerro San Jose, Cerro Las Gordas, Cerro Caballerisa, Cerro Choro Blanco and San Miguel intrusions, plus the Hualgayoc rhyodacite (Fig. 2). U/Pb dating of zircon from the Cerro Corona intrusive complex yielded an age of 14.4 ± 0.1 Ma (James, 1998).

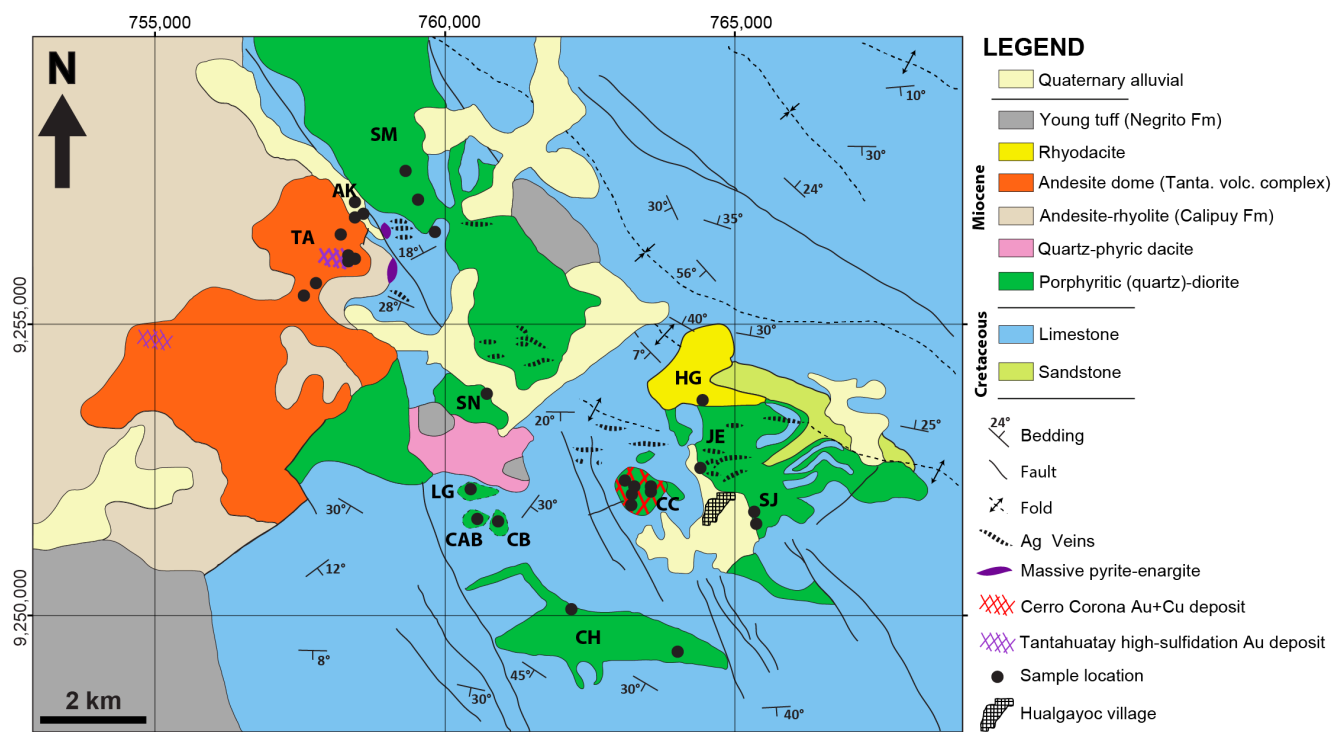


Figure 4.2: Simplified geological map of the Hualgayoc district showing sample locations and igneous units. Abbreviations: AK= AntaKori, CAB= Caballerisa, CB= Choro Blanco, CC= Cerro Corona, CH = Coymolache, HG= Hualgayoc, JE = Cerro Jesus, LG= Las Gordas, SJ = San Jose, SM= San Miguel, SN= San Nicolas, TA= Tantahuatay. Modified after S. Canchaya, J. Paredes and R. Tosdal (1996), cited by Gustafson et al. (2004). UTM coordinates in meters are WGS84 Zone 17.

4.2.3. Mineralization and alteration

The Hualgayoc district was an important Ag-producing area during Spanish colonization at the end of the 18th century (Gustafson et al., 2004). Historic mining activity extracted Ag from Ag-bearing veins hosted by the San Miguel, Cerro Jesus and Cerro San Jose intrusions (Fig. 2; Gustafson et al., 2004), although the Ag occurrences and their veins have not been documented and not preserved.

The Cerro Corona porphyry Au+Cu deposit is located 2 km west of the Hualgayoc village in the western part of the district (CC in Fig. 2). The deposit is hosted by the circular Cerro

Corona intrusive complex, which is composed of at least six successive quartz-diorite intrusions. All contain coarse-grained phenocrysts of plagioclase, amphibole, quartz and biotite, and microphenocrysts of magnetite, zircon and apatite.

High-temperature potassic alteration producing K-feldspar + biotite, subsequently overprinted by minor illite, affects most intrusive phases of the deposit. The alteration is the most intense in intrusive phases 2 and 3, where chalcopyrite and minor bornite mineralization also occurs in veins of quartz $\pm$ K-feldspar $\pm$ magnetite $\pm$ pyrite. Other alteration styles in the Cerro Corona deposit were reported by James (1998) and Longridge (2016). They describe a gradual zonation from potassic alteration to chlorite and white mica + pyrite alteration at shallower depth, and illite $\pm$ smectite $\pm$ kaolinite alteration in the upper part of the deposit that overprinted all other earlier alteration styles.

The Tantahuatay volcanic complex hosts high-sulfidation Au deposits where enargite and pyrite are associated with pervasive silicification and alteration consisting of pyrophyllite $\pm$ alunite. Fragments of brecciated porphyritic rocks displaying secondary K-feldspar and biotite intersected by drill core indicates high-temperature potassic alteration below the volcanic complex (Gustafson et al., 2004). A K/Ar age of hypogene alunite associated with mineralization (12.4 ± 0.4 ; Macfarlane et al., 1994) indicates the mineralization at Tantahuatay is slightly younger than the Cerro Corona intrusive complex. Similar ages of the Tantahuatay epithermal mineralization and the igneous rocks suggest these host rocks are likely the causative intrusions that contributed ore-forming fluids at depth.

The AntaKori project (AK in Fig. 2) located north the Tantahuatay mine contains several porphyritic intrusive units emplaced in Cretaceous limestone and overlain by volcanic and volcanoclastic rocks of the Calipuy formation. The mineralization includes Cu $\pm$ Au $\pm$ Ag skarn mineralization hosted in the limestone.

Other igneous rocks in the Hualgayoc district are hydrothermally altered except for the Coymolache sill, San Nicolas intrusion and Hualgayoc rhyodacite. Alteration includes K-feldspar + biotite + magnetite in the Cerro San Jose intrusions, and weak to moderate alteration of ferromagnesian minerals by chlorite $\pm$ epidote in the San Miguel, Cerro Choro Blanco, Cerro Caballerisa and Cerro Jesus intrusions. Moderate to intense alteration of white mica is present in the Cerro San Jose and Cerro Jesus intrusions. Silicification and quartz stockwork veinlets occur in the Cerro Las Gordas intrusion.

4.2.4. Sample descriptions

Most samples were collected from outcrops, including the intrusions of San Miguel, Cerro Jesus, Cerro San Jose, Cerro Caballerisa, Cerro Choro Blanco and Cerro Las Gordas, the Coymolache sill and the Hualgayoc rhyodacite (Fig. 2). Their locations are listed in Table A2-1 in the Appendix. Two samples from the San Jose intrusion were obtained from drill core provided by Gold Fields La Cima S.A. Samples from Cerro Corona were collected from the mine open pit. All samples from the Tantahuatay area were obtained from drill core in the Tantahuatay mine of Compañía de Minas Buenaventura S.A.A. Samples from the AntaKori area were obtained from drill core of Regulus Resources Inc.

Porphyry-style mineralization is represented by the occurrence of chalcopyrite in veinlets and/or disseminated, in association with K-feldspar + biotite alteration. Such mineralization is present in all Cerro Corona samples (intrusive phases CC1, 4, 5 and 6) and one drill core sample from the San Jose intrusion (sample SJD-05). Samples from Cerro Corona consist of porphyritic quartz-diorite with phenocrysts of plagioclase, biotite, amphibole and quartz with minor magnetite, apatite and zircon. They all were moderately altered with secondary biotite after

primary biotite and amphibole, and secondary K-feldspar and white mica after plagioclase.

Sample CC6 is affected by later alteration of chlorite + epidote replacing primary and secondary biotite and primary amphibole. All samples contain minor amount of disseminated pyrite and chalcopyrite with trace amount of bornite. The San Jose intrusion, similar in lithology and alteration to the Cerro Corona samples, is a quartz-diorite porphyry containing phenocrysts of quartz, plagioclase, biotite and amphibole with minor magnetite. The alteration consists of K-feldspar and white mica locally replacing plagioclase, the formation of secondary biotite replacing primary biotite and amphibole, and minor chlorite replacing secondary biotite. Minor chalcopyrite containing a trace amount of bornite inclusions occurs disseminated and in pyrite + K-feldspar + quartz veinlets.

All drill core samples from the Tantahuatay volcanic complex (samples tanta-351, 352, 355, 356 and 357) are medium to fine-grained porphyritic rocks affected by pervasive alunite ± pyrophyllite alteration replacing all primary minerals except quartz, with evidence for relict plagioclase and amphibole phenocrysts. All samples contain small amount of pyrite, disseminated or forming narrow (<10 mm in width) veinlets with quartz. Sample tanta-351 also contains minor enargite in the groundmass and in pyrite veinlets, which is intergrown with alunite.

4.3. Analytical methods

Zircon grains were separated after crushing using conventional magnetic and density techniques. Clear pink grains, ranging from 50 µm to 200 µm and up to 500 µm in size, were handpicked under a binocular microscope and mounted into an epoxy resin. Grains were examined under a transmitted light microscope and cathodoluminescence detector attached to a scanning electron microscope (SEM-CL) at the University of Ottawa MicroAnalysis Laboratory.

Transparent zircon grains without inclusions and fractures were selected for analysis. Zircon grains showing sector zoning were not selected, as they are known to have highly heterogeneous compositions (Hoffman & Long 1984). Zircon showing anomalous zoning and alteration textures were not used.

Trace element abundances were determined at the University of Ottawa using an Agilent 7700x inductively coupled plasma mass spectrometer (ICP-MS) coupled with a Photon Machines Analyte Excite 193 nm excimer laser for laser ablation (LA). The presence of minute inclusions was monitored using ^{42}Ca , ^{54}Fe , ^{31}P , ^{88}Sr and ^{139}La . Reference materials included NIST 612, BCR and GSEG1 (Jochum et al., 2005), 91500 zircon (Wiedenbeck et al., 1995) and Plešovice zircon (Sláma et al., 2008), and were analyzed after every seven unknown zircon sample grains. Raw data were reduced using the GLITTER! software (Griffin et al., 2008) with NIST612 reference material as the primary standard. Trace element concentrations were obtained based on the count ratios of the element to ^{29}Si and the composition of NIST612 (72.1 wt% SiO_2 ; Jochum et al., 2011) and the stoichiometric zircon SiO_2 content (31.57 wt%). BCR and GSEG1 reference materials were used as secondary standard, and 91500 and Plešovice zircon were used to validate the analytical data. The instrument at the University of Ottawa is identical to that of the LA-ICP-MS at the Geological Survey of Canada, described in Jackson et al (2004). The analytical procedure is described in detail in Kobylinski et al. (2020).

4.4 Results

4.4.1. Zircon petrography

Most zircon grains are euhedral prismatic crystals with length/width ratios ranging from 1.5 to 3. Grains show fine, well-developed oscillatory growth zoning in SEM-CL images (Fig.

3A, B, C, D, F). There are no major difference in texture, crystal habit and shape of zircon grains among the different intrusions and volcanic rocks. Several zircon grains from the Tantauatay volcanic complex are corroded and show patchy to feathery bright areas that overprint oscillatory growth zoning (Fig. 3E), suggesting sub-solidus alteration. Since these rocks were intensely altered by acidic hydrothermal fluids to form alunite $\pm$ pyrophyllite, the alteration of zircon is attributed to the hydrothermal activity.

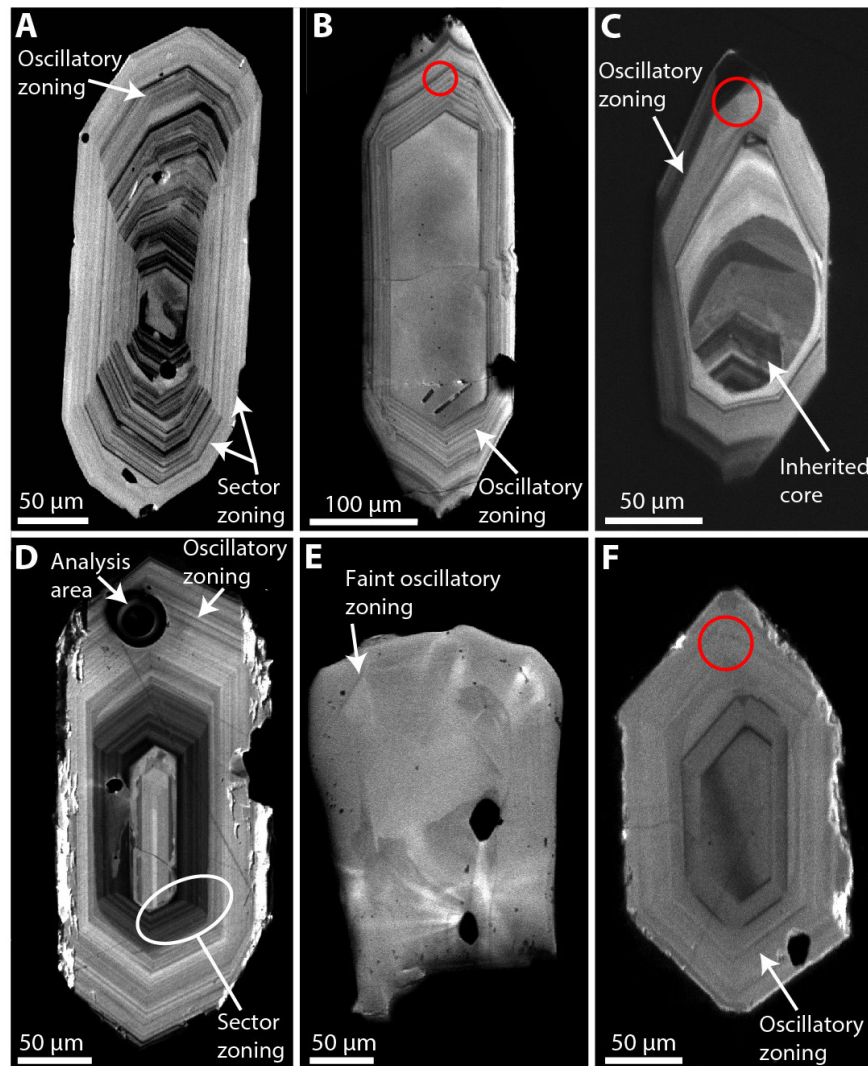


Figure 4.3: Cathodoluminescence images of representative zircon grains. (A) Zircon from phase 1 of the Cerro Corona Complex displaying oscillatory and sector zoning (sample CC1). (B) Zircon from the San Jose intrusion displaying magmatic oscillatory zoning (sample 25-4). (C)

Zircon from the Hualgayoc rhyodacite with resorbed core of inherited zircon, and coarse oscillatory-zoned overgrowth (sample 25-6). (D) Zircon from rhyolite of the Calipuy Formation, displaying magmatic oscillatory zoning and faint sector zoning near the center (sample Anta-8). (E) Zircon from the Tantauatay area showing faint magmatic oscillatory zoning overprinted by hydrothermal alteration (sample Tanta-352). (F) Zircon from Tantauatay displaying magmatic oscillatory zoning (sample Tanta-356). Red circles show the locations of analysis.

4.4.2. Zircon trace element compositions

Cerium anomalies, Ce^{4+}/Ce^{3+} , are defined as $Ce_{cn}/(La_{cn}+Pr_{cn})/2$ where “cn” in the subscript denotes the chondrite-normalized values. The La content of magmatic zircon is low, commonly below the detection limit, ~ 0.005 ppm, of the LA-ICP-MS analysis. Therefore, the ratios of Ce^{4+}/Ce^{3+} in zircon are commonly calculated following the method of Ballard et al. (2002). The amount of Ce^{3+} is calculated based on mineral-melt partitioning of REE^{3+} using the bulk rock composition as parental melt composition. Ce anomalies are also expressed as Ce/Nd (Chelle-Michou et al., 2014) and Ce/Ce^* ($Ce^* = [(Nd_{cn})^2]/[Sm_{cn}]$) (Loader et al., 2017). Both Ce/Nd and Ce/Ce^* are obtained solely from the composition of zircon. These two parameters offer good approximation of Ce^{4+}/Ce^{3+} in zircon especially for zircon from highly altered rocks, whose bulk rock compositions are likely different from those of the parental magmas. All samples from the Hualgayoc district except for the Coymolache sill, Nicolas intrusion and Hualgayoc rhyodacite are hydrothermally altered. Therefore, this paper uses Ce/Ce^* to show Ce anomalies, as proposed by Loader et al. (2017).

Zircon trace element data are presented in Table A2-2 in the Appendix. All zircon grains ($n = 458$) from the Hualgayoc area show a similar chondrite-normalized REE pattern (Fig. 4), with very high Ce anomalies ($Ce/Ce^* = 12-574$), and moderate to weak negative Eu anomalies ($Eu/Eu^* = [Eu_{cn}]/[(Sm_{cn}*Gd_{cn})^{0.5}] = 0.17-0.97$) (Fig. 2.5). Zircon grains in individual rock samples have median values of Ce/Ce^* that range from 46 to 210, and Eu/Eu^* ranging from 0.36 to 0.7. The zircons also have moderate to low concentrations of middle REE (Sm, Eu, Gd, Tb and

Dy) increasing steadily towards heavy REE (Ho, Er, Tm, Yb and Lu) and Y. The sum of middle and heavy REE in zircon range from 8 to 200 ppm and from 123 to 1680 ppm respectively, and Y ranges from 130 to 2235 ppm.

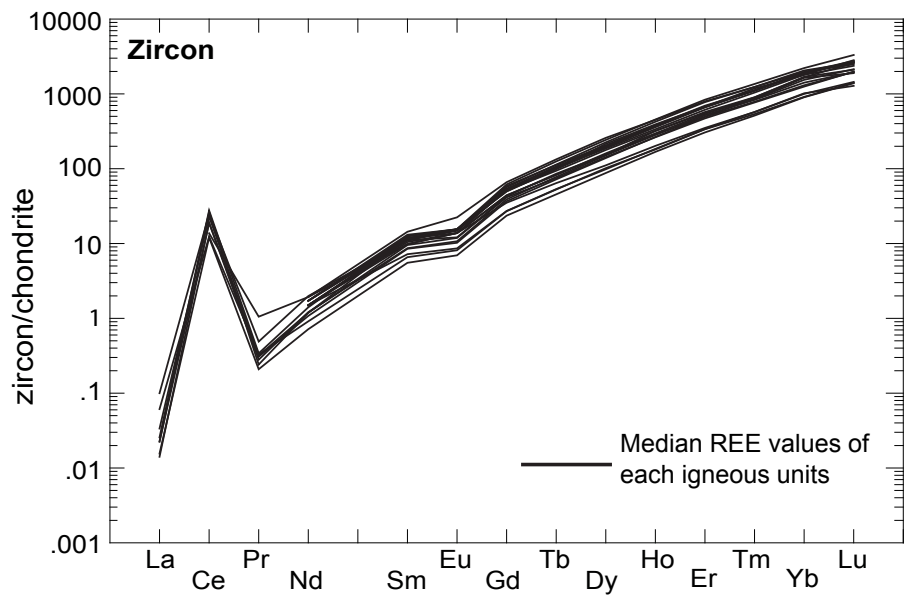


Figure 4.4: Chondrite-normalized REE patterns for media values of REEs in zircon from each igneous unit from the Hualgayoc district. Chondrite values are from McDonough and Sun (1995). All zircon grains ($n = 458$) show significant positive Ce anomalies and weak negative Eu anomalies.

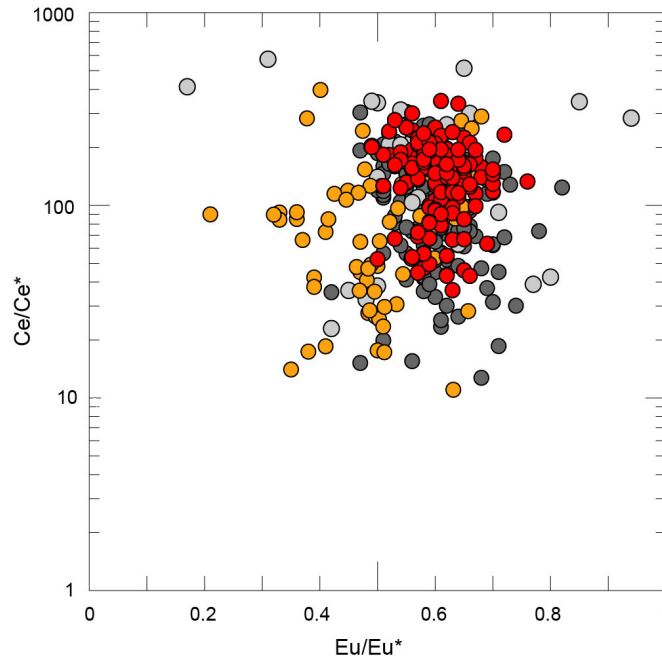


Figure 4.5: Eu/Eu* vs Ce/Ce* of all 458 individual zircon grains. Zircon grains from intrusions associated with porphyry-style mineralization (Cerro Corona, San Jose) are shown as solid red circles. Zircon grains from intrusions related to epithermal deposits (Tanta-351, 352, 355, 356 and 357) are shown as solid orange circles. Zircon grains from intrusions with no apparent relation to porphyry-style mineralization (Anta-PF, Caballerisa, Choro Blanco, San Miguel, Anta-PK, Las Gordas, Coymolache, Jesus and San Nicolas) are shown as dark gray circles. Zircon grains from volcanic rocks (rhyolite and andesite from the Calipuy Formation, and Hualgayoc rhyodacite) are shown as light gray circles.

4.5. Discussion

4.5.1. Origin of zircon

All analyzed zircon grains examined in this study are of igneous origin. They show very low light REE, especially La (< 0.15 ppm); about half of the zircon grains have a La concentration below the detection limit of 0.03 ppm. Sharp oscillatory growth zoning supports an igneous origin of zircon. Hydrothermal zircons commonly show elevated light REE (La > 1 ppm) (Hoskin, 2005), and oscillatory zoning is commonly obliterated or broad (Corfu et al., 2003). An igneous origin of zircon is further supported by Th/U ratios ranging from 0.1 to 1.62, largely

between 0.2 and 0.9. These values are common in zircon from rocks with dioritic to granitic composition (Kirkland et al., 2015).

4.5.2. Zircon composition in the Hualgayoc district

4.5.2.1 Ce anomalies in zircon in the Hualgayoc district

Zircon grains from the Hualgayoc district have a wide range in Ce/Ce* values, from 11 to 574 (Fig. 6A), and do not appear to correlate with an association to apparent mineralization. For example, the Cerro Corona intrusive complex, host to the Cerro Corona Au+Cu porphyry deposit, has Ce/Ce* median values of 150, 135, 135 and 125 for intrusive phases CC1, CC4, CC5 and CC6 respectively (Table A2-2 in the Appendix). These median values are lower than that of the San Jose intrusion (median value of 180), which only contains localized minor chalcopyrite veinlets. Several intrusions that are apparently not associated with porphyry-type Au±Cu mineralization, such as the San Miguel, Caballerisa and Choro Blanco intrusions, and samples Anta-PF and Anta-PK, show similarly high median Ce/Ce* values in zircon (140, 145, 160, 140 and 125, respectively).

The igneous rocks hosting the Tantauatay high-sulfidation Au deposit (samples Tanta-355, 356, 351, 357, 352) have moderate median Ce/Ce* values (88, 82, 75, 65 and 46, respectively), which may be representative of the causative intrusions at depth. These values are similar to those of the barren Coymolache sill (median value of 75), and the intrusions of Cerro Jesus (75) and San Nicolas (49), all of which are not significantly altered and not associated with any known porphyry-type mineralization.

Volcanic rocks in the district have high to very high median Ce/Ce* values, similar to those of mineralized intrusions. Andesite from the Calipuy Formation and the Hualgayoc rhyodacite show median values of 104 and 102, respectively, which are similar to those of the

Cerro Corona intrusive complex. Rhyolite from the Calipuy Formation show a median value of 209 for Ce/Ce^* , which is the highest value of zircon data among all igneous rocks in the district.

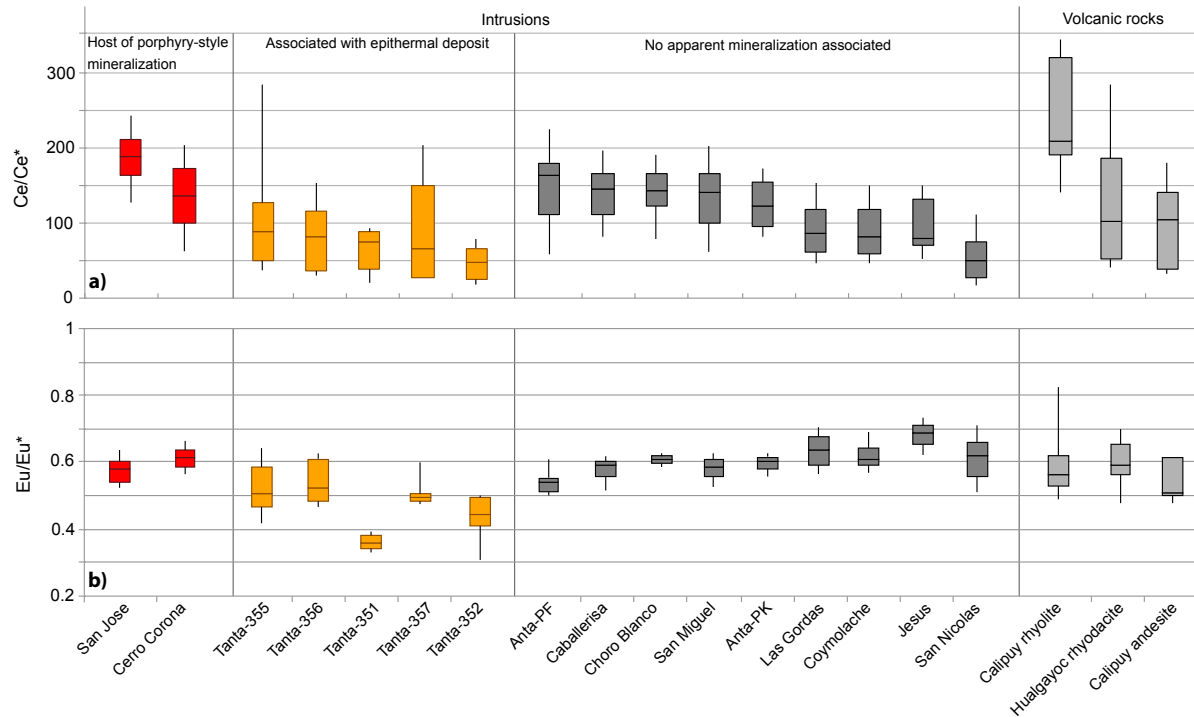


Figure 4.6: Box-and whiskers plot diagram of Ce/Ce^* (a) and Eu/Eu^* (b) for zircon for each unit of igneous rocks in the Hualgayoc district. Whiskers represent 10th and 90th percentile values.

4.5.2.2. *Eu anomalies in zircon of the Hualgayoc district*

Europium anomalies, Eu/Eu^* , in zircon do not vary significantly in the study area (Fig. 6B). Most samples have similar median Eu/Eu^* in zircon, ranging from 0.7 to 0.5, independent of the mode of occurrence of igneous rocks and apparent association with mineralization. Only two samples (Tanta-351 and 352) from the Tantauatay volcanic complex show slightly lower median Eu/Eu^* in zircon, 0.44 and 0.36, than other samples in the district.

The ratios of Eu/Eu^* in a melt is controlled not only by oxidation conditions of the melt, but also by the crystallization of mineral phases, such as plagioclase, apatite and titanite (Loader et al., 2017). Since plagioclase preferentially incorporates Eu^{2+} , earlier or co-crystallization of plagioclase leads to profound negative Eu/Eu^* anomalies in the melt and zircon. On the other hand, titanite and apatite preferentially incorporate Sm and Gd over Eu^{2+} , and therefore their crystallization has the opposite effect (Fujimaki, 1986; Bachmann et al., 2005; Loader et al., 2017). Titanite was not observed in the studied samples, but sample Anta-PF contains a rare aggregate of fine-grained TiO_2 , which may be a replacement product magmatic titanite. However, this sample has significant negative anomalies of Eu in zircon (median value of 0.54), indicating that the possible presence of titanite in the magma has a very minor effect on zircon Eu/Eu^* for this sample. Euhedral to sub-euhedral apatite crystals are present in minor amounts ($< 1\%$) in most weakly to moderately altered intrusions, but it is unclear whether they crystallized prior, during, or after zircon crystallization. The values of Eu/Eu^* in zircon from the district decrease slightly with increasing Hf content in zircon (Fig. 7). Hf is incompatible with many minerals, and its content commonly increases in a melt during fractional crystallization (e.g. Claiborne et al., 2010). Considering the similar mineralogy and lithology of igneous rocks in the district, the inverse correlation between Eu/Eu^* and Hf content in zircon appears to indicate that plagioclase was co-crystallizing alongside zircon during magma evolution.

Zircon from barren intrusions and volcanic rocks has similar Ce and Eu anomalies as zircon from intrusions associated with Cu and Au mineralization. The data indicate that the parental magmas for all igneous rocks in the district are oxidized, both barren and those associated with mineralization.

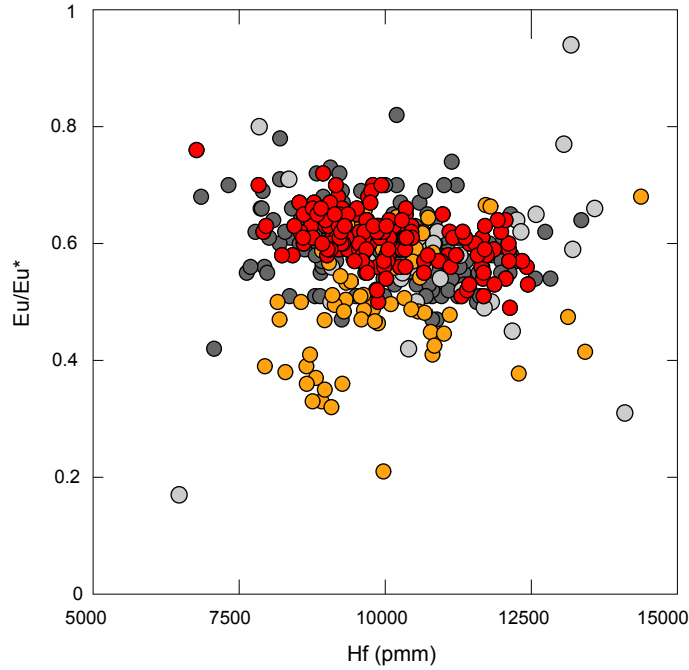


Figure 7: Hf vs Eu/Eu* of individual zircon grains. Symbols are the same as Fig. 5.

4.5.2.3. *Water content in magma and its effect on zircon composition*

It is generally accepted that magmas responsible for porphyry-type Cu±Au and high-sulfidation Au mineralization are sufficiently hydrous to be saturated with water and exsolve a magmatic fluid, which can extract metals from the melt and subsequently concentrate these to economic values (Burnham, 1979; Cline and Bodnar, 1991). High water contents (> 3 wt%) of magma results in the early crystallization of amphibole (Naney, 1983; Ridolfi et al., 2010; Rooney et al., 2011). Amphibole preferentially incorporates middle REE compared to heavy REE (Tiepolo et al., 2007); partition coefficients between amphibole and melt for Dy and Yb in andesitic melt are around 4.4 and 2.7 respectively (Sisson, 1994). Therefore, igneous rocks formed from hydrous magmas commonly show low middle and heavy REE + Y, and low ratios of middle REE/heavy REE as the result of amphibole crystallization.

Since zircon composition reflects that of magma, zircon grains formed in hydrous magmas record the geochemical signature caused by crystallization of amphibole. Zircon grains from the Hualgayoc district have a low ratio of Dy/Yb ranging from 0.1 to 0.3 (Fig. 8). We suggest that these values reflect amphibole crystallization in magmas, which is consistent with the common occurrence of amphibole phenocrysts in most igneous rocks in the Hualgayoc district. Other factors may lower the ratios of middle and heavy REE in magmas, including crystallization of REE-bearing minerals such as titanite (Loader et al., 2017), zircon or monazite, and magmatic processes such as magma mixing. Since titanite is only observed in one sample, Anta-PF, we suggest that the influence of titanite on REE in parental magmas is unlikely to be significant.

In hydrous magma, early crystallization of plagioclase is suppressed (Sisson and Grove, 1993; Müntener et al., 2001), leading to weak negative Eu anomalies in parental magmas. Therefore, Eu/Eu^* in zircon can be influenced by the water content of the melt in addition to oxidation conditions, since Eu^{2+} occurs in reduced magmas. Lu et al. (2016) suggest that Eu/Eu^* in zircon greater than 0.3, $10,000 \times \text{Eu}/\text{Eu}^*/\text{Y}$ in zircon greater than 1 and Dy/Yb in zircon lower than 0.3 reflects high water content of the parental magmas. Nearly all zircon grains from the Hualgayoc district satisfy the above criteria for high water contents of magmas as defined by Lu et al. (2016) (Figs. 7, 8). Given the hydrous nature of magmas in the Hualgayoc district, small Eu anomalies and low middle REE likely reflect the suppression of early plagioclase crystallization, and fractional crystallization of amphibole. Therefore, the influence of other factors, such as magma oxidation conditions and the crystallization of apatite, on the Eu/Eu^* in zircon, is unclear.

Although many zircons from igneous rocks associated with porphyry systems effectively have Eu/Eu^* greater than 0.3 (Lu et al., 2016), there are examples of zircon with low Eu/Eu^* from igneous rocks associated with porphyry Cu deposits. Examples include zircon grains in the

Gibraltar porphyry Cu+Mo deposit in British Columbia, Canada, with zircon quartile Eu/Eu* values ranging from 0.27 to 0.31 (Kobylinski et al., 2020), and the Erdenet porphyry Cu+Mo deposit in Mongolia, with zircon Eu/Eu* ranging from 0.28 to 0.33 (Shen et al., 2015).

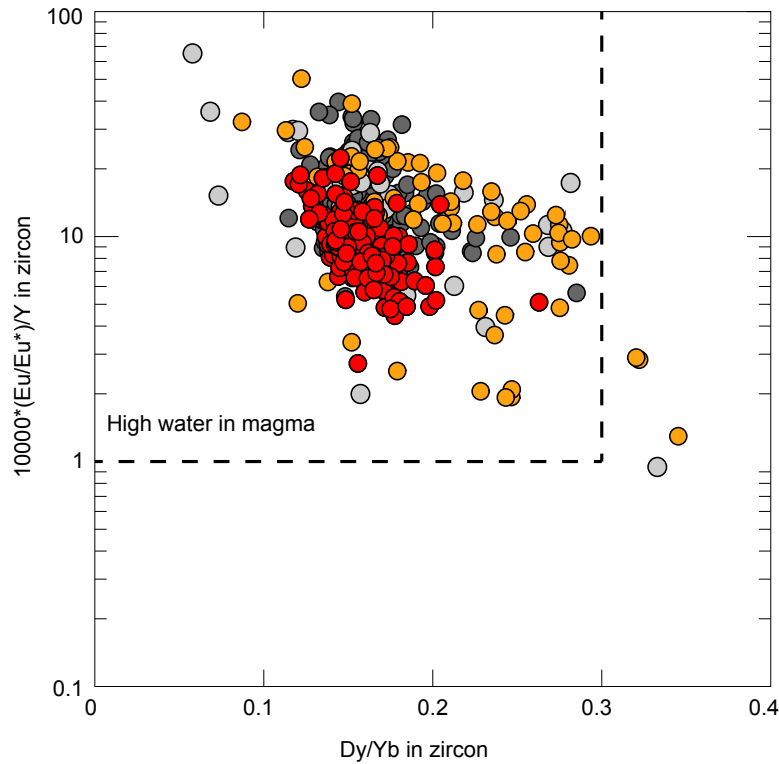


Figure 8: Dy/Yb vs $10,000 \cdot (\text{Eu}/\text{Eu}^*)/\text{Y}$ of individual zircon grains. High water in magma field defined by Lu et al. (2016). Symbols are the same as Fig. 5.

4.5.3. Zircon composition and Cu tonnage of porphyry deposits.

Shen et al. (2015) compared the Ce and Eu anomalies of porphyry Cu deposits of various tonnage in the Central Asian Orogenic belt. They reported that intrusive rocks associated with porphyry Cu deposits of intermediate to high tonnage (1.5 to > 4 Mt Cu) have higher Ce anomalies in zircon than intrusive rocks associated with porphyry Cu deposits of smaller size (<1.5 Mt Cu), suggesting that the degree of magma oxidation condition may have an influence on

Cu tonnage. However, this relationship between Ce anomalies in zircon and Cu tonnage of the deposit does not appear to be applicable globally. Zircon grains from igneous rocks associated with porphyry Cu±Au±Mo deposits in various terranes have a variation in Ce/Ce* and Eu/Eu* anomalies, with median values ranging from 50 to 192 and 0.43 to 0.77, respectively (Fig. 9), but there is no apparent correlation between Ce/Ce* in zircon and the Cu tonnage of these deposits (Fig. 10). Two giant porphyry deposits, El Teniente (128 Mt Cu; Singer et al., 2008) and Chuquicamata (126 Mt Cu; Singer et al., 2008), both in Chile, have different median Ce/Ce* in zircon (87 and 200, respectively) despite similar tonnages. The Ce/Ce* values of zircon from the Cerro Corona deposit (0.55 Mt Cu) are similar or higher than those from many larger porphyry deposits in the 1 to 10 Mt Cu range (Fig. 10). Tonnages are from Singer et al. (2008).

High oxygen fugacity is considered to be an important factor for the formation of porphyry-style mineralization, as Cu solubility in the melt increases with increasing fO_2 (Zajacz et al., 2012). However, the Cu tonnage of a porphyry deposit is also controlled by many other factors. The intrinsic Cu content in the melt is important, and high melt oxidation condition does not necessarily imply that it will contain a high amount of Cu. The depth of magma emplacement is also a critical factor in the formation of large porphyry-type deposits, as effective exsolution of aqueous magmatic fluids occurs at shallow depths <5 km (Fournier, 1999). When magma emplacement is too shallow (<1 km), the exsolved magmatic fluids are vapors that have a low capacity to transport metals (Hedenquist, 1995). The mode of occurrence and shape of the intrusion are also critical. Sills are difficult to form focused hydrothermal systems for mineralization. Porphyry-type deposits are usually associated with, and typically hosted by narrow (<1 km in diameter) plug-like porphyritic intrusions that are focused in one area (Sillitoe, 2010). This localized supply of magma allows for focused precipitation of metals leading to the

formation of economic mineralization (Sillitoe 2010). Zircon compositions do not record all of these factors critical to generate significant porphyry Cu mineralization.

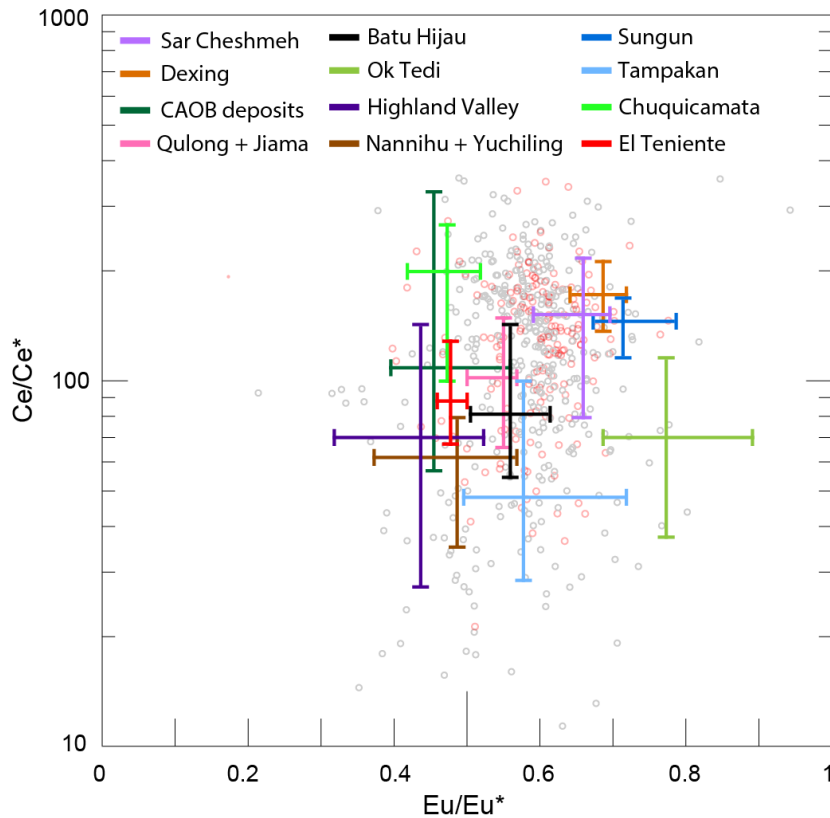


Figure 4.9: Eu/Eu^* vs Ce/Ce^* of zircon grains from igneous rocks considered to be genetically associated with porphyry $\text{Cu}\pm\text{Au}\pm\text{Mo}$ deposits containing greater than 0.5 Mt Cu, up to 130 Mt Cu (Fig. 10). They include the Sar Cheshmeh $\text{Cu}+\text{Mo}+\text{Au}$ deposit, the Batu Hijau and Tampakan $\text{Cu}+\text{Au}$ deposit, the Sungun and Qulong $\text{Cu}+\text{Mo}$ deposit, the Jiamia $\text{Cu}+\text{Mo}+\text{Au}$ deposit, the Nannihu and Yuchiling Mo deposit (Lu et al., 2016); the Dexing $\text{Cu}+\text{Mo}+\text{Au}$ deposit (Lu et al., 2016; Zhang et al., 2017); the El Teniente $\text{Cu}+\text{Mo}$ deposit (Muñoz et al., 2012); the Ok Tedi $\text{Au}+\text{Cu}$ deposit (Large et al., 2018); the Highland Valley $\text{Cu}+\text{Mo}$ deposit (D’Angelo et al., 2017); the Chuquicamata $\text{Cu}+\text{Mo}+\text{Au}$ deposit (Ballard et al., 2002); and $\text{Cu}+\text{Au}$ deposits in the Central Asian Orogenic Belt (CAOB) including Bozshakol, Nurkazghan, Kounrad, Aktogai, Erdenet, Koksai, Tuwu-Yandong, Borly and Baogutu (Shen et al., 2015) and Oyu Tolgoi $\text{Cu}+\text{Au}$ (Wainwright et al., 2011). Crosses represent median and quartile values. Individual zircon data from the Cerro Corona intrusive complex are indicated by open red circles. Individual zircon data from other igneous rocks in the Hualgayoc district are indicated by open gray circles.

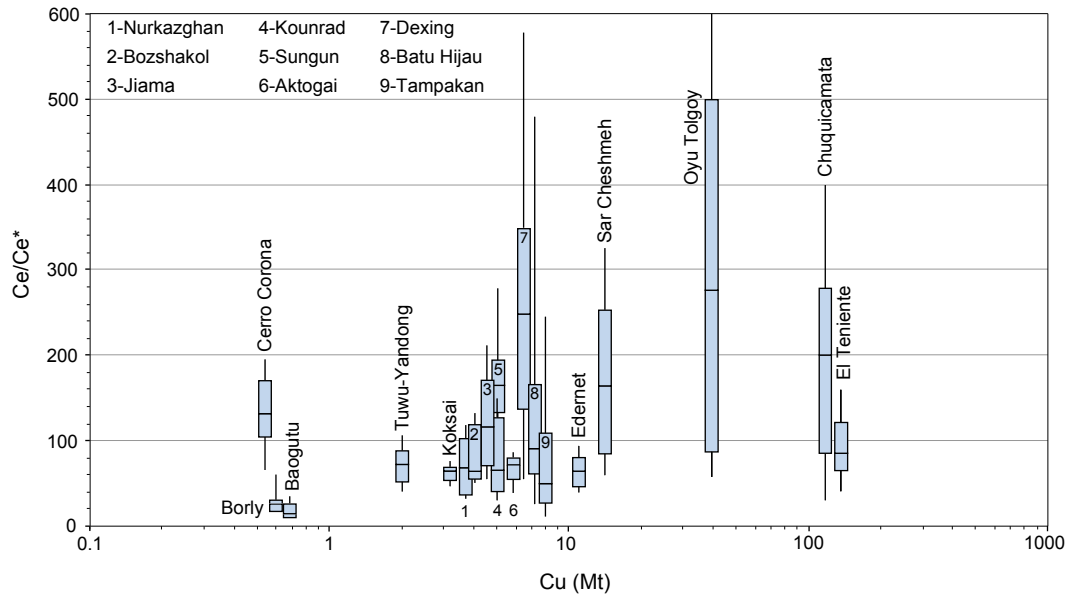


Figure 10: Box-and whiskers plot diagram of Ce/Ce^* of zircon grains from mineralization-related intrusions vs copper tonnage (Mt) of various porphyry deposits. Whiskers represent 10th and 90th percentile values. Most intrusions considered to be associated with Cu deposits have median Ce/Ce^* in zircon >40 , except for the small Borly and Baogutu deposits. The Cerro Corona deposit has the highest ratio of Ce/Ce^* to Cu tonnage, whereas the giant El Teniente deposit has the lowest ratio. Cu tonnages from Singer et al. (2008), Shen et al. (2015) and Lu et al. (2016).

4.6. Conclusions

Zircon grains from a variety of igneous rocks in the Hualgayoc district of northern Peru have similar trace-element composition with large positive Ce anomalies, weak to moderate negative Eu anomalies, and low ratios of middle REE/heavy REE, reflecting an oxidized and hydrous nature of parental magmas.

The results from the Hualgayoc district indicate that zircon composition is not always reliable to identify specific intrusions associated with porphyry $Cu\pm Au\pm Mo$ deposits. However, zircon composition is still a useful indicator during exploration, to identify regions containing oxidized and hydrous magmas, some of which may be associated with porphyry-type $Cu\pm Au$ deposits.

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CHAPTER 5.

Global conclusions

Geology, alteration and mineralization in the district

The Hualgayoc district consists of weakly deformed Cretaceous sedimentary rocks, which are intruded by dioritic stocks, plugs and sills, and overlaid by andesitic to rhyolitic volcanic flows and domes of Miocene age. The primary mineralogy of intrusive rocks consists of plagioclase, amphibole, quartz $\pm$ biotite phenocrysts in a fine-grained quartz and plagioclase matrix. Volcanic rocks consist of plagioclase, K-feldspar, biotite and quartz phenocrysts in a glassy matrix.

Porphyry-style mineralization occurs at the Cerro Corona intrusive complex and the mineralization consists of chalcopyrite + bornite in veinlet or disseminated, and is associated with potassic alteration forming K-feldspar and secondary biotite. Similar style of mineralization and alteration are found locally in the San Jose intrusion. High-sulfidation epithermal Au-style mineralization occurs at the Tantahuatay volcanic complex. The mineralization consists of enargite and associated with pervasive silicification and alteration of pyrophyllite $\pm$ alunite.

Almost all igneous rocks in the Hualgayoc district are affected by hydrothermal alteration despite the apparent lack of mineralization. They include weak to moderate propylitic alteration forming chlorite and epidote, weak to intense white mica $\pm$ clay minerals alteration. Zircon U-Pb dating of igneous rocks in the Hualgayoc district reveals nearly continuous magmatism from 14.8 Ma to 9.7 Ma. The Cerro Corona porphyry Au-Cu deposit formed in a short period of time at around 14.5 Ma. Most igneous rocks hosting the Tantahuatay high-sulfidation Au epithermal deposit formed later at around 13.7-11.5 Ma, and are contemporaneous to the high sulfidation epithermal mineralization. The magmatic activity in the Hualgayoc district cease at 9.7 Ma with the emplacement of the Hualgayoc rhyodacite.

Ce and Eu anomalies in zircon

All zircon from the Hualgayoc district show, weak to moderate negative Eu anomalies and low ratios of middle REE/heavy REE reflecting oxidized and hydrous nature of parental magmas, which supports the data obtained from amphibole composition. There does not seem to be any clear pattern in the magnitude of zircon Ce and Eu anomalies from mineralized and apparently barren intrusions. Several barren intrusions have higher Ce and lower Eu anomalies in zircon than intrusions associated with mineralization in the Hualgayoc district and vis versa. This suggests that the magnitude of Ce and Eu in zircon cannot identify individual intrusions associated with mineralization. However, it may remain useful in identifying areas associated with oxidized and hydrous magmatism.

Characteristics of parental magmas in the Hualgayoc district

Bulk rock composition indicates amphibole had a major control on the parental magmas composition, and parental magmas likely originated from an amphibole-rich source. Increasing garnet content in the source and fractional crystallization of amphibole in parental magmas were likely responsible for the observed compositional evolution of igneous rocks in the Hualgayoc district. The evolution of the magma source is also observed in other Miocene igneous rocks in the Cajamarca region. Zircon and amphibole composition suggests parental magmas suggest all magmas in the Hualgayoc district were oxidized above the FMQ rock buffer and water-rich above 3 wt% H₂O, suggesting the absence of mineralization in some intrusions were due to other factors such as the intrusion shape and depth of emplacement.

Appendices.

Appendix 1. Supplementary material for Chapter 3

Table A1-1. Lithology, mineralogy, alteration, age and sample location of intrusions and volcanic rocks in the Hualgayoc District.

Abbreviations: Aln: alunite; Anh: anhydrite; Bt: biotite; Ccp: chalcopyrite; Chl: chlorite; Dsp: diaspore; Ep: epidote; Hbl: hornblende; Ilm: ilmenite; Kal: kaolinite; Kfs: potassic feldspar; Mag: magnetite; Pl: plagioclase; Prl: pyrophyllite; Py: pyrite; Qz: quartz; Ttn: titanite; WM: white mica; Zrn: zircon.

¹UTM coordinates are WGS84 Zone 17.

²Uncertainties are 2sigma

Sample	Igneous unit	Abbreviations in the map	Sample location ¹		Lithology	Primary minerals	Intensity of alteration and alteration minerals	Zircon age (Ma) ²	Zircon appearance
			Easting (m)	Northing (m)					
CC1	Cerro Corona Phase 1	CC	762,812	9,252,019	Qz-diorite porphyry	Bt. Hbl. Pl. Qz. Ap. Mag. Ilm. Zrn	Weak – Bt. Kfs. Mag. Chl	14.57 ± 0.16	Euhedral to sub-euhedral
CC4	Cerro Corona Phase 4		763,296	9,251,870	Qz-diorite porphyry	Bt. Hbl. Pl. Qz. Ap. Mag. Ilm. Zrn	Moderate – Bt. Kfs. Mag. Chl	14.40 ± 0.28	Euhedral to sub-euhedral
CC4b			763,281	9,251,816	Qz-diorite porphyry	Bt. Hbl. Pl. Qz. Ap. Mag. Ilm. Zrn	Moderate – Bt. Kfs. Mag. Chl	14.51 ± 0.21	Euhedral to sub-euhedral
CC5	Cerro Corona Phase 5		762,934	9,251,586	Qz-diorite porphyry	Bt. Hbl. Pl. Qz. Ap. Mag. Ilm Zrn	Moderate – Bt. Kfs. Mag. Chl	14.42 ± 0.20	Euhedral to sub-euhedral
CC5n			762,951	9,251,723	Qz-diorite porphyry	Bt. Hbl. Pl. Qz. Ap. Mag. Ilm. Zrn.	Moderate – Bt. Kfs. Mag. Chl	14.40 ± 0.12	Euhedral to sub-euhedral
CC6	Cerro Corona Phase 6		763,085	9,251,843	Qz-diorite porphyry	Bt. Hbl. Pl. Qz. Ap. Mag. Ilm. Zrn.	Moderate – Bt. Kfs. Mag. Chl	14.59 ± 0.13	Euhedral to sub-euhedral
SJD-05	San Jose	SJ	764,830	9,251,099	Qz-diorite porphyry	Bt. Hbl. Pl. Qz Ilm. Zrn	Moderate – Bt. Kfs. Mag. Chl	14.73 ± 0.13	
SJD-02			765,137	9,251,308	Qz-diorite porphyry	Bt. Hbl. Pl. Qz. Zrn	Intense – WM. clay minerals		Euhedral to sub-euhedral
25-4			765,119	9,251,258	Altered porphyry	Qz (residual). Zrn	Intense – WM. Clay minerals		Euhedral to sub-euhedral
Tanta-352	Tantahuatay	TA	757,458	9,255,461	Altered porphyry	Qz (residual). Zrn	High to intense – Aln±Prl	13.09 ± 0.27	Round
Tanta-355			758,118	9,255,898	Altered porphyry	Qz (residual). Zrn	High to intense – Aln±Prl	12.91 ± 0.56	Euhedral to round
Tanta-356			758,015	9,255,942	Altered porphyry	Qz (residual). Zrn	High to intense – Aln±Prl	12.64 ± 0.56	Euhedral to sub-euhedral
Tanta-357			758,008	9,255,855	Altered porphyry	Qz (residual). Zrn	High to intense – Aln±Prl	12.46 ± 0.49	Sub-euhedral to rounded
Tanta-358	Tantahuatay – Cienaga	CNG	754,547	9,254,613	Altered porphyry	Pl. Qz. Zrn	High – WM	14.06 ± 0.49	Sub-euhedral to rounded

CNG-1			754,389	9,253,072	Altered Pl porphyry	Qz (residual). Zrn	Intense – Aln	14.52 ± 0.49	Euhedral to sub-euhedral
Anta-PK	AntaKori PK	AK	758,093	9,256,788	Altered Pl-Qz porphyry	Pl. Qz. Zrn	High – WM	14.44 ± 0.25	Sub-euhedral
Anta-PF	AntaKori PF		758,116	9,256,564	Altered Pl-Qz-Bt porphyry	Pl. Qz. Bt. Ttn. Zrn	High – WM	12.01 ± 0.26	Euhedral
CJ	Cerro Jesus	JE	764,114	9,252,182	Qz-diorite porphyry	Pl. Hbl. Qz. Zrn	High – WM		Euhedral to sub-euhedral
25-7			763,832	9,252,892	Qz-diorite porphyry	Pl. Hbl. Qz. Zrn	High – WM	14.83 ± 0.36	Euhedral to sub-euhedral
18-2			765,179	9,252,480	Qz-diorite porphyry	Pl. Hbl. Qz. Zrn	Weak – Chl. Ep.		
CB	Cerro Choro Blanco	CB	760,586	9,251,265	Diorite porphyry	Pl. Hbl. Qz. Zrn	None	14.22 ± 0.25	Euhedral to sub-euhedral
CAB	Cerro Caballerisa	CAB	760,244	9,251,364	Diorite porphyry	Pl. Hbl. Qz. Zrn	None	14.11 ± 0.18	Euhedral to sub-euhedral
LG	Las Gordas	LG	760,081	9,252,023	Silicified intrusive rock	Qz (residual)	Intense – Qz. WM.	14.35 ± 0.28	Euhedral to sub-euhedral
CD	Coymolache	CO	761,877	9,249,776	Qz-diorite porphyry	Pl. Hbl. Bt. Qz. Kfs. Mag. Zrn	Weak – Chl		Euhedral to sub-euhedral
25-5			763,733	9,249,006	Qz-diorite porphyry	Pl. Hbl. Bt. Qz. Kfs. Mag. Zrn	Weak – Chl	14.32 ± 0.28	Euhedral to sub-euhedral
SCO-1	San Miguel	SM	759,532	9,256,283	Qz-diorite porphyry	Pl. Hbl. Bt. Qz. Kfs. Mag. Ilm. Zrn	Weak to moderate – Chl. Ep	14.52 ± 0.14	Euhedral to sub-euhedral
SCO-2			759,214	9,256,907	Qz-diorite porphyry	Pl. Hbl. Bt. Qz. Kfs. Mag. Ilm. Zrn	Weak to moderate – Chl. Ep		Euhedral to sub-euhedral
SCO-3			758,993	9,257,411	Qz-diorite porphyry	Pl. Hbl. Bt. Qz. Kfs. Mag. Ilm. Zrn	Weak to moderate – Chl. Ep		Euhedral to sub-euhedral
SN	San Nicolas	SN	760,473	9,253,673	Qz-diorite porphyry	Pl. Hbl. Bt. Mag. Zrn	Weak – Chl. Ep	13.67 ± 0.28	Sub-euhedral to round
Anta-6	Calipuy	AK	757,858	9,256,301	Andesite	Bt. Pl. Qz. Hbl. Zrn	Intense – Prl. Kal. Dsp	13.18 ± 0.37	Sub-euhedral to rounded
Anta-8			758,236	9,256,684	Rhyolite	Bt. Pl. Qz. Kfs. Hbl. Zrn	Moderate – WM	11.51 ± 0.37	Euhedral to sub-euhedral
25-6	Hualgayoc	HG	764,213	9,253,208	Rhyodacite	Bt. Pl. Kfs. Qz. Zrn	None	9.74 ± 0.31	Euhedral to sub-euhedral

Table A1-2. Bulk rock compositions of samples

a: Total Fe expressed as Fe₂O₃

b: XRF=X-ray fluorescence spectrometry

c: ICP-MS/ICP-EOS

nd: not determined

bdl: below detection limit

Analyte symbol	SiO ₂	Al ₂ O ₃	CaO	Na ₂ O	K ₂ O	Fe ₂ O ₃ (T) ^a	TiO ₂	MgO	MnO	P ₂ O ₅	LOI	Total	Ba	Cs	Nb	Ni	Rb	Sr	V	Zr	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Y	Th	U	
Method	XRF ^b	XRF	XRF	XRF	XRF	XRF	XRF	XRF	XRF	XRF			MS ^c	MS	MS	MS	MS	XRF	MS	XRF	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS
Detection limit	0.04	0.05	0.03	0.09	0.02	0.01	0.02	0.03	0.002	0.01			3	0.1	2.4	10	0.4	16	5	14	0.4	0.8	0.1	0.4	0.1	0.1	0.1	0.1	0.3	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1
unit	%	%	%	%	%	%	%	%	%	%	%	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
CC1	63.2	17.1	3.11	3.97	2.17	1.94	0.546	1.80	0.098	0.206	4.23	98.4	340	4	15.8	39	54.4	525	86	99	16.4	35.2	3.9	15.8	2.5	0.6	2.1	0.2	1.4	0.3	0.8	0.1	0.7	8.8	3.6		
CC4	60.3	16.6	3.65	3.66	1.41	5.14	0.564	1.81	0.043	0.236	6.28	99.6	572	0.8	20.4	21	35.8	687	85	104	23	48.4	5.4	20.4	3	0.8	2.5	0.2	1.6	0.3	0.9	0.1	0.9	8.2	4.1	1	
CC4b	64.4	14.2	2.14	2.09	2.86	6.89	0.505	2.12	0.038	0.220	3.91	99.3	707	1.2	20.5	22	30.1	318	93	112	18.9	42.6	4.9	20.5	3.3	1	2.6	0.3	1.9	0.4	1	0.2	1	11.8	3.7	1.1	
CC5	62.4	15.5	2.66	3.68	2.99	6.69	0.495	1.90	0.045	0.223	2.34	98.9	517	6.1	13.9	25	48.1	496	72	111	12.2	27.7	3.3	13.9	2.4	0.7	2.1	0.2	1.5	0.3	0.7	0.1	0.8	8.7	3.2	0.4	
CC5n	59.8	17.1	3.35	3.97	2.24	6.54	0.608	2.08	0.043	0.293	3.32	99.3	343	8.4	16.1	16	41.5	544	87	102	15.3	34.2	4	16.1	2.6	0.8	2.2	0.3	1.6	0.3	0.9	0.1	0.8	8.9	3.5	0.8	
CC6	60.1	16.9	4.51	3.75	2.03	5.49	0.593	1.76	0.12	0.252	3.61	99.1	1164	1.4	18	20	42.1	866	99	97	17.4	36.7	4.2	18	2.9	0.8	2.5	0.3	1.7	0.4	0.9	0.2	0.9	10.9	3.5	0.9	
SJD-05	62.9	16.9	4.00	4.35	1.94	4.12	0.466	1.63	0.064	0.186	2.97	99.6	377	10.9	19	19	57.8	576	86	95	18.7	36.4	4.7	19	3.2	1	2.7	0.3	1.8	0.3	1	0.2	1	9.2	3.7	1.7	
SJD-02	66.9	15.4	0.00	0.23	2.86	3.61	0.475	0.476	0.006	0.096	5.98	96.0	2207	nd	nd	29	nd	427	nd	99	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
25-4	51.5	12.9	0.00	0.51	6.88	0.66	0.269	0.300	0.002	0.008	2.87	75.8	818	2.6	4.3	29	221	130	61	90	2.3	5.4	0.7	4.3	0.9	bdl	1.1	0.2	0.8	bdl	0.5	bdl	0.5	4.6	2.4	1.4	
Tanta-352	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	bdl	13.3	bdl	2.7	1090	85	nd	18.6	35.5	4.2	13.3	1.1	0.3	0.5	bdl	bdl	bdl	0.2	bdl	0.3	1.5	4	1.2	
Tanta-355	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	1.2	14.2	bdl	56.3	639	73	nd	16.9	31.4	3.9	14.2	2.1	0.5	1.3	0.1	0.5	bdl	0.2	bdl	0.3	1.5	11.5	1.4	
Tanta-356	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	1.6	21	bdl	21.1	1040	80	nd	24.5	46	5.7	21	3	0.8	2	0.2	1.1	0.2	0.6	0.1	0.7	5.2	10.9	2.3	
Tanta-357	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	2	6.7	bdl	105	82	60	nd	9.8	15.7	1.8	6.7	0.8	0.2	0.5	bdl	bdl	bdl	bdl	bdl	0.2	0.5	2.5	1	
Tanta-358	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	3.8	17.3	bdl	50.4	255	128	nd	18	33.9	4.4	17.3	2.9	0.9	2.6	0.3	1.7	0.3	0.9	0.1	0.8	8	3	0.9	
CNG-1	55.0	13.4	0.30	1.15	1.39	1.48	0.571	0.019	0.005	0.08	19.8	93.2	735	bdl	17	91	4.8	324	111	104	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	3.2	3.6	0.9	
Anta-PK	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	325	16.9	16.6	10	383	21	163	nd	16.5	33.4	4.4	16.6	3.1	0.7	2.7	0.3	2.1	0.4	1.2	0.2	1.1	11.7	2.9	1.6	
Anta-PF	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	546	5.3	14.7	bdl	223	20	69	nd	18.6	33.8	4.1	14.7	2.5	0.6	2.1	0.2	1.3	0.3	0.7	0.1	0.7	7.6	4.8	1.7	
CJ	63.1	17.1	0.06	0.54	4.38	6.16	0.583	0.691	0.009	0.061	6.3	98.98	562	3.8	17.8	18	183	23	83	148	20	44.5	4.6	17.8	3.2	0.8	2.7	0.3	1.7	0.4	0.9	0.1	0.8	11.5	3.2	1	

[illegible]

Table A1-3. U-Pb zircon ages

San Jose. sample SJD-02				
Grains	$^{206}\text{Pb}/^{238}\text{U}$	1 σ error (abs.)	age (Ma)	1 σ error (abs.)
SJD-1	0.00218	0.00004	14.1	0.26
SJD-2	0.00218	0.00004	14.0	0.24
SJD-3	0.00230	0.00003	14.8	0.21
SJD-4	0.00231	0.00005	14.8	0.34
SJD-5	0.00225	0.00004	14.5	0.23
SJD-7	0.00222	0.00005	14.3	0.32
SJD-8	0.00225	0.00005	14.5	0.32
SJD-9	0.00220	0.00004	14.2	0.28
SJD-10	0.00235	0.00005	15.2	0.29
SJD-11	0.00231	0.00003	14.9	0.22
SJD-13	0.00222	0.00005	14.3	0.31
SJD-14	0.00228	0.00004	14.7	0.29
SJD-15	0.00229	0.00005	14.7	0.32
SJD-16	0.00233	0.00005	15.0	0.32
SJD-17	0.00228	0.00004	14.7	0.29
SJD-18	0.00239	0.00004	15.4	0.26
SJD-19	0.00224	0.00005	14.5	0.29
SJD-20	0.00244	0.00005	15.7	0.35
SJD-21	0.00222	0.00003	14.3	0.17
SJD-22	0.00231	0.00005	14.9	0.29
SJD-23	0.00250	0.00005	16.1	0.31
SJD-24	0.00232	0.00003	14.9	0.17
SJD-25	0.00243	0.00006	15.6	0.36

San Jose. sample 161025-4				
25-4-1	0.00229	0.00004	14.7	0.27
25-4-2	0.00228	0.00005	14.7	0.34
25-4-3	0.00230	0.00004	14.8	0.26
25-4-4	0.00231	0.00004	14.9	0.26
25-4-5	0.00226	0.00005	14.5	0.30
25-4-6	0.00227	0.00005	14.6	0.33
25-4-7	0.00233	0.00004	15.0	0.28
25-4-8	0.00229	0.00005	14.8	0.31
25-4-9	0.00231	0.00004	14.8	0.26
25-4-10	0.00218	0.00006	14.0	0.38
25-4-11-1	0.00229	0.00003	14.8	0.16
25-4-11-2	0.00237	0.00004	15.2	0.28
25-4-13	0.00241	0.00005	15.5	0.29

Tantahuatay igneous rock. sample T-352				
352-1	0.00218	0.00019	14.1	1.21
352-2	0.00201	0.00013	12.9	0.86
353-3	0.00212	0.00012	13.7	0.78
352-4	0.00223	0.00017	14.3	1.06
352-8	0.00220	0.00018	14.2	1.16
352-12	0.00174	0.00017	11.2	1.10
352-27-1	0.00220	0.00014	14.1	0.92
352-27-2	0.00195	0.00013	12.6	0.84
352-27-3	0.00180	0.00014	11.6	0.88
352-26	0.00192	0.00012	12.4	0.76

352-23	0.00174	0.00015	11.2	0.95
352-16	0.00206	0.00018	13.3	1.19
352-15	0.00206	0.00019	13.3	1.23
352-14	0.00202	0.00017	13.0	1.11
352-13	0.00196	0.00014	12.6	0.90
352-30	0.00204	0.00002	13.2	0.15
352-46	0.00191	0.00012	12.3	0.76
352-41-1	0.00189	0.00015	12.1	1.00
352-41-2	0.00242	0.00031	15.6	2.00
352-41-3	0.00205	0.00023	13.2	1.49

Tantahuatay igneous rock. sample T-355				
355-17	0.00128	0.00022	8.2	1.39
355-19	0.00219	0.00016	14.1	1.03
355-20	0.00206	0.00012	13.3	0.76
355-26	0.00184	0.00010	11.8	0.62
355-29	0.00223	0.00018	14.4	1.13
355-30	0.00212	0.00013	13.7	0.81
355-32	0.00239	0.00018	15.4	1.18
355-34	0.00182	0.00017	11.7	1.11
355-39	0.00205	0.00016	13.2	1.05
355-48	0.00220	0.00015	14.2	0.99
355-49	0.00209	0.00023	13.5	1.46
355-52	0.00192	0.00018	12.4	1.15
355-56	0.00203	0.00013	13.1	0.83
355-61	0.00180	0.00018	11.6	1.15
355-63	0.00218	0.00019	14.1	1.21

355-68	0.00163	0.00020	10.5	1.29
355-65	0.00195	0.00015	12.6	0.95
355-89	0.00183	0.00013	11.8	0.82
355-109	0.00180	0.00018	11.6	1.17
355-111	0.00216	0.00018	13.9	1.18

Tantahuatay igneous rock. sample T-356				
356-5	0.00191	0.00017	12.3	1.07
356-6	0.00231	0.00013	14.8	0.83
356-8	0.00206	0.00017	13.3	1.11
356-9	0.00227	0.00014	14.6	0.92
356-10	0.00209	0.00014	13.4	0.92
356-24	0.00172	0.00013	11.1	0.84
356-34	0.00162	0.00011	10.4	0.71
356-44	0.00191	0.00012	12.3	0.76
356-46	0.00209	0.00016	13.4	1.01
356-48	0.00174	0.00010	11.2	0.65
356-51	0.00197	0.00024	12.7	1.53
356-64	0.00210	0.00020	13.5	1.29
356-67	0.00176	0.00013	11.3	0.84
356-76	0.00215	0.00013	13.8	0.81
356-78	0.00200	0.00017	12.9	1.09
356-98	0.00183	0.00013	11.8	0.86
356-120	0.00204	0.00007	13.1	0.45
356-121	0.00210	0.00013	13.5	0.82
356-125	0.00199	0.00013	12.8	0.83
356-130	0.00196	0.00013	12.6	0.81

Tantahuatay igneous rock. sample T-357				
357-11	0.00184	0.00010	11.8	0.66
357-6	0.00193	0.00012	12.4	0.75
357-3	0.00192	0.00006	12.4	0.38
357-2	0.00181	0.00006	11.6	0.42
357-1	0.00199	0.00008	12.8	0.50
357-13	0.00205	0.00015	13.2	0.96
357-18	0.00206	0.00010	13.3	0.64
357-19	0.00180	0.00015	11.6	0.95
357-20	0.00168	0.00014	10.8	0.87
357-21	0.00224	0.00010	14.4	0.64
357-34	0.00226	0.00014	14.5	0.93
357-30	0.00189	0.00013	12.2	0.83
357-26	0.00179	0.00009	11.5	0.56
357-25	0.00196	0.00009	12.6	0.59
357-40	0.00157	0.00017	10.1	1.07
357-42	0.00235	0.00012	15.1	0.78
357-52	0.00200	0.00005	12.9	0.31
357-65	0.00186	0.00008	12.0	0.53
357-61	0.00146	0.00014	9.4	0.92
357-78	0.00194	0.00010	12.5	0.63

Tantahuatay igneous rock. sample T-358				
358-2	0.00227	0.00011	14.6	0.73
358-3	0.00220	0.00012	14.2	0.75
358-4	0.00234	0.00013	15.0	0.86

358-5	0.00207	0.00012	13.4	0.76
358-6	0.00227	0.00007	14.6	0.47
358-8	0.00207	0.00008	13.3	0.54
358-9	0.00207	0.00006	13.3	0.39
358-11	0.00261	0.00012	16.8	0.79
358-16	0.00245	0.00012	15.8	0.80
358-23	0.00223	0.00011	14.4	0.69
358-24	0.00201	0.00009	13.0	0.60
358-26	0.00256	0.00017	16.5	1.09
358-31	0.00213	0.00009	13.7	0.55
358-32	0.00211	0.00009	13.6	0.60
358-33	0.00253	0.00013	16.3	0.82
358-35	0.00202	0.00011	13.0	0.74
358-36	0.00205	0.00009	13.2	0.58
358-37	0.00215	0.00010	13.9	0.64
358-38	0.00222	0.00009	14.3	0.59

Tantahuatay Igneous rock. sample CNG-1				
CNG-1	0.00223	0.00007	14.4	0.45
CNG-2	0.00295	0.00010	19.0	0.65
CNG-3	0.00225	0.00008	14.5	0.51
CNG-4	0.00213	0.00005	13.7	0.35
CNG-5	0.00214	0.00007	13.8	0.43
CNG-6	0.00214	0.00007	13.8	0.47
CNG-7	0.00253	0.00008	16.3	0.49
CNG-8	0.00244	0.00009	15.7	0.58
CNG-9	0.00222	0.00008	14.3	0.49

CNG-10	0.00211	0.00007	13.6	0.48
CNG-11	0.00204	0.00006	13.1	0.41
CNG-12	0.00235	0.00007	15.1	0.47
CNG-13	0.00248	0.00008	16.0	0.51
CNG-14	0.00200	0.00009	12.9	0.55
CNG-15	0.00220	0.00008	14.2	0.50
CNG-16	0.00242	0.00007	15.6	0.47
CNG-17	0.00222	0.00009	14.3	0.59
CNG-18	0.00211	0.00007	13.6	0.48
CNG-19	0.00253	0.00010	16.3	0.63
CNG-20	0.00239	0.00007	15.4	0.46
CNG-21	0.00269	0.00012	17.3	0.78
CNG-22	0.00237	0.00010	15.2	0.65

AntaKori porphyry PK. sample Anta-PK				
A2-1	0.00242	0.00013	15.6	0.81
A2-2	0.00212	0.00011	13.6	0.69
A2-11	0.00222	0.00011	14.3	0.72
A2-4	0.00236	0.00009	15.2	0.60
A2-15	0.00224	0.00009	14.5	0.55
A2-7	0.00222	0.00011	14.3	0.69
A2-18	0.00228	0.00011	14.7	0.69
A2-23	0.00217	0.00011	14.0	0.73
A2-25	0.00218	0.00010	14.0	0.66
A2-34	0.00227	0.00011	14.6	0.69
A2-26	0.00212	0.00010	13.7	0.65
A2-36	0.00216	0.00011	13.9	0.69

A2-39	0.00239	0.00010	15.4	0.62
A2-41	0.00267	0.00012	17.2	0.79
A2-48	0.00224	0.00009	14.4	0.59
A2-58	0.00227	0.00012	14.6	0.79
A2-42	0.00233	0.00007	15.0	0.42
A2-60	0.00217	0.00006	14.0	0.39
A2-45	0.00221	0.00009	14.2	0.55
A2-64	0.00244	0.00010	15.7	0.61
A2-56	0.00228	0.00008	14.7	0.54
A2-47	0.00220	0.00007	14.2	0.47
A2-12	0.00209	0.00009	13.5	0.55

AntaKori porphyry PF. sample Anta-PF				
A4-1	0.00197	0.00003	12.7	0.21
A4-3	0.00159	0.00009	10.3	0.59
A4-6	0.00157	0.00014	10.1	0.90
A4-12	0.00186	0.00007	12.0	0.43
A4-11	0.00195	0.00010	12.6	0.66
A4-24	0.00225	0.00016	14.5	1.04
A4-26-1	0.00180	0.00012	11.6	0.79
A4-26-2	0.00187	0.00012	12.1	0.76
A4-27	0.00178	0.00014	11.5	0.92
A4-29	0.00195	0.00007	12.6	0.48
A4-31	0.00174	0.00009	11.2	0.60
A4-33	0.00208	0.00013	13.4	0.81
A4-41	0.00192	0.00007	12.3	0.44
A4-39	0.00182	0.00006	11.7	0.38

A4-37	0.00224	0.00005	14.4	0.34
A4-52	0.00188	0.00006	12.1	0.41
A4-55	0.00184	0.00007	11.8	0.45
A4-57	0.00211	0.00017	13.6	1.12
A4-60	0.00182	0.00004	11.7	0.23
A4-71	0.00189	0.00006	12.2	0.41
A4-81	0.00181	0.00011	11.7	0.74
A4-78	0.00178	0.00009	11.4	0.61
A4-76	0.00188	0.00007	12.1	0.43
A4-92	0.00176	0.00007	11.3	0.42
A4-107	0.00184	0.00008	11.8	0.54
A4-118	0.00179	0.00006	11.5	0.40
A4-133	0.00200	0.00012	12.9	0.78

Cerro Jesus. sample 25-7				
25-7-1	0.00233	0.00003	15.0	0.17
25-7-2	0.00235	0.00003	15.1	0.22
25-7-3	0.00227	0.00003	14.6	0.21
25-7-4-1	0.00226	0.00002	14.6	0.15
25-7-4-2	0.00249	0.00007	16.0	0.44
25-7-5	0.00552	0.00005	35.5	0.29
25-7-6	0.00235	0.00004	15.1	0.27

Cerro Choro Blanco. sample CB				
CHCB-1	0.00207	0.00005	13.3	0.33
CHCB-2	0.00224	0.00005	14.5	0.31
CHCB-3	0.00235	0.00008	15.1	0.48

CHCB-4	0.00216	0.00007	13.9	0.45
CHCB-5	0.00219	0.00004	14.1	0.27
CHCB-6	0.00221	0.00005	14.2	0.35
CHCB-7	0.00220	0.00006	14.1	0.41
CHCB-8	0.00219	0.00005	14.1	0.34
CHCB-9	0.00211	0.00006	13.6	0.38
CHCB-10	0.00211	0.00006	13.6	0.36
CHCB-11	0.00222	0.00005	14.3	0.34
CHCB-12	0.00227	0.00005	14.6	0.31
CHCB-13	0.00225	0.00004	14.5	0.28
CHCB-14	0.00235	0.00005	15.1	0.33
CHCB-15	0.00228	0.00006	14.7	0.40
CHCB-16	0.00238	0.00006	15.3	0.37
CHCB-17	0.00207	0.00007	13.3	0.45
CHCB-18	0.00217	0.00006	14.0	0.41
CHCB-19	0.00221	0.00005	14.2	0.32
CHCB-20	0.00228	0.00005	14.7	0.31

Cerro Caballerisa. sample CAB				
CAB-1	0.00229	0.00006	14.8	0.40
CAB-2	0.00230	0.00005	14.8	0.34
CAB-3-1	0.00221	0.00005	14.2	0.35
CAB-3-2	0.00219	0.00007	14.1	0.42
CAB-4	0.00219	0.00006	14.1	0.36
CAB-5	0.00214	0.00006	13.8	0.40
CAB-6	0.00212	0.00007	13.7	0.45
CAB-7-1	0.00206	0.00006	13.3	0.40

CAB-7-2	0.00225	0.00008	14.5	0.52
CAB-8	0.00212	0.00005	13.6	0.34
CAB-9	0.00216	0.00005	13.9	0.35
CAB-10	0.00226	0.00007	14.5	0.48
CAB-11	0.00215	0.00005	13.8	0.33
CAB-12	0.00217	0.00009	14.0	0.56
CAB-13	0.00224	0.00005	14.4	0.30
CAB-14	0.00218	0.00006	14.0	0.36
CAB-15	0.00222	0.00008	14.3	0.48
CAB-16	0.00233	0.00015	15.0	0.97
CAB-17	0.00223	0.00007	14.4	0.43
CAB-18	0.00205	0.00005	13.2	0.35
CAB-19	0.00231	0.00007	14.9	0.46
CAB-20	0.00225	0.00006	14.5	0.39

Cerro Las Gordas. sample LG				
SG-17	0.00219	0.00006	14.1	0.37
SG-1	0.00224	0.00007	14.4	0.43
SG-2	0.00213	0.00006	13.7	0.39
SG-3	0.00234	0.00007	15.1	0.45
SG-4	0.00218	0.00008	14.0	0.52
SG-5	0.00211	0.00006	13.6	0.37
SG-6	0.00237	0.00005	15.2	0.32
SG-7	0.00233	0.00006	15.0	0.37
SG-8	0.00219	0.00006	14.1	0.36
SG-9	0.00224	0.00005	14.4	0.31
SG-10	0.00209	0.00005	13.5	0.31

SG-11	0.00223	0.00005	14.3	0.32
SG-12	0.00221	0.00005	14.2	0.33
SG-13	0.00214	0.00005	13.8	0.29
SG-14	0.00218	0.00009	14.0	0.57
SG-15	0.00242	0.00006	15.6	0.40
SG-16	0.00221	0.00006	14.2	0.37
SG-18	0.00226	0.00005	14.5	0.31
SG-19	0.00242	0.00006	15.6	0.40
SG-20	0.00222	0.00004	14.3	0.28

Sill Coymolache. sample 161025-5				
I2-39	0.00206	0.00008	13.3	0.51
I2-19	0.00228	0.00008	14.7	0.51
I2-20-1	0.00218	0.00006	14.0	0.36
I2-20-2	0.00229	0.00007	14.8	0.42
I2-21	0.00234	0.00009	15.0	0.55
I2-3	0.00215	0.00008	13.8	0.51
I2-4	0.00227	0.00009	14.6	0.59
I2-12	0.00189	0.00007	12.2	0.45
I2-47	0.00226	0.00007	14.6	0.48
I2-51	0.00212	0.00009	13.7	0.59
I2-10	0.00214	0.00013	13.8	0.82
I2-12	0.00228	0.00006	14.7	0.37
I2-52	0.00218	0.00008	14.1	0.54
I2-82	0.00214	0.00007	13.8	0.45
I2-33	0.00216	0.00011	13.9	0.69
I2-13-1	0.00203	0.00010	13.1	0.62

I2-13-2	0.00237	0.00010	15.3	0.64
I2-13-3	0.00224	0.00008	14.4	0.54
I2-16	0.00224	0.00008	14.5	0.48
I2-36	0.00208	0.00007	13.4	0.44
I2-59	0.00213	0.00007	13.7	0.44
I2-94	0.00233	0.00004	15.0	0.24

San Miguel. sample SCO-1				
I12-1	0.00234	0.00005	15.1	0.33
I12-2	0.00239	0.00009	15.4	0.61
I12-3	0.00223	0.00003	14.4	0.22
I12-4	0.00229	0.00006	14.8	0.36
I12-5	0.00221	0.00007	14.2	0.42
I12-6	0.00222	0.00004	14.3	0.28
I12-7	0.00229	0.00004	14.7	0.27
I12-8	0.00221	0.00005	14.2	0.34
I12-9	0.00222	0.00008	14.3	0.50
I12-10-1	0.00225	0.00006	14.5	0.40
I12-10-2	0.00214	0.00008	13.8	0.54

San Miguel. sample SCO-2				
I5-10	0.00229	0.00005	14.8	0.34
I5-14	0.00229	0.00004	14.7	0.28
I5-61	0.00234	0.00008	15.1	0.50
I5-62	0.00218	0.00003	14.0	0.19
I5-21-1	0.00226	0.00005	14.5	0.34
I5-21-2	0.00227	0.00005	14.6	0.31

I5-22	0.00218	0.00007	14.0	0.48
I5-24	0.00229	0.00006	14.8	0.42
I5-26	0.00222	0.00005	14.3	0.31
I5-68	0.00222	0.00004	14.3	0.24
I5-69	0.00232	0.00006	15.0	0.37
I5-71	0.00241	0.00005	15.5	0.35
I5-152	0.00227	0.00006	14.6	0.42
I5-156	0.00229	0.00007	14.7	0.47
I5-116	0.00232	0.00005	14.9	0.34
I5-117	0.00215	0.00004	13.8	0.28
I5-118	0.00233	0.00005	15.0	0.34
I5-75	0.00210	0.00007	13.5	0.48
I5-33	0.00243	0.00007	15.6	0.46
I5-79	0.00227	0.00003	14.6	0.21
I5-42	0.00235	0.00009	15.1	0.57
I5-126	0.00224	0.00006	14.4	0.40

San Miguel. sample SCO-3				
I3-78	0.00217	0.00009	14.0	0.61
I3-77	0.00216	0.00008	13.9	0.51
I3-74	0.00249	0.00009	16.0	0.59
I3-73	0.00236	0.00007	15.2	0.48
I3-36	0.00216	0.00010	13.9	0.63
I3-34	0.00218	0.00010	14.0	0.65
I3-70	0.00225	0.00009	14.5	0.58
I3-61	0.00214	0.00007	13.8	0.43
I3-101	0.00233	0.00006	15.0	0.37

I3-100	0.00200	0.00010	12.9	0.64
I3-59	0.00231	0.00007	14.9	0.47
I3-99	0.00234	0.00009	15.1	0.58
I3-98	0.00231	0.00008	14.9	0.49
I3-23	0.00251	0.00013	16.2	0.86
I3-22	0.00215	0.00012	13.8	0.80
I3-51	0.00240	0.00011	15.5	0.70
I3-16	0.00208	0.00008	13.4	0.55
I3-47	0.00223	0.00006	14.4	0.38
I3-46	0.00237	0.00009	15.3	0.55
I3-41	0.00224	0.00005	14.4	0.35
I3-81	0.00208	0.00010	13.4	0.64

San Nicolas. sample SN				
SN-1	0.00204	0.00006	13.2	0.37
SN-2	0.00225	0.00015	14.5	0.95
SN-3	0.00262	0.00011	16.9	0.70
SN-4	0.00214	0.00009	13.8	0.61
SN-5	0.00208	0.00003	13.4	0.21
SN-6	0.00223	0.00009	14.4	0.60
SN-7	0.00196	0.00008	12.6	0.53
SN-8-1	0.00200	0.00010	12.9	0.66
SN-8-2	0.00204	0.00009	13.1	0.55
SN-8-3	0.00211	0.00006	13.6	0.38
SN-9	0.00234	0.00008	15.1	0.53
SN-10	0.00208	0.00007	13.4	0.43
SN-11	0.00218	0.00012	14.0	0.74

SN-12-1	0.00228	0.00008	14.7	0.49
SN-12-2	0.00211	0.00008	13.6	0.53
SN-13	0.00226	0.00006	14.5	0.35
SN-14	0.00201	0.00010	12.9	0.66
SN-15-1	0.00223	0.00018	14.4	1.13
SN-15-2	0.00226	0.00012	14.6	0.79
SN-16-1	0.00221	0.00012	14.2	0.76
SN-16-2	0.00185	0.00019	11.9	1.22
SN-17	0.00211	0.00010	13.6	0.62
SN-18	0.00223	0.00010	14.4	0.66
SN-19	0.00189	0.00015	12.2	0.99
SN-20-1	0.00220	0.00009	14.2	0.57
SN-20-2	0.00197	0.00009	12.7	0.59

Calipuy andesite. sample Anta-6				
A6-1	0.00215	0.00015	13.8	0.94
A6-11	0.00190	0.00009	12.2	0.57
A6-21	0.00207	0.00018	13.3	1.18
A6-32	0.00218	0.00014	14.0	0.87
A6-22	0.00165	0.00012	10.6	0.77
A6-17	0.00224	0.00014	14.4	0.88
A6-9	0.00216	0.00015	13.9	0.97
A6-41	0.00229	0.00016	14.7	1.05
A6-27	0.00201	0.00013	12.9	0.82
A6-37	0.00208	0.00017	13.4	1.10
A6-39	0.00206	0.00011	13.2	0.71
A6-48	0.00215	0.00014	13.8	0.87

A6-42	0.00187	0.00015	12.0	0.97
A6-49	0.00219	0.00012	14.1	0.78
A6-43	0.00211	0.00012	13.6	0.78
A6-52	0.00204	0.00014	13.2	0.89
A6-63	0.00190	0.00008	12.3	0.50
A6-18	0.00212	0.00013	13.7	0.84
A6-58	0.00237	0.00013	15.2	0.86
A6-75	0.00181	0.00012	11.6	0.77
A6-81	0.00201	0.00010	13.0	0.63
A6-90	0.00208	0.00009	13.4	0.58
A6-93	0.00253	0.00013	16.3	0.84
A6-96	0.00200	0.00010	12.9	0.62
A6-25	0.00197	0.00012	12.7	0.78

Calipuy rhyolite. sample Anta-8				
A8-9	0.00181	0.00003	11.7	0.22
A8-10	0.00498	0.00008	32.0	0.49
A8-14	0.00191	0.00005	12.3	0.32
A8-5	0.00186	0.00006	12.0	0.40
A8-6	0.00150	0.00006	9.7	0.38
A8-15	0.00168	0.00007	10.8	0.45
A8-17	0.00201	0.00006	12.9	0.40
A8-18	0.00227	0.00013	14.6	0.84
A8-25	0.00189	0.00007	12.2	0.43
A8-20	0.00185	0.00009	11.9	0.57
A8-21	0.00197	0.00012	12.7	0.76
A8-26	0.00175	0.00002	11.3	0.14

A8-27	0.00173	0.00003	11.1	0.16
A8-22	0.00168	0.00005	10.8	0.32
A8-35	0.00164	0.00002	10.5	0.15
A8-32	0.00204	0.00005	13.2	0.34
A8-39	0.00226	0.00025	14.5	1.58
A8-41	0.00164	0.00007	10.6	0.47
A8-50	0.00171	0.00010	11.0	0.66
A8-57	0.00179	0.00005	11.5	0.31
A8-63	0.00195	0.00002	12.5	0.16
A8-22	0.00201	0.00004	12.9	0.28
A8-60	0.00176	0.00004	11.3	0.25
A8-19	0.00184	0.00015	11.8	0.94
A8-66	0.00160	0.00008	10.3	0.54

Hualgayoc rhyodacite. sample 25-6				
I1-1	0.02641	0.00011	168.1	0.66
I1-2	0.00828	0.00006	53.1	0.40
I1-3	0.00145	0.00002	9.4	0.14
I1-5	0.00149	0.00007	9.6	0.45
I1-6	0.00165	0.00003	10.6	0.22
I1-7	0.00143	0.00002	9.2	0.10
I1-8	0.00209	0.00007	13.5	0.44
I1-10	0.00139	0.00002	9.0	0.15
I1-11	0.00192	0.00003	12.3	0.18
I1-12	0.00178	0.00003	11.5	0.20
I1-13	0.00180	0.00003	11.6	0.20
I1-14	0.00142	0.00002	9.1	0.15

I1-15	0.00160	0.00003	10.3	0.18
I1-16	0.00155	0.00002	10.0	0.13
I1-17	0.00143	0.00002	9.2	0.15
I1-18	0.00155	0.00002	10.0	0.10
I1-19	0.00141	0.00002	9.1	0.15
I1-20-1	0.00158	0.00002	10.2	0.14
I1-20-2	0.00154	0.00002	9.9	0.15
I1-21-1	0.00138	0.00003	8.9	0.19
I1-21-2	0.00148	0.00003	9.5	0.21
I1-21-3	0.00146	0.00004	9.4	0.28
I1-22	0.00159	0.00003	10.3	0.21
I1-23	0.00146	0.00005	9.4	0.29
I1-24	0.00146	0.00008	9.4	0.51
I1-25	0.00169	0.00004	10.9	0.26

Table A1-4. Result of zircon SHRIMP U-Pb dating

spot Name	Ppm U	Common Pb 207/206	Common Pb 208/206	Total 238/206	% err	Total 207 /206	% err	7-corr %com ²⁰⁶ Pb	7corr 206*/238	% err	207corr ²⁰⁶ Pb/ ²³⁸ U Age	1s err
Sample CC1												
CC1-004.1	286	0.895	2.09	443.8	2.2	0.0674	8.4	2.48	0.0022	0.74	14.1	0.3
CC1-017.1	321	0.895	2.09	435.5	1.1	0.0498	8.8	0.41	0.0023	0.38	14.7	0.2
CC1-016.2	265	0.895	2.09	437.5	1.4	0.0518	9.4	0.64	0.0023	0.47	14.6	0.2
CC1-016.1	342	0.895	2.09	40.3	1.1	0.0502	2.5	0.12	0.0248	0.34	158	2
CC1-021.1	251	0.895	2.09	441.3	1.1	0.0521	10.5	0.68	0.0023	0.41	14.5	0.2
CC1-023.1	803	0.895	2.09	432.2	1.3	0.0499	9.6	0.42	0.0023	0.44	14.8	0.2
CC1-024.1	307	0.895	2.09	449.4	2.1	0.0541	8.8	0.92	0.0022	0.70	14.2	0.3
CC1-025.1	134	0.895	2.09	436.4	1.0	0.0642	13.0	2.10	0.0022	0.46	14.4	0.2
CC1-027.1	329	0.895	2.09	441.0	1.4	0.0445	9.4	-0.22	0.0023	0.48	14.6	0.2
CC1-029.1	418	0.895	2.09	446.1	1.2	0.0460	13.9	-0.03	0.0022	0.46	14.4	0.2
CC1-022.1	540	0.895	2.09	430.5	1.4	0.0503	6.8	0.47	0.0023	0.45	14.9	0.2
Sample CC4												
CC4-020.1	141	0.895	2.09	133.2	6.6	0.6257	2.6	68.26	0.0024	2.83	15.3	1
CC4-015.2	315	0.895	2.09	248.5	8.6	0.2949	18.8	29.28	0.0028	4.03	18.3	2
CC4-002.1	172	0.895	2.09	451.7	2.8	0.0492	13.6	0.33	0.0022	0.92	14.2	0.4
CC4-009.1	82	0.895	2.09	37.8	22.0	0.7816	4.3	86.64	0.0035	12	22.7	8
CC4-012.1	110	0.895	2.09	413.3	1.7	0.1028	20.7	6.65	0.0023	1.01	14.5	0.5
CC4-001.1	166	0.895	2.09	441.1	4.0	0.0586	12.5	1.44	0.0022	1.32	14.4	0.6
CC4-003.1	143	0.895	2.09	429.5	3.0	0.0571	13.7	1.26	0.0023	1.02	14.8	0.5
CC4-006.1	137	0.895	2.09	430.0	4.1	0.0625	13.0	1.91	0.0023	1.33	14.7	0.6
CC4-007.1	152	0.895	2.09	429.1	1.0	0.0645	11.6	2.14	0.0023	0.43	14.7	0.2
CC4-013.1	215	0.895	2.09	431.9	1.7	0.0659	15.7	2.31	0.0023	0.66	14.6	0.3
CC4-011.1	237	0.895	2.09	450.3	1.8	0.0728	9.0	3.12	0.0022	0.64	13.9	0.3
CC4-015.1	807	0.895	2.09	159.5	1.9	0.1491	10.3	12.07	0.0055	0.89	35.4	1.0
CC4-016.1	95	0.895	2.09	430.4	2.3	0.0852	14.8	4.58	0.0022	0.89	14.3	0.4
CC4-019.1	150	0.895	2.09	457.5	2.1	0.0650	12.8	2.20	0.0021	0.73	13.8	0.3

Sample CC4b

CC4b-013.1	1353	0.895	2.09	439.6	1.3	0.0504	4.1	0.49	0.0023	0.43	14.6	0.2
CC4b-023.1	244	0.895	2.09	424.8	1.3	0.0543	10.1	0.94	0.0023	0.46	15.0	0.2
CC4b-002.1	317	0.895	2.09	410.9	1.7	0.0737	8.0	3.22	0.0024	0.59	15.2	0.3
CC4b-006.1	406	0.895	2.09	438.2	1.8	0.0580	14.3	1.38	0.0023	0.65	14.5	0.3
CC4b-025.1	152	0.895	2.09	255.9	7.0	0.2930	5.1	29.07	0.0028	2.36	17.8	1
CC4b-025.2	750	0.895	2.09	444.1	1.5	0.0589	5.8	1.48	0.0022	0.49	14.3	0.2
CC4b-026.1	250	0.895	2.09	430.5	1.0	0.0698	9.2	2.77	0.0023	0.39	14.5	0.2
CC4b-021.1	296	0.895	2.09	446.0	2.0	0.0729	8.2	3.14	0.0022	0.69	14.0	0.3
CC4b-029.1	319	0.895	2.09	447.5	1.3	0.0575	8.7	1.31	0.0022	0.44	14.2	0.2
CC4b-009.1	144	0.895	2.09	410.1	2.2	0.0664	12.2	2.36	0.0024	0.76	15.3	0.4
CC4b-026.2	284	0.895	2.09	431.3	0.9	0.0629	9.2	1.96	0.0023	0.37	14.6	0.2
CC4b-027.1	188	0.895	2.09	449.7	1.7	0.0759	11.0	3.48	0.0021	0.62	13.8	0.3
CC4b-030.1	157	0.895	2.09	416.1	2.8	0.0479	16.1	0.18	0.0024	0.93	15.4	0.5
CC4b-030.2	178	0.895	2.09	428.6	2.2	0.0574	12.5	1.31	0.0023	0.75	14.8	0.3
CC4b-032.1	496	0.895	2.09	450.0	1.4	0.0555	7.6	1.08	0.0022	0.47	14.2	0.2
CC4b-031.1	257	0.895	2.09	440.0	2.4	0.0622	10.0	1.87	0.0022	0.82	14.4	0.4

Sample CC5

CC5-001.1	422	0.895	2.09	440.8	1.8	0.0572	7.3	1.28	0.0022	0.60	14.4	0.3
CC5-004.1	212	0.895	2.09	427.3	1.9	0.0469	11.6	0.06	0.0023	0.65	15.1	0.3
CC5-005.1	280	0.895	2.09	464.7	5.6	0.0613	9.1	1.77	0.0021	1.81	13.6	0.8
CC5-007.1	190	0.895	2.09	450.3	2.7	0.0540	13.2	0.91	0.0022	0.89	14.2	0.4
CC5-009.1	251	0.895	2.09	441.7	1.6	0.0664	9.3	2.36	0.0022	0.56	14.2	0.2
CC5-010.1	512	0.895	2.09	443.5	1.1	0.0594	12.5	1.55	0.0022	0.44	14.3	0.2
CC5-014.1	410	0.895	2.09	438.4	1.0	0.0563	7.4	1.17	0.0023	0.37	14.5	0.2
CC5-011.1	224	0.895	2.09	435.2	1.7	0.0630	10.1	1.96	0.0023	0.59	14.5	0.3
CC5-012.1	219	0.895	2.09	444.1	1.8	0.0587	20.9	1.45	0.0022	0.74	14.3	0.3
CC5-020.1	203	0.895	2.09	433.8	2.7	0.0548	21.7	0.99	0.0023	0.98	14.7	0.4

Sample CC5n

CC5n-005.1	129	0.895	2.09	463.6	3.5	0.0560	14.9	1.14	0.0021	1.15	13.7	0.5
CC5n-001.1	121	0.895	2.09	408.2	2.7	0.0616	24.4	1.80	0.0024	1.03	15.5	0.5
CC5n-002.1	179	0.895	2.09	395.2	2.7	0.1492	20.7	12.13	0.0022	1.58	14.3	0.7

CC5n-003.1	202	0.895	2.09	442.0	2.1	0.0689	10.2	2.66	0.0022	0.72	14.2	0.3
CC5n-009.1	361	0.895	2.09	437.9	1.0	0.0557	8.5	1.11	0.0023	0.38	14.5	0.2
CC5n-010.1	265	0.895	2.09	426.0	1.5	0.0716	8.2	2.97	0.0023	0.54	14.7	0.2
CC5n-013.1	279	0.895	2.09	437.0	0.9	0.0708	8.8	2.88	0.0022	0.38	14.3	0.2
CC5n-015.1	156	0.895	2.09	411.1	1.3	0.1045	9.1	6.86	0.0023	0.57	14.6	0.3
CC5n-019.1	285	0.895	2.09	442.4	1.4	0.0548	10.1	1.00	0.0022	0.49	14.4	0.2
CC5n-019.2	354	0.895	2.09	429.8	1.2	0.0740	7.8	3.26	0.0023	0.46	14.5	0.2
CC5n-018.1	247	0.895	2.09	435.1	1.2	0.0612	10.1	1.75	0.0023	0.46	14.5	0.2
CC5n-024.1	241	0.895	2.09	444.4	1.5	0.0617	9.6	1.81	0.0022	0.53	14.2	0.2
CC5n-023.1	176	0.895	2.09	426.0	1.8	0.0968	9.7	5.94	0.0022	0.68	14.2	0.3
CC5n-023.2	282	0.895	2.09	439.2	2.5	0.0701	9.2	2.81	0.0022	0.85	14.2	0.4
Sample CC6												
CC6-027.1	230	0.895	2.09	383.8	3.2	0.2098	17.6	19.26	0.0021	2.01	13.5	0.9
CC6-001.1	389	0.895	2.09	435.4	1.4	0.0735	13.6	3.20	0.0022	0.58	14.3	0.3
CC6-003.1	370	0.895	2.09	424.1	1.1	0.0643	15.9	2.12	0.0023	0.53	14.9	0.2
CC6-005.1	273	0.895	2.09	422.7	1.1	0.0744	8.8	3.30	0.0023	0.42	14.7	0.2
CC6-005.2	131	0.895	2.09	411.3	2.9	0.0943	13.7	5.66	0.0023	1.06	14.8	0.5
CC6-009.1	390	0.895	2.09	434.9	1.1	0.0617	8.0	1.81	0.0023	0.41	14.5	0.2
CC6-012.1	247	0.895	2.09	424.5	1.9	0.0806	8.4	4.03	0.0023	0.66	14.6	0.3
CC6-010.1	153	0.895	2.09	441.8	3.7	0.1142	10.0	7.99	0.0021	1.26	13.4	0.5
CC6-016.1	137	0.895	2.09	416.2	2.6	0.0889	25.7	5.02	0.0023	1.22	14.7	0.6
CC6-020.1	108	0.895	2.09	405.2	3.5	0.0985	20.0	6.14	0.0023	1.36	14.9	0.6
CC6-023.1	394	0.895	2.09	440.5	0.9	0.0613	8.0	1.77	0.0022	0.35	14.4	0.2
CC6-023.2	229	0.895	2.09	435.8	1.5	0.0707	10.4	2.87	0.0022	0.56	14.4	0.3
CC6-024.1	287	0.895	2.09	429.1	2.2	0.0728	8.5	3.12	0.0023	0.73	14.5	0.3
CC6-028.1	265	0.895	2.09	423.7	1.3	0.0736	14.5	3.21	0.0023	0.58	14.7	0.3

A1.1. Weighted mean diagrams of zircon $^{206}\text{Pb}/^{238}\text{U}$ ages

The diagrams were generated by the IsoplotR software (Vermeesch, 2018). Individual zircon grains are plotted along the x axis. The y axis represent the age in Ma. Green bars represent $^{206}\text{Pb}/^{238}\text{U}$ ages of individual zircon grains. The centre of each green bar corresponds to the calculated age, and the length of bars from the centre represents the range of 2σ uncertainties. Blue bars represent grains rejected by the IsoplotR software.

The black horizontal line corresponds to the weighted mean age of a sample and the gray band below and above represent confidence interval of the weighted mean age. The equation in the top of diagram, $\text{mean} = \mu \pm x \mid y \mid z$, shows the weighted mean age (μ), uncertainty (x), the width of the $100(1-\alpha)\%$ confidence interval (y) and the approximate $100(1-\alpha)\%$ confidence interval for time with overdispersion (z). This z is calculated from mean square of the weighted deviate (MSWD), $z = y\sqrt{\text{MSWD}}$. MSWD corresponds to age homogeneity. MSWD values $\gg 1$ indicate that the ages are overdispersed with respect to the stated analytical uncertainties. $p(\chi^2)$ corresponds to the Chi-squared p-value for the age homogeneity test. p-values $\ll 0.05$ indicate that the ages are overdispersed with respect to the stated analytical uncertainties.

Figure A1-1. San Jose intrusion. Samples 25-4 and SJD-02

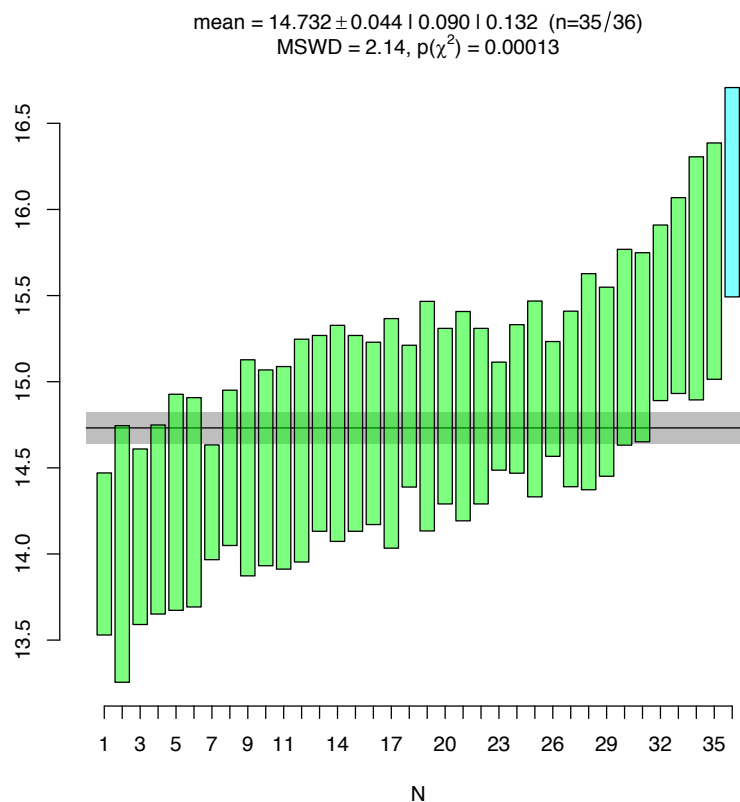


Figure A1-2. Tantahuatay igneous rock. Sample Tanta-352

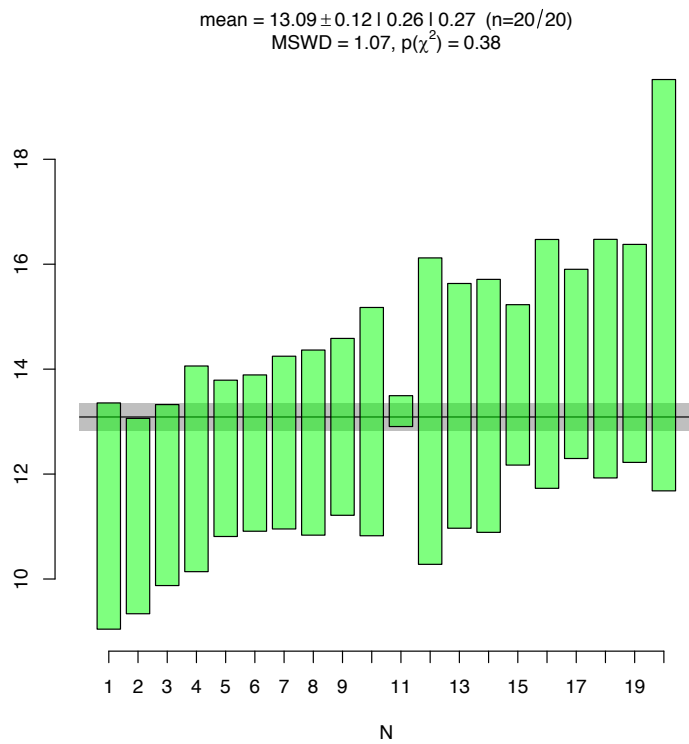


Figure A1-3. Tantahuatay igneous rock. Sample Tanta-355

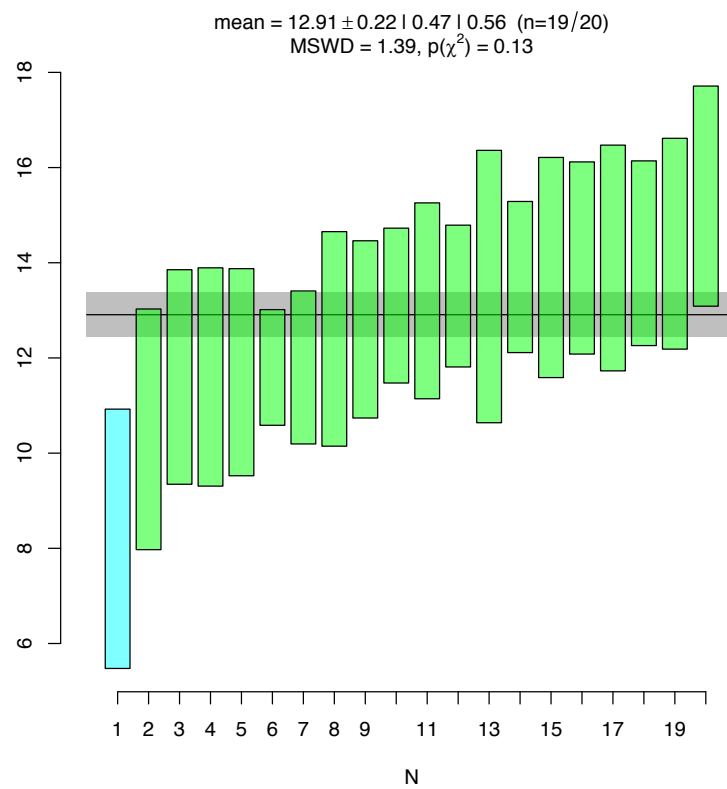


Figure A1-4. Tantauhuatay igneous rock. Sample Tanta-356

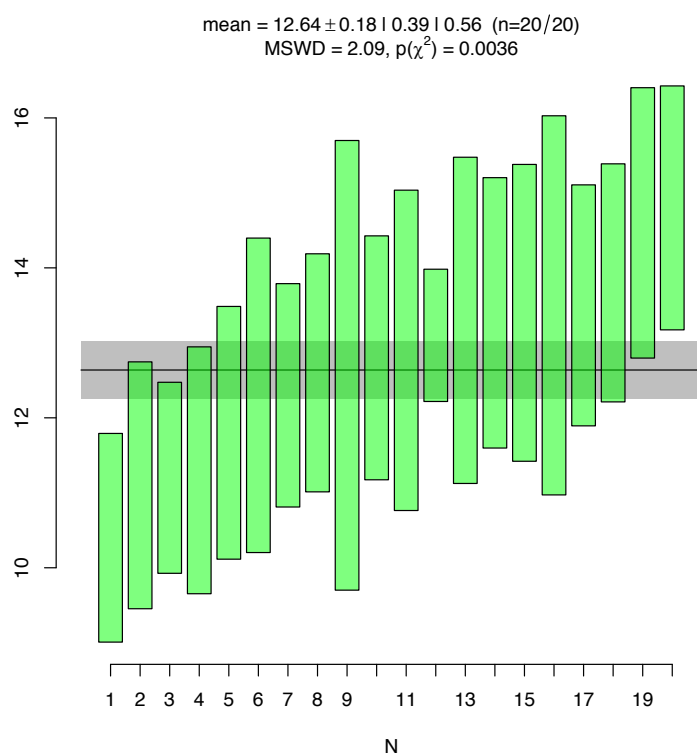


Figure A1-5. Tantauhuatay igneous rock. Sample Tanta-357

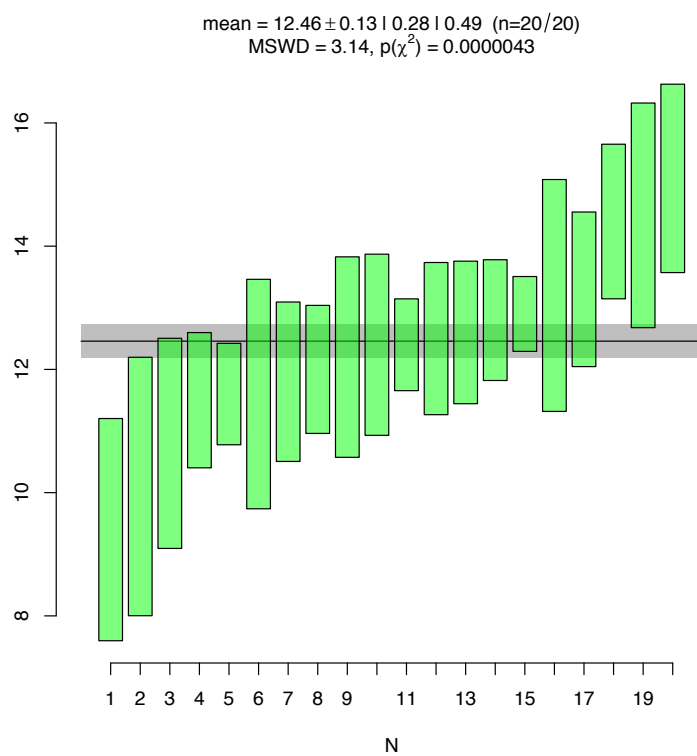


Figure A1-6. Tantahuatay igneous rock. Sample Tanta-358

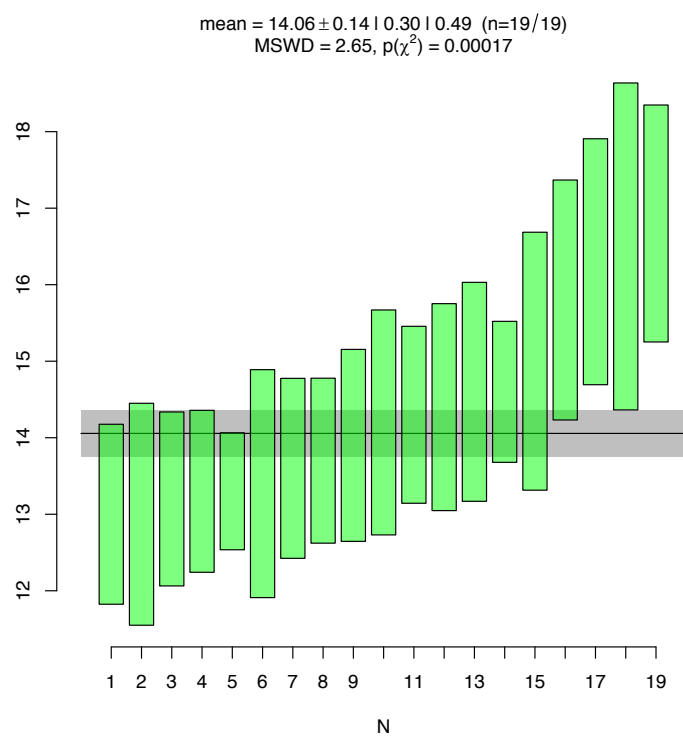


Figure A1-7. Tantahuatay igneous rock. Sample CNG-1

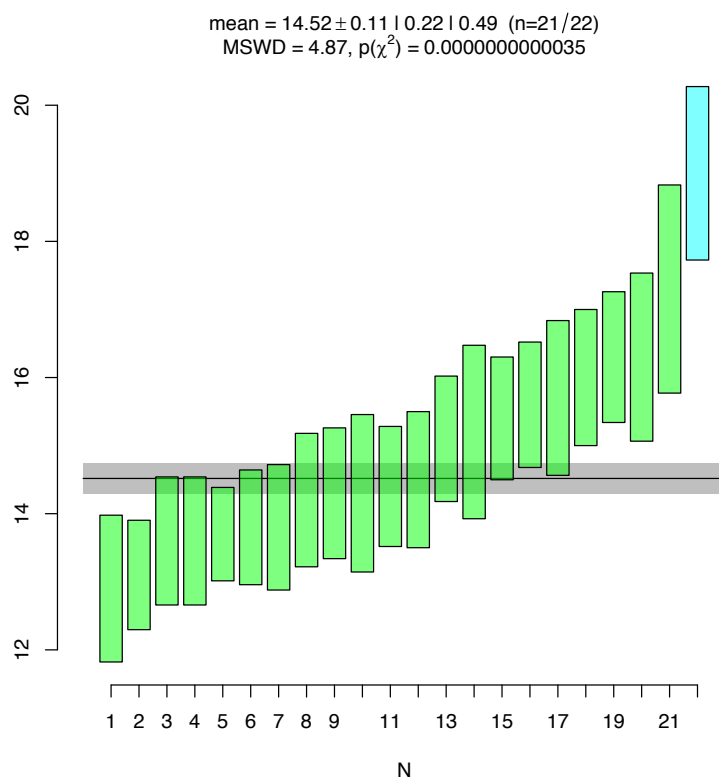


Figure A1-8. AntaKori porphyry PK. Sample Anta-PK

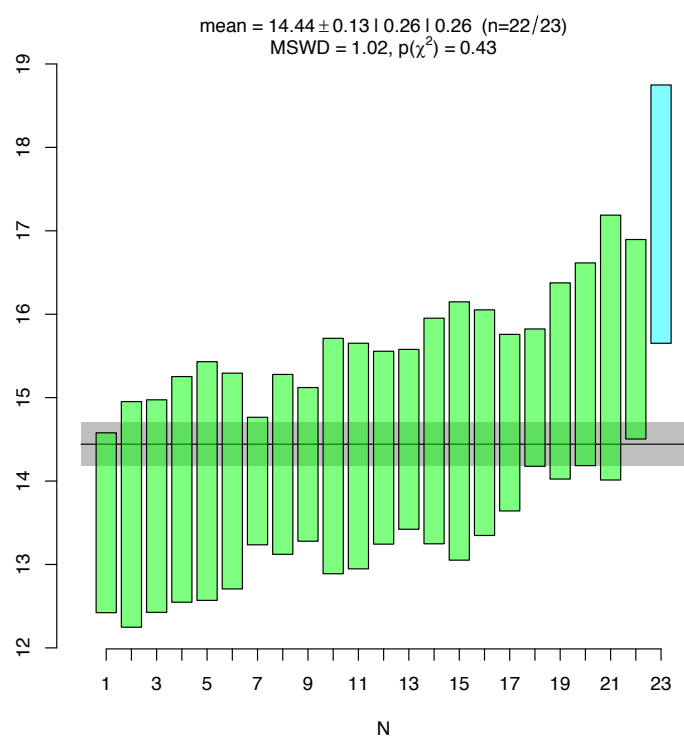


Figure A1-9. AntaKori porphyry PF. Sample Anta-PF

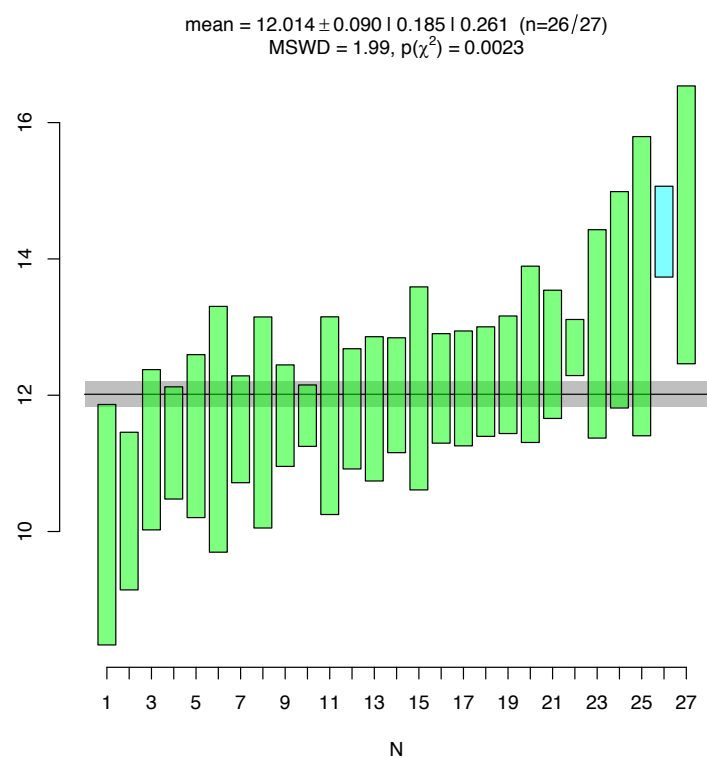


Figure A1-10. Cerro Jesus. Sample 25-7

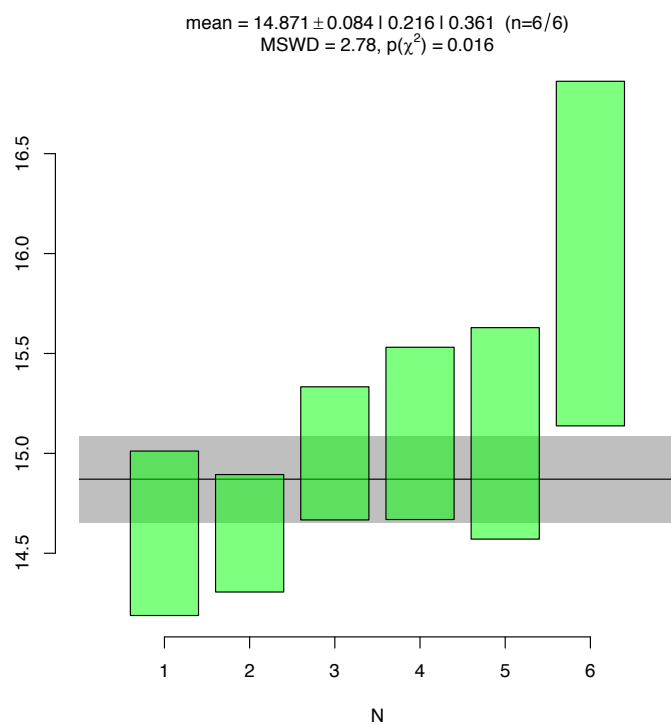


Figure A1-11. Cerro Choro Blanco. Sample CB

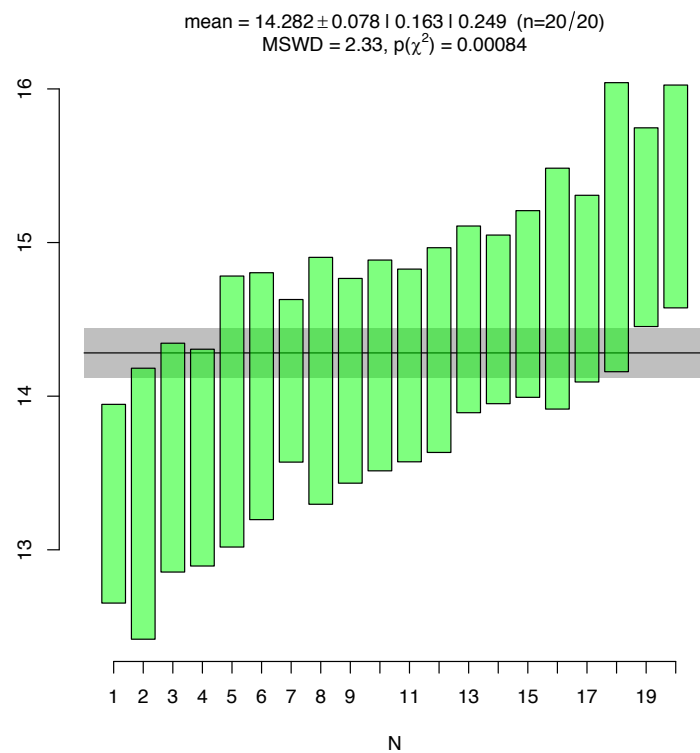


Figure A1-12. Cerro Caballerisa. Sample CAB

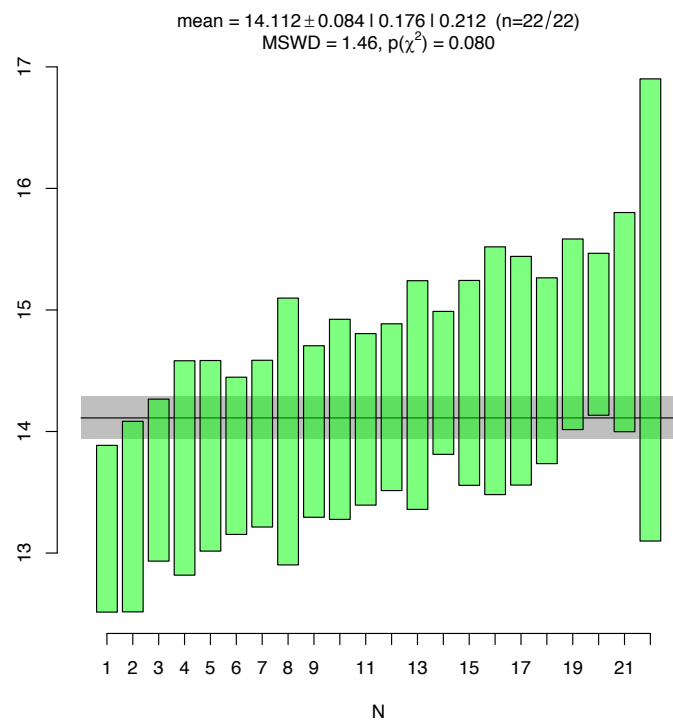


Figure A1-13. Cerro Las Gordas. Sample LG

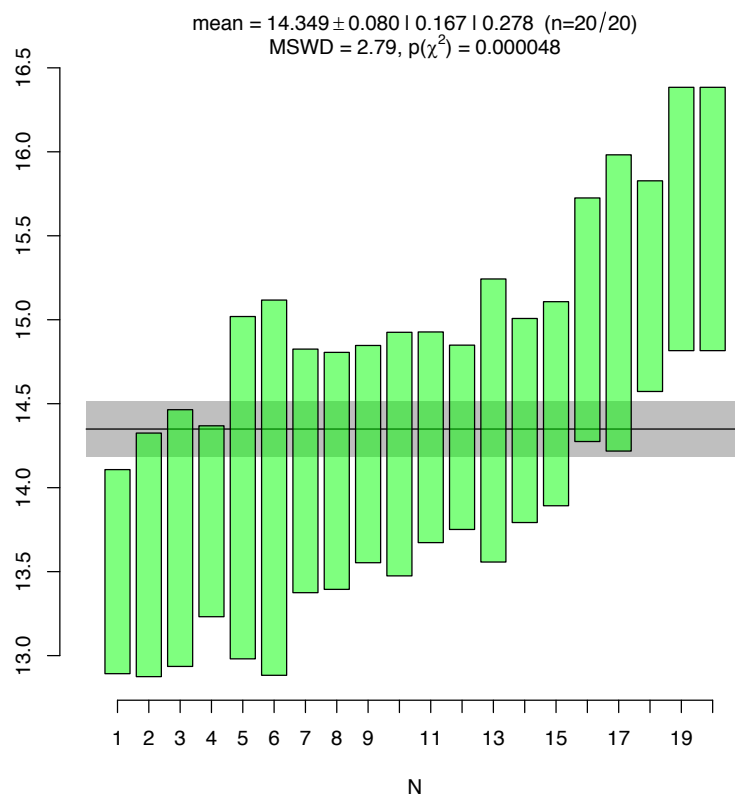


Figure A1-14. Sill Coymolache. Sample 161025-5

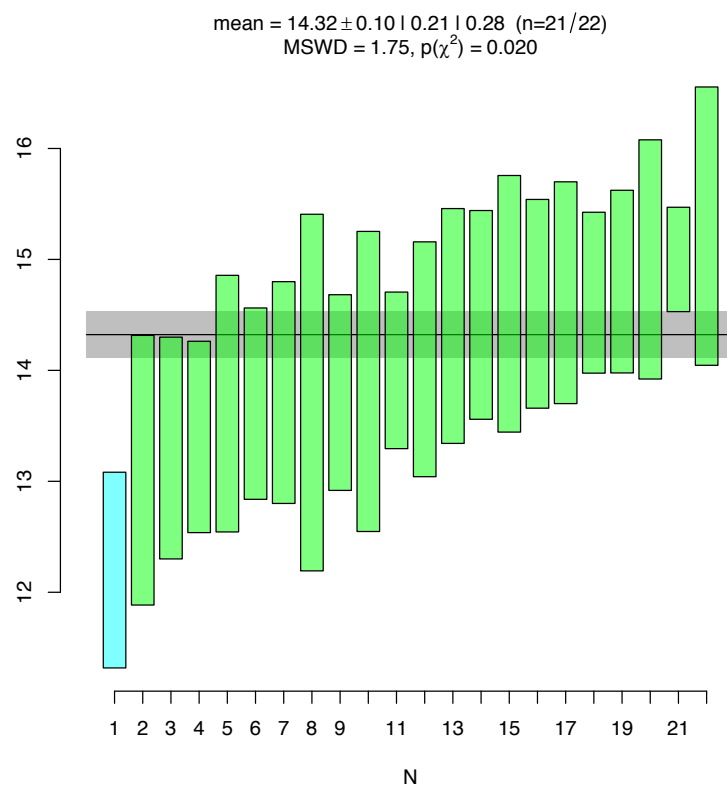


Figure A1-15. San Miguel. Samples SCO-1. SCO-2 and SCO-3

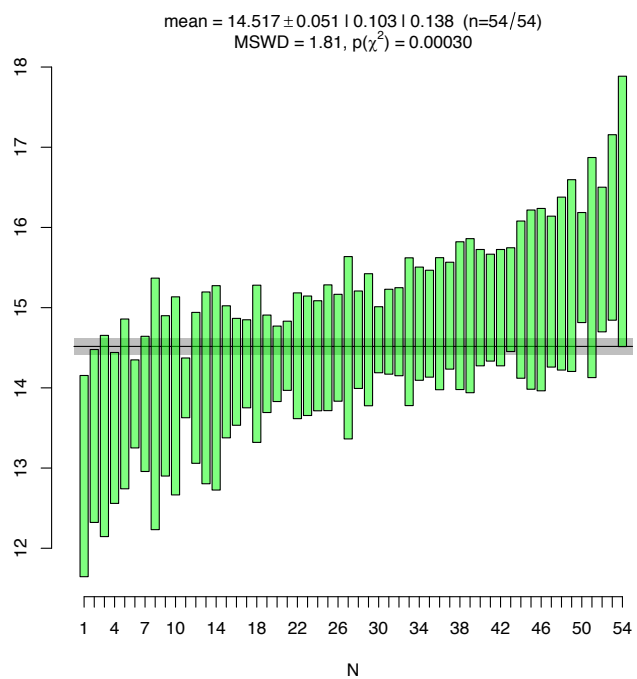


Figure A1-16. San Nicolas. Sample SN

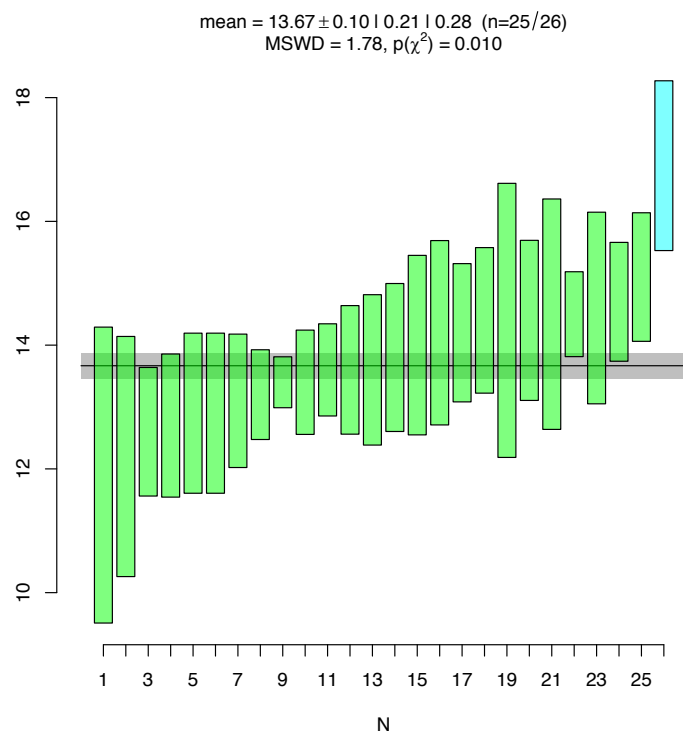


Figure A1-17. Calipuy andesite. Sample Anta-6

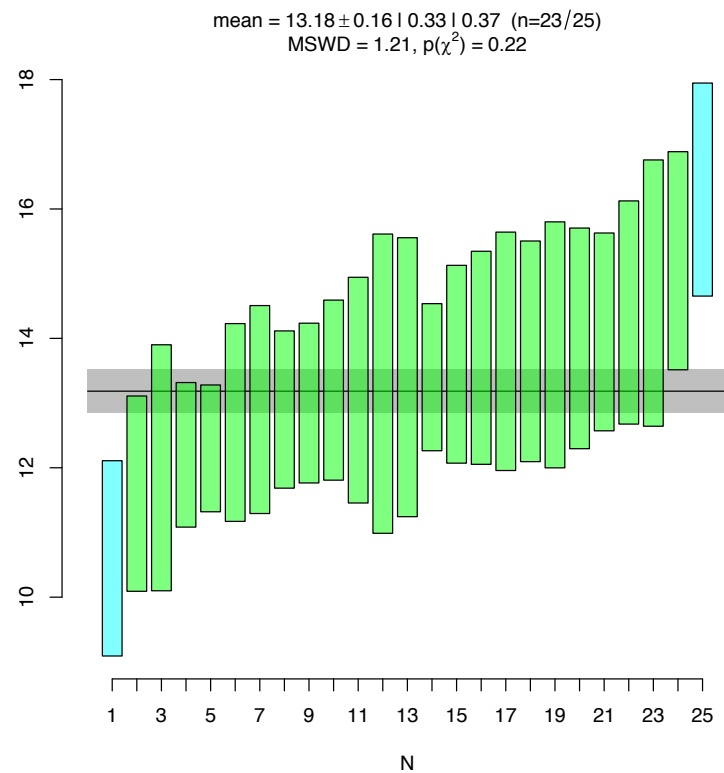


Figure A1-18. Calipuy rhyolite. Sample Anta-8

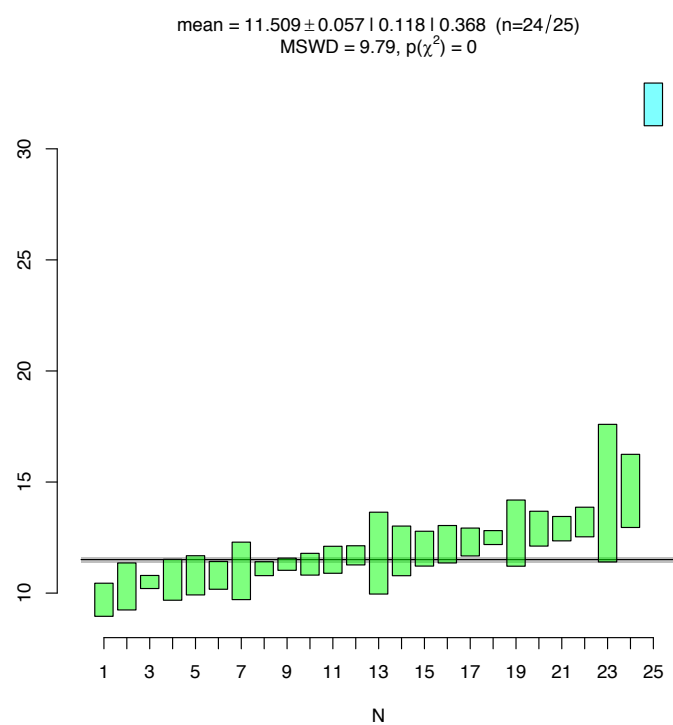


Figure A1-19. Hualgayoc rhyodacite. Sample 25-6

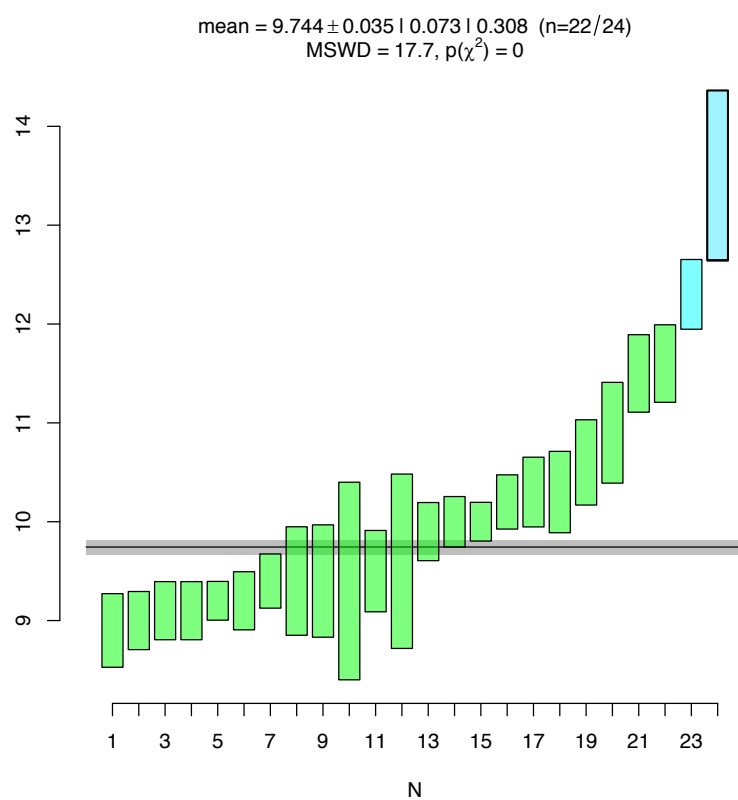


Figure A1-20. Cerro Corona. Sample CC1

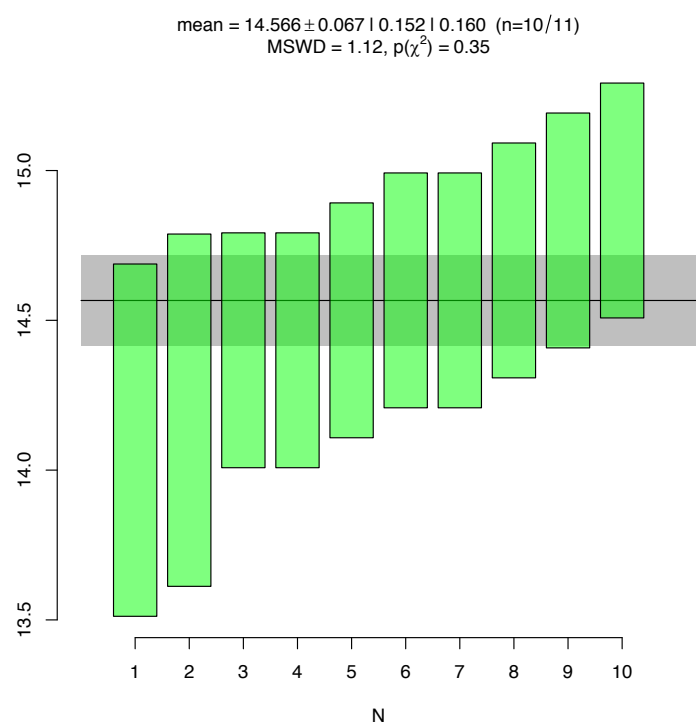


Figure A1-21. Cerro Corona. Sample CC4

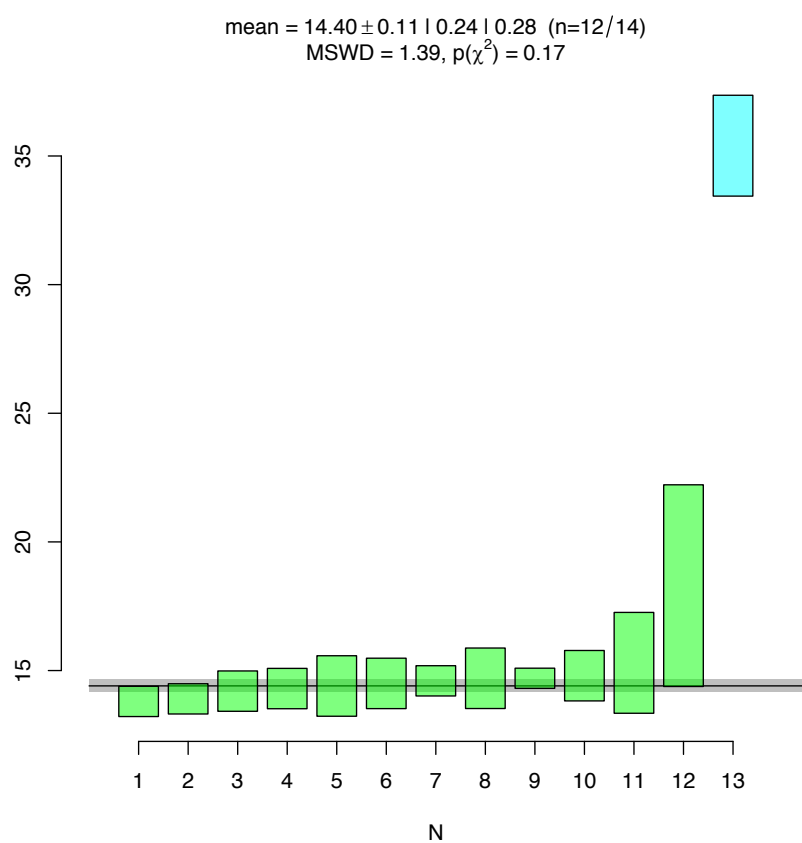


Figure A1-22. Cerro Corona. Sample CC4b

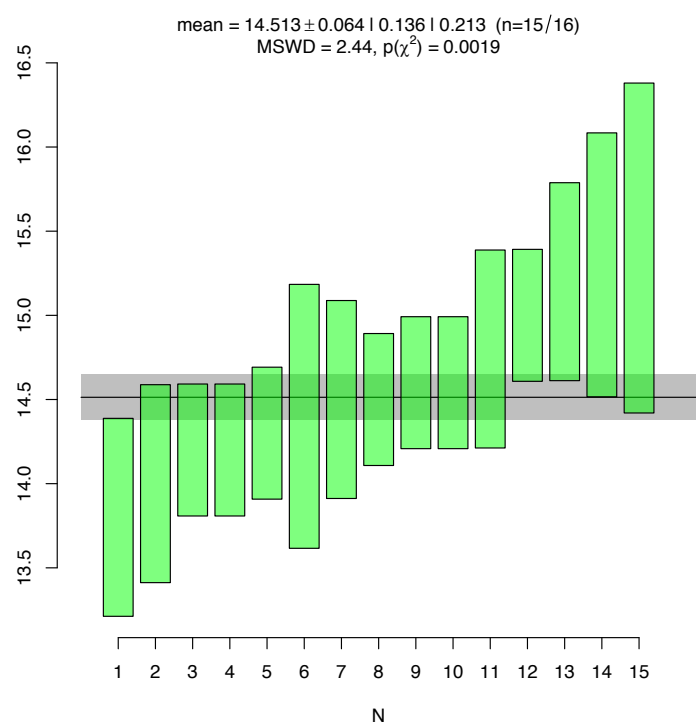


Figure A1-23. Cerro Corona. Sample CC5

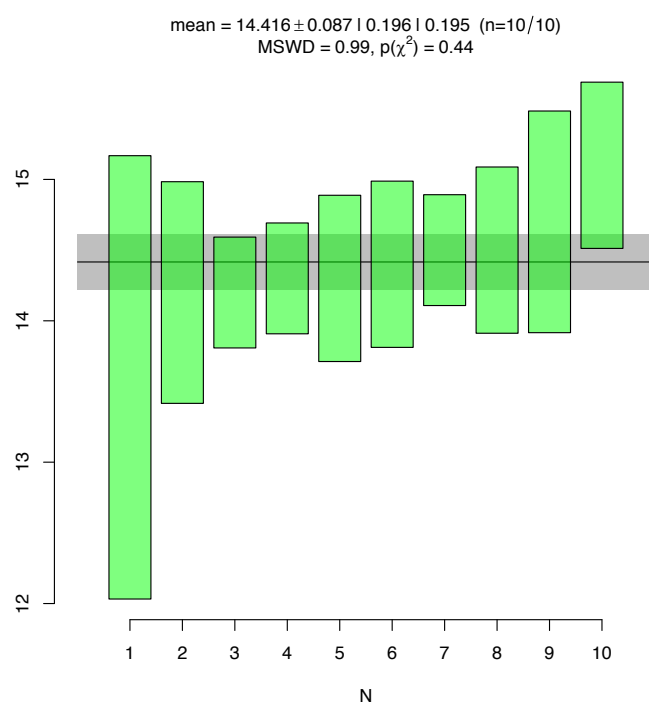


Figure A1-24. Cerro Corona. Sample CC5n

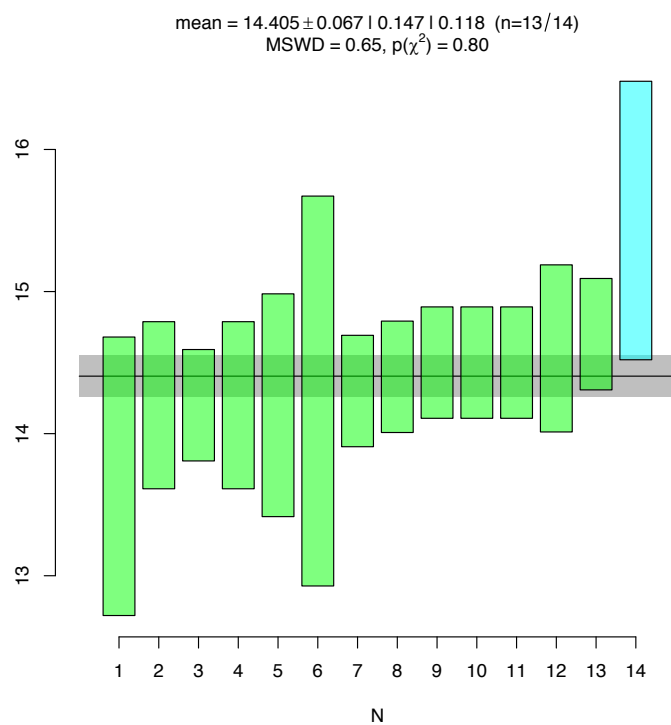


Figure A1-25. Cerro Corona. Sample CC6

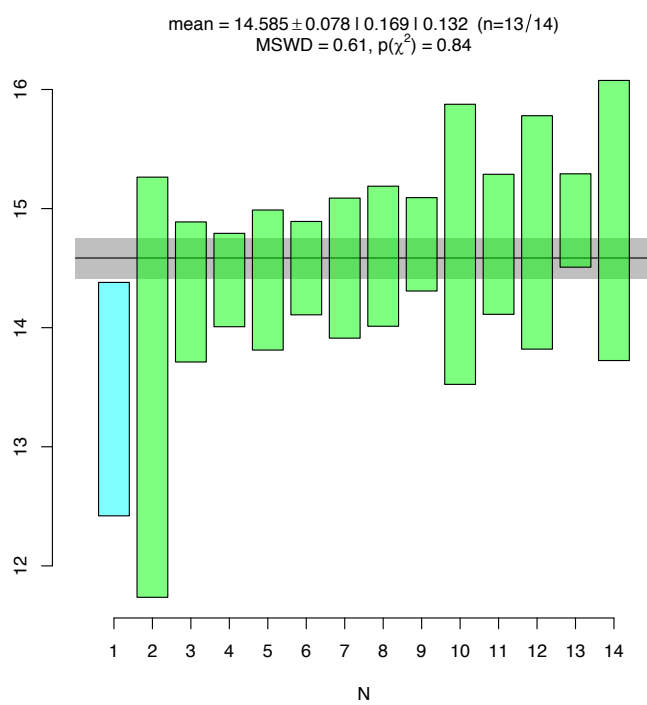


Table A1-5. Trace element abundance (ppm) in zircon and crystallization temperature calculated using Ti contents.

¹Ti-in-zircon geothermometry based on the method of Watson et al. (2006), assuming 0.7 as the activity of TiO₂ and 1 as the activity of SiO₂.

Analysis	Ca	Ti	Sr	Y	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Pb	Th	U	T(°C) ¹
Cerro Corona phase 1. Sample CCI																							
CC1-1-1	<58.25		0.466	628	0.00560	15.7	0.0213	0.483	1.64	0.780	9.54	3.52	49.1	20.7	105	26.9	333	63.8	8603	2.29	60.2	275	
CC1-1-2	<58.15	2.01	0.481	651	<0.0040	11.9	0.0459	0.992	2.39	1.12	12.4	4.20	52.9	20.2	104	26.2	299	57.8	9034	2.30	70.8	282	640
CC1-10-1	<59.48	2.85	0.441	564	0.00250	14.8	0.0277	0.456	1.37	0.711	8.01	2.86	41.3	17.5	92.7	24.2	298	59.2	8968	2.11	55.5	246	667
CC1-11-1	<60.84		0.530	692	<0.0038	17.2	0.0370	0.626	1.77	0.877	9.78	3.71	48.7	20.8	116	29.8	349	70.4	9677	2.60	70.2	292	
CC1-11-2	73.1	2.86	0.570	709	0.0604	13.4	0.0709	1.34	2.90	1.22	13.4	4.52	54.7	21.5	113	28.4	326	65.0	9202	2.64	82.1	295	668
CC1-12-1	<63.90		0.451	738	<0.0031	14.8	0.0191	0.632	1.46	0.845	10.6	4.02	54.6	23.3	121	30.3	324	71.5	9262	3.18	76.7	293	
CC1-13-1	<58.79		0.605	662	0.0644	19.4	0.0528	0.654	1.86	0.835	11.2	4.01	51.3	21.2	108	26.7	313	60.1	9689	3.11	114	357	
CC1-13-2	<59.32	2.98	0.486	625	<0.0033	16.7	0.0268	0.531	1.55	0.838	9.69	3.57	46.0	19.0	99.8	25.0	301	57.3	9515	3.00	107	327	671
CC1-5-1	<60.07	1.93	0.472	645	0.0184	11.0	0.0385	0.819	2.11	0.963	11.1	3.82	49.9	20.3	106	26.3	301	63.3	9320	2.59	68.2	287	637
CC1-6-1	<62.53		0.503	859	<0.0030	15.1	0.0909	1.91	3.82	1.73	18.0	5.97	71.9	27.2	138	32.4	357	71.5	9202	2.76	96.2	299	
CC1-6-2	<62.34	3.07	0.478	654	<0.00	12.7	0.0180	0.466	1.35	0.682	9.03	3.38	46.1	19.7	106	27.7	323	66.0	9358	2.37	61.8	271	673
CC1-39-1	<61.50		0.521	689	<0.00176	12.1	0.0166	0.501	1.23	0.689	9.10	3.45	46.7	20.4	111	28.9	329	69.4	9865	2.48	57.8	266	
CC1-39-2	<62.20	2.96	0.506	653	<0.0038	12.6	0.0174	0.474	1.47	0.714	9.13	3.41	46.2	19.5	106	27.0	321	66.6	9549	2.50	55.4	275	670
CC1-30-1	<63.04		0.510	660	<0.0046	13.7	0.0161	0.387	1.60	0.810	9.33	3.40	48.7	20.9	109	27.2	311	69.6	10070	2.75	73.6	290	
CC1-30-2	<59.80	3.41	0.492	749	<0.0039	18.6	0.0197	0.765	1.91	1.03	11.2	4.32	55.8	22.4	115	29.5	329	68.2	9707	3.81	144	409	682
CC1-44-1	<60.72	4.00	0.592	647	0.1116	13.9	0.0563	0.656	1.59	0.793	9.52	3.53	47.8	19.9	105	27.8	327	60.7	9642	2.89	82.8	321	695
CC1-83-1	<63.84	1.82	0.578	896	0.00990	21.2	0.0464	0.828	2.16	1.05	13.8	4.90	65.4	26.6	141	34.3	391	85.3	9666	2.97	110	333	633
CC1-95-1	<60.63	2.93	0.529	689	0.0071	14.6	0.0519	1.14	2.44	1.28	13.1	4.17	52.2	21.5	109	25.2	290	64.9	9762	2.29	76.0	256	670
CC1-84-1	<62.40	2.67	0.538	605	0.0469	15.9	0.0317	0.578	1.48	0.834	9.87	3.22	46.7	19.7	101	22.9	277	62.2	10353	3.05	97.0	311	662
CC1-86-1	<65.23	4.77	0.650	788	0.0580	15.9	0.0400	0.718	1.85	0.909	11.4	4.29	58.0	23.5	121	31.2	357	75.0	9551	3.00	90.5	330	711
CC1-89-1	<57.59		0.804	753	0.0313	16.0	0.0262	0.535	1.52	0.835	11.1	3.93	49.5	22.2	123	30.5	319	70.1	9928	2.86	91.2	307	
CC1-89-2	<58.80	2.71	0.517	812	0.00520	18.6	0.0329	0.592	1.59	0.947	11.8	4.33	55.5	24.4	134	33.3	358	76.8	9745	3.23	104	362	663

CC1-87-1	57.6		0.544	793	0.00460	10.1	0.0426	1.09	2.68	1.01	14.2	4.57	63.3	26.5	135	31.4	349	71.9	9880	14.8	85.4	480	
CC1-90-1	<62.86	2.52	0.492	777	0.00680	21.3	0.0334	0.845	2.04	1.03	12.5	4.58	56.5	23.3	124	31.1	329	72.3	9969	4.07	201	449	658
CC1-113-1	<60.52		0.525	773	<0.0024	16.2	0.0273	0.578	1.87	0.878	11.2	4.23	58.1	24.5	125	31.5	381	78.3	9612	3.20	104	372	
CC1-113-2	<59.34	2.60	0.979	607	0.0930	12.9	0.0419	0.689	1.26	0.683	9.09	3.29	42.6	18.4	101	23.8	264	59.5	10363	2.33	61.8	237	660

**Cerro Corona phase 4.
Sample CC4**

CC4-4-1	<54.23		0.390	386	0.0025	8.75	0.0135	0.344	0.928	0.503	5.55	2.03	26.6	11.5	63.7	17.4	221	42.2	9193	1.50	33.4	181	
CC4-4-2	<53.33	2.67	0.336	532	0.0037	14.4	0.0276	0.556	1.41	0.685	7.73	2.80	39.4	16.3	87.5	23.9	293	56.8	8980	1.94	54.7	221	662
CC4-12	<63.95		0.514	922	0.0032	20.9	0.0301	0.907	2.32	1.09	14.6	5.15	66.3	27.4	145	35.2	382	83.0	10666	4.32	199	461	
CC4-13-1	<60.43		0.431	633	0.0083	17.1	0.0427	0.841	1.80	0.794	9.52	3.44	43.8	18.3	97.8	24.6	279	59.5	9371	2.38	120	280	
CC4-13-2	<57.34	2.87	0.466	751	0.0605	21.2	0.0662	0.947	2.03	0.994	10.9	4.00	53.8	22.3	119	30.3	348	73.3	9065	2.81	135	325	668
CC4-18	<48.32	3.35	0.346	419	0.0031	10.2	0.0215	0.494	1.20	0.617	6.47	2.39	30.1	12.8	70.0	18.9	240	45.9	8531	1.60	44.2	197	681
CC4-20	<50.86	3.00	0.373	799	<0.0024	20.4	0.0388	0.759	2.12	0.960	12.9	4.52	57.6	24.0	128	32.2	358	72.2	9867	3.70	151	420	672
CC4-23	<58.26	2.95	0.412	609	0.0125	11.7	0.0564	1.16	2.37	0.998	11.5	3.76	46.7	18.2	95.4	23.9	270	57.2	10020	1.93	72.4	237	670
CC4-24-1	<51.61		0.486	764	0.0022	15.9	0.0314	0.625	1.80	0.890	10.9	4.16	55.3	23.1	129	33.8	387	75.7	9982	2.65	69.1	327	
CC4-24-2	<53.24	3.64	0.417	624	<0.00159	10.4	0.0161	0.371	1.37	0.666	8.56	3.23	43.1	18.5	101	26.1	308	62.9	10163	2.43	54.1	283	687
CC4-26	<56.73	5.28	0.453	729	0.0182	16.1	0.0407	0.900	1.90	0.926	11.6	4.13	52.6	22.0	116	30.1	345	70.4	9533	2.73	91.5	307	720
CC4-47	<46.57	3.63	0.360	431	0.0010	13.2	0.0208	0.558	1.36	0.755	6.66	2.56	34.0	13.5	69.7	20.5	289	39.6	6770	2.07	43.9	259	687
CC4-49	<55.89		0.494	1041	0.0057	24.2	0.0370	0.888	2.73	1.28	16.1	5.85	77.0	31.8	163	41.8	482	89.6	9516	4.27	161	507	
CC4-60	61.3	3.65	0.446	666	0.0075	17.2	0.0295	0.734	1.44	0.725	9.57	3.51	45.7	19.6	107	26.8	291	65.2	9731	2.41	86.5	253	688
CC4-69	<49.51	4.36	0.370	446	<0.0020	10.5	0.0188	0.487	1.15	0.566	6.94	2.43	32.0	13.5	74.1	20.3	249	48.6	9427	1.75	42.4	201	703
CC4-86	<43.95	4.56	0.468	877	0.0205	28.9	0.0593	1.22	3.03	1.45	16.6	5.57	71.4	27.5	133	36.2	440	71.9	7914	4.77	217	610	707
CC4-93	<46.92	3.61	0.480	656	0.0304	15.6	0.0506	0.763	1.67	0.856	10.8	3.72	47.7	19.4	107	28.3	344	64.0	9561	2.53	84.3	314	687
CC4-94	<61.53	3.94	0.447	772	0.0045	25.6	0.0431	0.917	2.19	1.02	13.8	4.57	56.9	22.7	117	28.7	315	68.3	10345	4.27	247	500	694
CC4-96	<51.27	3.82	0.465	813	<0.0020	18.2	0.0421	0.983	2.45	1.15	13.8	4.76	62.4	24.9	127	33.5	393	72.1	9732	3.17	115	405	692
CC4-98-1	<55.15		0.464	903	<0.00149	25.2	0.0381	1.02	2.23	1.18	14.8	5.12	65.9	26.5	141	34.8	393	81.5	10032	3.71	182	450	
CC4-98-2	<51.27	5.36	0.491	756	0.0152	16.9	0.0360	0.792	1.94	0.974	11.4	4.17	52.9	22.2	118	29.2	337	72.8	10257	3.12	152	348	721
CC4-103	<52.47	2.72	0.368	449	0.0030	7.52	0.0092	0.266	1.00	0.444	5.77	2.23	30.8	13.2	74.1	19.7	228	49.6	10253	1.50	31.3	171	664
CC4-105	<48.91	3.88	0.395	614	<0.0026	14.6	0.0238	0.621	1.54	0.794	9.19	3.39	44.7	18.5	99.9	25.9	309	59.4	9687	1.91	53.2	231	693

CC4-109	<52.40	3.40	0.547	949	0.0150	22.9	0.0497	1.13	2.90	1.45	17.3	5.95	73.4	29.1	148	37.2	420	79.5	10317	4.56	223	569	682
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**Cerro Corona phase 4.
Sample CC4b**

CC4b-37-2	<56.32	0.507	669	<0.0019	12.0	0.0167	0.515	1.22	0.677	9.63	3.47	45.1	19.3	106	27.8	318	68.8	11441	2.37	63.1	282
CC4b-60	<60.10	0.481	547	0.0856	10.9	0.0602	0.824	1.54	0.691	8.59	3.03	38.6	15.7	86.5	21.7	246	58.8	11075	1.61	58.2	170
CC4b-66	<52.29	0.485	873	<0.00146	19.2	0.0243	0.724	2.01	0.936	12.1	4.45	59.9	24.9	134	35.3	416	77.7	10062	2.57	76.0	326
CC4b-77	<70.87	0.433	549	0.0043	9.78	0.0471	1.00	1.99	0.824	9.59	3.25	39.9	16.5	87.2	21.2	233	56.5	10953	1.45	59.6	174
CC4b-78	<53.03	0.560	1033	0.0047	31.4	0.0387	1.15	3.28	1.51	18.5	6.37	78.0	31.3	158	40.2	453	84.9	10283	4.70	251	626
CC4b-82	<57.52	0.564	911	0.0629	19.0	0.0460	0.894	2.16	1.11	13.4	5.19	66.9	27.6	142	36.2	405	80.9	10448	3.31	124	401
CC4b-83	<59.86	0.438	759	0.0138	13.0	0.0566	1.22	2.73	1.24	13.6	4.60	58.8	23.0	118	30.5	357	69.7	10445	2.56	79.4	307
CC4b-95-1	<53.86	0.445	494	0.0265	9.43	0.0233	0.367	1.05	0.526	6.53	2.57	34.9	14.9	81.8	21.9	263	53.3	11662	1.80	46.1	226
CC4b-95-2	<51.64	0.417	666	0.0227	11.6	0.0436	0.968	2.41	1.03	12.7	4.18	52.1	20.1	104	26.1	302	59.9	10912	1.95	66.1	252
CC4b-97-3	<57.25	0.561	1042	0.0118	25.7	0.0459	0.976	2.36	1.20	15.1	5.63	75.5	31.4	165	40.8	443	97.1	11160	3.06	121	359
CC4b-104	<55.25	0.370	420	0.0143	9.64	0.0169	0.411	1.05	0.530	5.85	2.24	29.6	12.2	65.7	18.4	225	44.7	10353	1.48	42.4	178
CC4b-107	<57.31	0.460	729	<0.0022	17.1	0.0232	0.668	1.76	0.830	10.5	3.79	50.6	21.5	117	30.6	363	72.9	10221	2.47	71.8	303
CC4b-115	<58.69	0.488	757	<0.0022	22.6	0.0279	0.759	2.32	1.06	13.1	4.62	56.7	22.8	115	28.2	306	64.9	11216	4.65	242	576
CC4b-117-1	<56.10	0.470	546	0.0015	16.2	0.0263	0.594	1.33	0.697	8.98	3.14	39.6	16.0	83.8	21.3	241	48.7	11101	3.17	143	374
CC4b-117-2	<66.88	0.437	679	0.0144	13.1	0.0235	0.510	1.42	0.696	9.14	3.41	44.9	19.4	107	27.0	306	74.0	11861	2.39	77.0	277
CC4b-126	<54.77	0.386	754	<0.0021	22.1	0.0406	0.824	2.36	1.16	13.2	4.67	59.7	23.0	116	30.4	356	61.8	10150	3.57	140	436

**Cerro Corona phase 5.
Sample CC5**

CC5-3-1	<52.68	0.719	781	0.0095	19.1	0.0292	0.681	1.96	0.944	11.5	4.23	57.0	23.2	122	31.9	371	69.1	9909	2.58	85.6	323
CC5-3-2	<50.88	0.475	686	0.0026	16.7	0.0391	0.666	1.83	0.812	10.2	3.69	48.7	20.3	112	29.0	345	68.3	9999	2.09	72.8	264
CC5-27	<55.30	0.601	686	0.0573	16.8	0.0529	1.11	2.14	0.935	11.0	3.99	51.0	20.6	109	28.0	333	63.0	10340	2.41	89.0	283
CC5-51	<58.57	0.419	554	<0.0030	13.2	0.0246	0.555	1.23	0.630	7.98	2.81	39.0	16.4	88.6	23.1	271	59.2	10335	1.78	56.8	195
CC5-60	<49.28	0.519	813	0.0224	19.9	0.0388	0.769	2.27	1.18	12.7	4.83	62.4	25.1	129	34.0	429	70.5	8783	3.43	104	426
CC5-69	<54.44	0.465	617	0.0158	16.4	0.0302	0.692	1.50	0.866	9.60	3.38	44.6	18.2	94.7	25.5	304	56.5	9789	2.25	70.6	297
CC5-70	<54.04	0.608	888	0.0424	21.1	0.0466	0.957	2.46	1.06	14.1	5.06	65.6	26.6	138	34.6	390	80.4	10662	3.56	138	441

CC5-71-1	<53.35	0.416	651	<0.0027	16.7	0.0306	0.643	1.52	0.805	9.29	3.40	46.5	19.7	106	28.5	340	67.6	9513	2.34	80.4	272
CC5-71-2	<51.82	0.514	840	0.0199	17.9	0.0361	0.811	2.10	1.03	12.5	4.71	63.2	25.8	138	36.1	436	80.9	10458	3.27	102	391
CC5-73	<57.09	0.542	1273	0.0346	26.0	0.1270	2.86	6.28	3.05	32.3	9.87	109	40.5	188	41.3	416	85.7	10983	2.51	143	269
CC5-93	<50.12	0.452	732	<0.0017	21.6	0.0372	0.811	2.15	1.03	12.1	4.40	56.5	23.2	118	31.1	381	65.2	9093	3.14	114	386
CC5-111-1	<49.37	0.426	686	0.0030	16.3	0.0210	0.598	1.67	0.859	10.5	3.80	51.2	21.2	111	30.1	371	62.6	8729	2.55	66.0	313
CC5-111-2	<52.19	0.418	527	0.0126	12.0	0.0241	0.662	1.50	0.703	8.14	2.93	37.7	15.4	83.0	22.1	274	51.7	9641	1.96	56.5	236
CC5-111-3	<44.99	0.302	380	<0.0019	11.1	0.0212	0.419	1.15	0.573	6.37	2.24	28.9	12.1	64.5	18.1	239	41.6	8604	1.27	37.9	164
CC5-114-1	<51.46	0.341	434	0.0060	8.95	0.0216	0.395	1.03	0.534	6.32	2.38	31.6	13.3	73.5	20.2	247	48.0	9060	1.75	41.7	215
CC5-114-2	54.9	0.312	330	<0.0022	7.57	0.0157	0.439	1.06	0.493	5.54	2.06	25.6	10.6	55.9	16.1	211	34.9	8549	1.14	28.8	131
CC5-115	<50.77	0.512	845	0.0050	21.1	0.0318	0.860	2.26	1.08	12.7	4.55	62.3	25.6	135	34.7	408	73.6	10067	2.66	77.1	332

**Cerro Corona phase 5.
Sample CC5n**

CC5n-3-1	<63.17	0.413	469	0.0036	12.5	0.0239	0.404	1.31	0.615	7.13	2.51	33.7	14.1	75.5	18.9	219	48.5	9217	1.66	68.6	187
CC5n-4-1	<67.27	0.527	741	0.0039	18.0	0.0243	0.673	1.64	0.873	11.5	4.02	54.8	22.5	117	29.6	332	71.1	10362	3.56	118	382
CC5n-7-1	<61.15	0.503	761	0.0039	20.4	0.0397	0.879	2.17	0.884	11.3	4.44	57.6	23.6	121	30.8	361	76.2	9691	2.93	107	334
CC5n-16-1	<64.79	0.506	542	0.0363	11.4	0.0372	0.806	1.79	0.743	8.91	3.10	40.1	16.2	86.6	21.9	257	57.4	9976	1.99	69.3	228
CC5n-15-1	<64.82	0.439	504	0.0386	13.6	0.0464	0.729	1.44	0.734	8.19	2.83	38.5	15.4	79.5	20.4	243	52.6	9360	1.68	66.3	193
CC5n-26-1	<61.70	0.513	526	0.0100	16.1	0.0329	0.559	1.22	0.706	7.70	2.88	37.9	15.3	81.1	22.5	255	48.7	9935	2.24	80.3	283
CC5n-26-2	<59.47	0.381	310	0.0250	7.87	0.0260	0.413	0.774	0.369	4.62	1.67	22.2	9.32	51.6	13.3	156	35.0	9042	0.873	33.8	109
CC5n-35-1	<58.71	0.451	585	0.0146	25.7	0.0288	0.818	2.15	0.954	11.2	3.93	50.1	18.6	91.3	23.1	283	48.7	9064	4.30	242	514
CC5n-34-1	<57.22	0.438	523	<0.0042	12.7	0.0276	0.584	1.50	0.760	8.22	2.92	39.4	15.4	83.5	22.0	268	51.7	8760	2.12	65.3	241
CC5n-33-1	<59.88	0.536	699	0.0277	16.2	0.0493	1.04	2.37	1.03	12.2	4.22	55.6	21.2	109	28.0	343	64.6	9015	3.50	153	422
CC5n-23-1	<56.63	0.423	502	<0.0037	14.9	0.0187	0.488	1.42	0.625	7.17	2.63	37.3	15.6	82.1	22.2	294	53.6	8923	1.79	52.8	206
CC5n-31-1	<53.77	0.371	375	0.0377	19.3	0.0359	0.628	1.36	0.732	7.45	2.49	33.5	12.9	63.3	15.3	200	33.7	7833	2.64	145	304
CC5n-42-1	<57.91	0.491	457	0.0247	15.5	0.0265	0.549	1.35	0.700	8.04	2.74	34.4	14.0	74.1	18.8	233	43.5	8838	2.50	88.6	285
CC5n-30-1	<59.45	0.505	690	0.0069	16.3	0.0254	0.589	1.68	0.827	9.81	3.63	50.8	21.3	111	27.9	339	67.4	9244	2.42	74.3	277
CC5n-30-2	<60.20	0.451	592	0.0048	15.5	0.0330	0.477	1.43	0.663	8.81	3.11	41.5	17.4	92.9	25.1	291	58.3	9474	1.88	65.4	231
CC5n-20-1	<62.40	0.579	959	0.0107	24.1	0.0468	1.00	2.51	1.24	14.5	5.37	70.4	28.9	149	39.3	458	89.0	9304	3.52	126	434
CC5n-76-1	<206.77	0.831	1088	0.0040	31.2	0.0470	1.19	2.72	1.25	16.2	5.92	76.9	33.4	177	43.8	518	111	17528	10.8	142	394

CC5n-78-1	<67.65	0.498	702	0.0094	16.0	0.0247	0.631	1.33	0.638	9.70	3.34	47.8	21.1	112	27.3	325	74.0	10015	2.54	80.6	273
CC5n-70-1	<61.69	0.543	769	0.0139	17.3	0.0460	1.15	2.21	1.14	12.8	4.54	58.8	22.9	119	30.6	364	69.6	9136	2.92	101	333
CC5n-69-1	<58.45	0.548	584	0.0428	19.6	0.0498	0.882	2.01	0.927	10.0	3.50	46.4	17.8	91.0	25.9	318	53.1	7961	3.02	118	381
CC5n-100-1	<58.27	0.474	688	0.0089	17.2	0.0231	0.650	2.09	0.879	10.2	3.75	56.1	22.8	114	29.7	377	70.8	8415	2.75	68.0	308
CC5n-104-1	<62.37	0.363	470	0.0169	10.2	0.0397	1.10	2.21	0.974	9.09	3.05	39.3	15.5	74.0	18.3	220	49.0	8900	1.32	53.9	138
CC5n-109-1	<56.79	0.331	331	0.0052	6.76	0.0297	0.546	1.08	0.469	5.59	1.94	25.5	11.0	54.9	13.9	168	38.7	8234	0.926	31.5	90.7

**Cerro Corona phase 6.
Sample CC6**

CC6-9-1	66.2	4.02	0.538	939	0.0058	18.6	0.0293	0.698	2.03	0.985	13.7	4.95	67.8	28.2	150	36.6	410	90.6	10042	3.37	98.7	376	696
CC6-13-1	<64.07	2.95	0.444	515	0.0039	14.0	0.0260	0.609	1.35	0.620	7.03	2.76	36.0	15.4	84.2	21.7	255	53.4	9166	1.75	56.7	199	670
CC6-18-1	<62.34		0.902	2235	0.0066	42.1	0.0371	0.914	3.00	1.69	23.9	10.2	151	66.1	364	89.4	969	191	8759	31.4	516	1299	
CC6-19-1	<72.47		0.646	1065	0.0154	28.2	0.0523	1.06	3.16	1.32	18.8	6.28	80.7	32.4	167	38.6	407	93.5	9860	3.98	200	428	
CC6-27-1	<64.84	2.61	0.383	420	0.0034	7.76	0.0236	0.447	1.09	0.545	6.32	2.27	30.1	12.6	66.0	17.1	204	43.5	9797	1.40	36.9	159	660
CC6-32-1	<63.18		0.666	639	0.1203	17.7	0.0832	0.865	1.82	0.945	10.1	3.64	48.3	19.6	103	26.1	313	64.0	9056	2.65	94.4	300	
CC6-38-1	<62.01		0.416	452	<0.0032	11.1	0.0224	0.457	1.28	0.548	6.50	2.31	31.7	13.7	73.1	18.5	218	48.0	9005	1.42	41.6	160	
CC6-38-2	<67.71	3.64	0.563	671	0.0556	12.0	0.0906	1.31	2.65	1.23	13.6	4.37	53.9	20.6	106	25.5	290	61.6	9860	2.25	75.6	244	687
CC6-43-1	<63.68	3.42	0.470	630	0.0397	13.6	0.0277	0.748	1.70	0.776	9.15	3.37	44.2	18.2	99.4	25.6	300	65.9	9283	2.68	82.2	285	682
CC6-45-1	<64.71		0.425	510	0.0034	14.4	0.0248	0.636	1.32	0.648	8.07	2.80	36.2	15.5	82.5	20.8	240	52.7	9334	2.07	81.6	220	
CC6-45-2	<65.14	2.96	0.586	699	0.0256	15.3	0.0506	0.823	1.88	0.865	10.8	3.78	50.0	20.7	109	27.8	317	68.9	9678	2.51	84.6	269	670
CC6-48-1	<55.93	4.29	0.387	347	<0.00	7.72	0.0118	0.478	1.17	0.527	5.47	1.88	26.3	10.9	58.1	15.1	195	38.6	8445	0.881	33.0	114	701
CC6-50-1	<60.72	4.30	0.567	515	0.0836	16.4	0.0571	0.763	1.45	0.701	8.87	3.08	38.8	15.5	80.9	21.4	252	51.1	9252	4.81	152	565	702
CC6-52-1	<66.56	3.36	0.469	467	0.0223	12.6	0.0359	0.400	1.14	0.525	6.92	2.49	32.2	14.1	76.2	18.8	218	50.4	9603	1.81	60.8	191	681
CC6-58-1	<64.64	3.19	0.432	724	0.0045	20.2	0.0416	0.823	1.82	0.949	10.7	4.06	52.9	21.8	115	29.3	336	68.3	9017	2.44	97.3	279	677
CC6-65-1	<64.66		0.491	666	0.0041	16.7	0.0329	0.696	1.52	0.773	9.11	3.45	46.6	20.6	109	27.9	327	72.7	10020	2.15	63.2	247	
CC6-65-2	<60.35		0.394	421	0.0017	12.8	0.0191	0.473	1.18	0.576	6.18	2.23	30.5	13.0	67.7	18.1	214	44.4	9214	1.49	52.1	170	
CC6-65-3	<62.13	2.06	0.409	472	0.0057	9.63	0.0123	0.397	1.24	0.564	6.54	2.56	34.7	14.1	76.6	21.0	261	50.3	9071	2.10	45.4	236	642
CC6-76-1	<60.71	2.81	0.379	501	0.0047	18.7	0.0260	0.698	1.45	0.730	8.21	2.91	38.3	14.9	79.3	20.3	230	46.3	8978	2.77	129	330	666
CC6-90-1	59.0	3.26	0.467	652	<0.0034	16.1	0.0477	0.895	1.95	0.899	10.5	3.76	47.1	19.3	100	26.2	297	57.3	8593	2.47	84.8	271	678
CC6-90-2	<62.20	3.26	0.466	663	0.0056	16.5	0.0285	0.697	1.65	0.907	9.53	3.54	46.1	19.4	106	27.3	325	63.5	9156	2.85	84.8	308	678

CC6-127-1	<49.32		0.417	533	<0.0019	19.9	0.0225	0.536	1.46	0.884	9.52	2.98	38.9	18.1	91.5	20.9	235	54.2	8936	2.81	123	291	
CC6-125-1	<67.01	1.47	0.493	791	0.0087	13.9	0.0248	0.567	1.66	0.788	11.0	4.08	52.9	23.4	131	32.3	346	73.5	9982	2.47	63.8	275	617

San Jose. Sample SJD-02

SJD-1	<58.13	2.90	0.473	740	0.0047	13.6	0.0241	0.496	1.55	0.763	9.99	3.72	50.9	21.4	114	27.9	301	69.8	12119	1.96	57.3	226	669
SJD-2	<59.70	2.85	0.505	1077	0.0072	18.0	0.0883	1.74	3.93	1.63	20.1	6.66	79.6	31.3	160	37.8	394	86.8	11646	2.96	111	322	667
SJD-3-1	<58.39	3.57	0.451	984	<0.0036	17.9	0.0156	0.599	1.93	0.942	13.3	5.01	67.9	28.8	154	37.5	398	91.6	12343	2.80	87.1	306	686
SJD-3-2	<56.13	4.06	0.449	1081	<0.0034	20.5	0.0347	0.755	2.19	1.08	14.9	5.62	75.5	32.2	168	40.8	427	98.5	11738	3.12	114	371	697
SJD-4	<58.94	3.33	0.460	812	0.0023	15.5	0.0338	0.650	1.74	0.872	11.3	4.26	56.3	24.2	128	32.1	345	78.6	11541	2.42	64.7	257	680
SJD-5	<58.51	3.22	0.454	791	<0.0031	16.5	0.0231	0.577	1.71	0.870	11.2	4.16	55.8	23.5	127	32.3	355	76.9	11369	2.41	68.1	263	677
SJD-6	<64.37	3.31	0.522	874	<0.0045	15.6	0.0284	0.575	1.95	0.905	12.1	4.46	60.9	25.5	139	34.6	377	84.2	12119	2.43	68.1	272	680
SJD-7	<63.47	3.38	0.463	757	0.0161	13.4	0.0344	0.598	1.71	0.874	10.7	3.94	53.4	22.5	119	28.9	310	73.4	11982	2.28	72.3	257	681
SJD-8	<63.10	3.96	0.538	1096	0.0050	22.6	0.0349	0.693	2.34	1.09	15.6	5.72	77.9	32.7	169	40.4	428	96.3	11683	3.06	104	347	695
SJD-9	<62.05	3.42	0.540	931	0.0378	17.7	0.0520	0.671	1.91	0.886	13.0	4.67	63.7	27.5	144	35.5	386	86.5	12063	2.58	76.4	300	682
SJD-10-1	<69.54	2.86	0.602	1054	0.0241	17.4	0.0300	0.815	2.09	0.907	13.9	5.23	69.3	29.5	161	38.6	403	94.5	11684	2.67	83.8	286	668
SJD-10-2	<62.64	3.65	0.473	939	0.0029	17.0	0.0274	0.683	1.87	0.891	12.7	4.70	63.8	27.3	147	35.8	384	89.4	12423	2.55	80.8	296	688
SJD-11	<57.58	2.85	0.459	879	0.0043	16.1	0.0248	0.617	1.93	0.859	12.2	4.57	61.5	25.7	135	33.5	358	79.9	11673	2.72	76.1	292	667
SJD-12	<55.58	3.74	0.339	461	<0.0037	11.7	0.0269	0.576	1.43	0.722	8.25	2.86	34.9	14.0	70.3	16.5	171	38.7	10286	1.35	102	161	690
SJD-13	<54.20	3.34	0.492	1146	<0.0029	22.8	0.0324	0.866	2.62	1.08	16.0	5.95	82.4	34.4	180	44.0	464	104	11305	3.28	113	377	680
SJD-14	<65.01	3.27	0.493	790	<0.0035	20.1	0.0368	0.654	1.94	0.966	12.4	4.44	57.6	23.7	124	30.4	321	72.7	12110	3.78	156	444	679
SJD-15	<69.59	2.47	0.554	834	0.0262	12.0	0.0684	1.05	2.67	1.09	14.5	4.89	60.0	24.4	124	29.8	317	71.3	12442	2.19	75.6	255	656

San Jose. Sample 25-4

25-4-1	<52.70	4.27	0.480	1127	<0.0027	26.9	0.0443	1.03	2.89	1.42	19.5	6.41	86.2	35.1	173	43.7	478	92.3	10728	3.08	129	379	701
25-4-2	<58.38	2.41	0.429	875	0.0052	14.8	0.0171	0.474	1.83	0.840	12.5	4.80	64.1	26.1	135	31.6	327	71.3	11437	2.50	71.5	259	654
25-4-3	<56.16	3.04	0.423	706	<0.0037	13.5	0.0190	0.528	1.55	0.741	9.66	3.54	47.7	20.4	108	26.8	291	67.4	11581	2.06	67.6	241	673
25-4-4	<59.25	3.33	0.477	1112	0.0054	20.9	0.0420	0.845	2.41	1.07	15.9	5.80	78.8	33.4	177	41.8	450	102	11868	3.15	105	363	680
25-4-5	<48.91	3.56	0.459	870	<0.0027	16.7	0.0212	0.571	1.80	0.884	11.7	4.74	62.2	25.8	134	32.7	363	68.7	10053	2.13	73.4	268	686
25-4-6	<56.50	3.81	0.489	840	<0.0035	17.7	0.0289	0.585	1.99	0.910	11.6	4.32	58.2	24.3	129	32.0	349	77.2	11211	2.81	105	307	691

25-4-7-1	<58.11	2.68	0.426	676	0.0469	21.2	0.0472	0.687	1.89	0.912	11.7	4.09	51.9	20.3	104	24.4	258	56.8	11703	4.06	223	473	663
25-4-7-2	<58.90	3.59	0.443	1003	<0.0117	22.5	0.0117	0.752	2.19	0.907	14.7	5.29	70.7	29.7	152	36.2	383	85.7	12134	4.17	182	466	686
25-4-8	<56.26	3.16	0.396	814	<0.0041	14.8	0.0238	0.580	1.62	0.854	11.0	4.17	56.2	23.7	128	31.5	338	79.9	11325	2.42	66.2	255	676
25-4-9	<60.35	2.82	0.467	524	<0.0025	12.6	0.0220	0.372	1.15	0.624	7.82	2.73	36.8	15.4	83.6	20.9	222	50.2	11707	2.05	57.1	219	667
25-4-10	<65.68	2.67	0.431	708	<0.0038	14.0	0.0203	0.532	1.51	0.810	9.99	3.67	49.7	20.8	112	26.2	282	67.3	12058	2.72	75.3	290	662
25-4-11	<62.13	1.58	0.381	286	<0.0035	4.93	0.0066	0.174	0.518	0.294	3.79	1.41	18.9	8.44	46.3	11.6	130	31.8	11925	0.801	16.9	92.0	622
25-4-12	<61.01	2.80	0.425	662	<0.0039	15.6	0.0239	0.467	1.47	0.662	10.1	3.63	47.2	19.9	105	25.6	278	62.7	11401	2.86	98.8	302	666
25-4-13	<59.58	2.59	0.477	845	<0.0033	19.8	0.0269	0.542	1.94	0.910	12.9	4.76	60.8	25.2	131	32.3	347	74.0	11117	3.61	128	413	660

Tantahuatay igneous rock.
Sample T-352

352-17	<57.85	10.9	0.306	485	0.0089	11.1	0.146	2.28	3.59	1.13	13.4	3.77	43.2	15.8	77.4	16.9	167	36.5	8559	0.537	39.4	59.5	789
352-22	<55.05	11.9	0.302	550	0.0074	10.5	0.124	2.25	3.88	1.04	15.6	4.57	51.0	18.4	85.7	18.7	182	36.2	8712	0.346	44.2	50.9	797
352-24	<57.13	5.17	0.406	446	0.0480	7.06	0.0258	0.468	1.21	0.213	7.59	2.82	37.7	15.4	75.6	17.0	166	32.9	9969	76.4	40.4	173	718
352-29	<57.80	13.1	0.326	415	<0.0050	10.7	0.0591	1.12	2.27	0.739	9.91	3.08	35.5	13.7	67.6	15.6	157	33.3	8191	0.461	29.0	50.2	808
352-30	<59.92	5.64	0.603	1624	0.0153	65.2	0.214	3.59	6.25	1.85	30.2	9.76	123	50.0	262	63.6	688	144	10808	6.34	784	797	725
352-35	<53.53	9.69	0.236	315	<0.0034	8.47	0.0450	0.839	1.75	0.614	7.97	2.39	27.7	10.3	49.5	11.5	118	24.6	8157	0.395	27.6	45.0	777

Tantahuatay igneous rock.
Sample T-355

355-5-1	<133.73	7.42	0.309	237	<0.0090	8.97	0.0209	0.327	0.652	0.278	4.29	1.44	18.1	7.38	38.9	8.99	97.4	22.0	10328	0.581	30.7	61.0	751
355-5-2	<123.63	7.51	0.321	426	<0.0061	10.0	0.0546	0.983	2.07	0.676	8.60	2.97	35.6	13.7	67.6	15.7	168	36.2	9793	0.557	43.3	66.7	752
355-22-1	<126.25	8.92	0.317	236	<0.0069	6.76	0.0238	0.407	0.900	0.378	4.27	1.48	18.4	7.40	39.0	9.62	105	23.7	8918	0.678	40.4	67.8	769
355-22-2	<123.42	7.39	0.332	313	<0.0085	7.79	0.0375	0.651	1.13	0.378	5.46	2.01	24.4	9.82	52.0	12.3	138	30.9	9876	0.511	33.0	62.3	751
355-23	<132.31	9.43	0.309	384	<0.0084	10.3	0.0651	1.39	2.50	0.874	9.99	2.99	34.3	12.8	59.6	13.1	134	27.7	9331	0.306	29.4	43.8	774
355-74-1	<120.59	8.17	0.340	411	<0.0081	10.0	0.0788	1.60	2.87	0.934	11.2	3.25	36.1	13.4	64.6	14.4	153	31.7	9668	0.421	41.5	56.1	760
355-74-2	<126.82	8.42	0.361	414	<0.0058	9.70	0.0781	1.51	2.91	0.905	11.1	3.33	36.9	13.4	65.2	14.2	151	31.3	9635	0.560	39.8	54.3	763
355-89-1	<122.08	6.07	0.294	277	<0.0067	9.04	0.0363	0.711	1.29	0.536	5.77	1.87	22.1	8.47	43.5	10.7	123	27.4	10120	0.636	48.9	84.8	732
355-89-2	<116.92	7.07	0.325	291	<0.0063	9.28	0.0575	0.810	1.62	0.612	6.87	2.05	24.0	9.05	45.9	10.7	119	26.2	10155	0.499	48.6	79.5	746
355-92-1	<123.39	7.12	0.387	564	0.0093	13.8	0.0824	1.59	3.25	1.09	14.7	4.38	49.9	18.0	87.4	19.2	196	40.5	10674	0.747	71.5	87.0	747

355-92-2	<124.20	6.17	0.380	321	<0.0064	11.0	0.0252	0.503	1.19	0.390	5.92	2.02	25.1	9.87	51.8	12.1	131	28.8	10778	0.504	43.4	76.5	734
355-105-1	<120.17	4.50	0.325	166	<0.0053	6.16	0.0155	0.159	0.490	0.243	2.69	0.932	11.8	5.10	27.3	6.79	77.7	18.7	10194	0.754	36.7	87.1	706
355-105-2	<119.32	5.19	0.341	466	<0.0070	10.0	0.0284	0.557	1.21	0.551	6.45	2.42	32.2	14.1	76.9	19.1	211	51.7	9943	1.26	59.3	137	718
355-120	<116.28	4.56	0.676	1114	<0.0065	17.6	0.0255	0.493	1.69	0.543	11.4	5.14	78.0	34.2	190	47.2	513	108	12285	10.1	321	1370	707
355-122	<129.35	8.19	0.325	233	<0.0068	6.95	0.0227	0.380	0.794	0.343	4.18	1.40	17.9	7.28	37.7	9.10	103	23.7	9455	0.513	29.6	57.6	760
355-138	<117.38	3.85	0.330	265	<0.0073	10.0	0.0205	0.410	0.927	0.319	4.29	1.41	18.1	7.64	43.4	11.5	138	34.4	10445	0.745	56.2	121	692
355-142	<120.01	6.31	0.381	358	<0.0082	12.8	0.0291	0.550	1.18	0.387	6.54	2.31	27.5	11.1	57.1	13.5	146	31.3	10841	0.919	63.0	117	736
355-173	<118.71	9.25	0.250	302	<0.0079	10.2	0.0249	0.561	1.30	0.500	6.25	2.10	24.8	9.63	47.3	10.5	114	24.0	9412	0.339	22.5	36.6	772
355-201-1	<126.25	2.87	0.591	794	0.0087	32.7	0.0324	0.558	1.64	0.551	10.7	3.71	51.8	22.9	135	35.2	431	114	15539	14.8	895	1980	668
355-201-2	<124.23	3.63	0.585	660	<0.0077	18.3	0.0476	1.06	2.26	0.653	10.2	3.64	45.7	19.2	107	27.6	331	84.3	13421	5.70	346	752	687
355-214	<115.59	1.91	0.457	210	<0.0071	14.0	0.0112	0.232	0.482	0.242	2.44	0.848	11.4	5.56	34.0	9.68	130	36.6	14377	4.07	243	533	636
355-250	<123.90	4.34	0.491	767	<0.0085	43.1	0.0531	0.870	1.91	1.00	11.1	4.04	54.7	23.3	127	31.4	364	83.7	11801	4.77	366	643	702

**Tantahuatay igneous rock.
Sample T-356**

356-9-1	<126.40	8.80	0.264	365	<0.0069	10.6	0.0473	0.809	1.73	0.582	8.23	2.63	30.7	11.5	56.9	12.6	131	27.1	9591	0.246	27.8	47.8	767
356-9-2	<123.06	9.14	0.257	493	<0.0082	12.5	0.0790	1.75	3.81	1.20	14.2	4.13	46.7	16.4	75.3	16.1	159	32.1	9135	0.374	42.6	53.8	771
356-9-3	<125.74	9.53	0.348	428	<0.0084	12.7	0.0644	1.32	2.81	0.901	11.5	3.47	39.0	14.3	67.5	14.4	142	29.1	9292	0.422	38.3	52.1	775
356-10-1	<136.93	10.0	0.277	361	0.0077	10.9	0.0461	1.20	2.07	0.655	8.76	2.74	31.9	11.7	56.5	12.6	127	25.7	8962	0.431	29.1	44.3	780
356-10-2	<129.00	9.46	0.364	437	<0.0095	11.9	0.0678	1.28	2.64	0.993	11.7	3.57	40.0	14.5	67.5	14.7	146	29.6	9234	0.283	35.4	47.8	774
356-11-1	<121.23	3.66	0.425	272	<0.0076	9.19	0.0157	0.310	0.799	0.344	4.03	1.46	19.0	8.14	45.7	11.8	134	32.4	10816	0.915	50.1	106	688
356-11-2	<140.43	7.30	0.351	554	0.0167	9.40	0.1860	2.65	3.58	1.45	13.7	3.98	45.0	17.2	88.2	20.2	219	49.4	9485	0.741	83.0	107	749
356-19-1	<130.24	7.62	0.365	327	<0.0069	10.8	0.0308	0.536	1.35	0.447	6.31	2.06	25.7	10.2	51.6	12.0	122	26.7	9823	0.500	25.6	47.5	753
356-19-2	<124.72	7.39	0.395	419	<0.0077	14.4	0.0367	0.786	1.53	0.567	7.19	2.42	30.8	12.9	69.0	16.5	183	42.2	9845	1.21	75.8	156	751
356-18-1	<136.86	6.97	0.305	250	<0.0074	8.27	0.0315	0.420	0.984	0.416	4.39	1.47	18.4	7.41	40.3	9.70	111	25.8	9750	0.574	31.0	60.8	745
356-18-2	<140.41	8.07	0.407	214	<0.0083	7.47	0.0252	0.402	0.803	0.345	3.42	1.15	14.6	6.11	37.6	10.9	129	29.6	9603	0.343	27.3	47.2	759
356-29-1	<125.43	5.16	0.278	272	<0.0076	7.31	0.0152	0.348	0.844	0.390	4.39	1.45	19.1	8.08	46.1	11.2	126	30.8	10636	0.756	37.7	103	718
356-29-2	<130.82	3.61	0.355	299	0.0058	5.59	0.0305	0.427	1.01	0.424	4.77	1.69	21.6	9.00	49.9	12.2	139	33.9	9956	0.669	27.8	81.9	687
356-77	<121.80	3.14	0.354	299	<0.0069	8.88	0.0156	0.345	0.725	0.380	4.46	1.64	21.3	8.81	48.8	12.1	136	32.6	10735	1.26	58.5	153	675
356-95-1	<133.70	8.27	0.307	543	<0.0091	9.38	0.125	2.15	3.70	1.24	14.7	4.34	49.0	17.9	85.0	17.9	178	37.8	9095	0.780	52.3	74.3	761

356-95-2	<134.71	8.88	0.292	268	<0.0084	6.99	0.0201	0.284	0.973	0.412	5.04	1.72	20.6	8.40	43.4	9.88	107	23.5	9038	0.449	26.0	54.4	768
356-135	<123.97	4.09	0.307	331	<0.0081	7.93	0.0274	0.426	0.863	0.420	5.04	1.77	22.4	9.74	54.6	13.4	151	36.9	10062	0.900	45.4	118	697
356-155-1	<116.51	5.19	0.363	274	<0.0086	12.5	0.0200	0.455	1.11	0.375	5.16	1.76	21.1	8.20	43.4	9.97	109	25.4	11104	1.30	65.9	120	718
356-155-2	<116.13	4.20	0.432	375	0.0072	11.5	0.0346	0.606	1.49	0.483	7.32	2.43	29.2	11.4	60.6	14.2	155	35.7	11005	0.910	56.4	108	700
356-156-1	<117.89	8.61	0.330	493	<0.0065	12.5	0.0874	1.82	3.43	1.18	14.3	4.22	46.0	16.5	77.3	16.7	168	33.7	9626	0.480	45.5	57.0	765
356-156-2	<117.52	9.34	0.346	524	<0.0083	12.7	0.0924	2.20	3.88	1.29	15.4	4.42	47.8	16.8	81.0	17.1	169	34.3	9576	0.390	45.4	55.5	773

**Tantahuatay igneous rock.
Sample T-357**

357-2	<159.25	7.20	0.409	580	<0.0083	13.3	0.103	2.01	3.65	1.17	14.9	4.35	49.9	18.1	88.9	19.8	210	45.1	10563	2.26	68.0	123	748
357-3	<146.17	9.81	0.274	374	<0.0079	10.5	0.0504	0.780	1.63	0.603	8.15	2.50	30.8	12.1	59.6	13.8	146	31.9	9325	0.392	35.8	62.6	778
357-11	<142.33	7.77	0.330	636	<0.0069	14.4	0.115	2.47	4.89	1.57	19.0	5.34	59.2	21.0	95.8	21.0	215	44.2	10095	0.620	69.5	79.5	755
357-44	<144.08	2.72	0.451	190	<0.0086	10.5	0.0104	0.220	0.490	0.180	2.73	0.905	12.7	5.46	32.2	8.27	102	27.6	13128	2.96	135	349	664
357-64	<144.61	3.37	0.311	132	<0.0066	9.93	0.0115	0.251	0.413	0.193	1.89	0.659	8.97	3.95	22.8	5.75	73.4	18.1	11718	0.987	47.3	125	681

**Tantahuatay igneous rock.
Sample T-358**

358-2	<133.38	4.48	0.325	430	<0.0049	8.38	0.0290	0.484	1.25	0.570	6.42	2.30	31.5	13.1	69.9	16.9	190	45.3	9801	2.76	55.2	122	705
358-5	<103.04	4.85	0.327	342	<0.0055	6.61	0.0149	0.389	0.978	0.481	5.18	1.90	24.7	10.5	57.4	14.3	163	39.6	10304	0.764	33.4	90.4	712
358-11	<104.92	6.47	0.425	723	0.0125	12.1	0.0939	1.66	2.79	1.29	12.9	4.28	53.9	21.4	115	27.4	303	69.9	9651	1.66	90.7	181	738
358-23	<134.51	5.03	0.343	492	<0.0089	10.1	0.0337	0.547	1.27	0.636	7.08	2.66	35.5	15.1	82.3	20.4	228	56.9	9498	1.26	58.4	143	715
358-32-1	<138.21	3.09	0.393	355	0.0182	8.83	0.0267	0.404	1.04	0.423	5.47	1.87	24.7	10.6	58.6	14.6	171	41.2	10595	1.16	35.2	122	674
358-32-2	<130.60	2.90	0.442	538	0.0075	13.5	0.0315	0.565	1.49	0.656	7.67	2.86	38.2	15.9	88.9	22.3	256	60.9	10521	1.77	55.5	192	669
358-32-3	<133.08	3.27	0.475	578	<0.0081	14.4	0.0386	0.571	1.45	0.655	8.50	2.98	41.0	17.7	96.4	23.7	273	65.4	10469	1.90	59.0	205	679

**Tantahuatay igneous rock.
Sample CNG-1**

CNG-1	<61.15	3.56	0.314	168	0.0031	6.06	0.00740	0.178	0.474	0.245	2.76	0.960	12.6	5.13	27.4	7.34	85.0	18.7	10307	0.0370	24.5	76.3	686
CNG-2	<58.60	3.60	0.367	446	<0.0033	12.8	0.0220	0.429	1.22	0.553	7.1	2.51	31.9	12.9	70.7	17.9	202	44.9	10624	0.136	95.5	204	687
CNG-3-1	<58.64	3.83	0.371	305	<0.0038	7.38	0.0152	0.298	0.656	0.404	4.38	1.64	20.9	9.14	49.9	12.7	143	35.1	11327	0.0290	30.8	84.5	692
CNG-3-2	<58.58	4.35	0.312	313	0.0030	7.25	0.0156	0.297	0.713	0.383	4.59	1.69	22.1	9.58	50.5	13.1	152	35.3	10774	0.0410	30.9	87.3	703

CNG-4	<53.50	3.54	0.313	228	<0.0022	7.57	0.0132	0.261	0.656	0.288	3.17	1.245	16.3	6.85	37.2	9.62	111	25.3	11146	0.0370	33.7	101	685
CNG-5	<61.69	4.14	0.382	401	0.0037	9.64	0.0219	0.405	1.15	0.532	5.96	2.13	29.1	12.4	65.5	16.7	192	43.2	10552	0.0470	53.5	131	698
CNG-6	<54.24	4.93	0.301	338	<0.0028	7.22	0.0222	0.408	1.021	0.465	5.26	1.88	25.2	10.5	56.3	14.6	172	37.7	9333	0.0590	35.4	93.2	713
CNG-7	<55.41	4.15	0.340	339	<0.0042	7.38	0.0253	0.343	0.890	0.405	5.44	1.8	24.3	10.5	56.2	14.3	171	37.8	9749	0.0400	36.3	94.5	699
CNG-8	<57.83	3.02	0.323	404	<0.0032	8.66	0.0201	0.322	0.907	0.455	5.53	2.01	26.7	11.9	65.4	16.3	186	45.0	11057	0.0560	40.0	127	672
CNG-9	<52.90	4.65	0.310	221	0.0050	6.76	0.0153	0.341	0.717	0.349	3.84	1.313	17.3	6.88	37.4	9.91	123	23.7	9598	0.0660	31.9	87.0	708
CNG-10	<60.69	4.80	0.333	409	<0.0043	7.69	0.0430	0.818	1.51	0.658	7.36	2.41	30.8	12.3	65.2	16.5	183	41.6	9915	0.0560	44.7	99.5	711
CNG-11	<59.17	3.74	0.357	279	0.0148	9.90	0.0239	0.313	0.784	0.382	4.66	1.66	20.6	8.55	44.9	11.2	127	28.1	10699	0.0660	83.3	148	690
CNG-12	<58.16	4.26	0.297	394	<0.0036	7.00	0.0491	0.892	1.63	0.669	7.75	2.4	31.1	12.1	63.8	15.6	176	40.0	9917	0.0330	41.8	89.7	701
CNG-13	<59.35	4.63	0.289	236	<0.0037	6.70	0.0186	0.306	0.644	0.281	3.62	1.285	16.6	7.07	37.8	9.52	106	25.4	10465	<0.029	39.0	94.8	708
CNG-14	<58.33	4.17	0.305	297	<0.00214	7.31	0.0184	0.327	0.838	0.403	4.81	1.71	22.5	9.26	50.6	12.9	155	33.1	9998	0.0680	34.7	96.2	699
CNG-15	<56.32	3.70	0.316	235	<0.0039	7.27	0.0118	0.275	0.851	0.317	3.74	1.36	17.6	7.26	39.4	10.1	118	26.6	10256	<0.026	33.4	96.7	689
CNG-16	<53.41	3.99	0.333	319	<0.0030	6.96	0.0211	0.379	0.818	0.443	4.86	1.64	22.0	9.4	50.3	13.0	151	35.3	9425	<0.026	31.1	84.1	695
CNG-17	<58.44	4.31	0.446	439	<0.0030	9.34	0.0196	0.525	1.04	0.565	6.38	2.28	31.1	13.3	72.2	17.9	203	47.4	10761	0.0270	43.7	118	702

**AntaKori porphyry PK.
Sample Anta-PK**

A2-2	<74.07	3.72	0.474	655	<0.0043	12.0	0.0217	0.412	1.22	0.640	8.27	3.09	42.9	18.7	105	27.1	315	80.9	10473	3.44	87.2	382	689
A2-3	<76.62	3.90	0.366	298	<0.0043	7.10	0.0176	0.319	0.762	0.355	4.27	1.57	20.7	8.88	48.7	12.2	139	33.5	9812	0.835	30.7	78.3	693
A2-13	<68.29	4.40	0.314	179	<0.0037	5.86	0.0083	0.243	0.522	0.241	2.83	0.969	13.0	5.43	29.2	7.45	84.8	19.7	9851	0.617	27.2	74.1	704
A2-8	<75.22	4.61	0.318	394	<0.0041	8.09	0.0215	0.435	0.947	0.476	5.80	2.03	27.6	11.6	63.8	16.0	177	43.1	9225	0.964	44.9	113	708
A2-29	<74.71	3.33	0.342	220	<0.0050	6.96	0.0114	0.222	0.676	0.277	3.35	1.14	15.5	6.39	35.4	8.95	101	24.6	10124	1.06	32.9	106	680
A2-32	<71.86	2.94	0.373	289	<0.0039	5.66	0.0117	0.348	0.686	0.358	4.19	1.55	20.8	8.60	47.5	12.1	137	33.6	9596	0.566	26.4	77.3	670
A2-23	<75.74	3.85	0.318	254	0.0075	6.30	0.0145	0.246	0.601	0.289	3.74	1.30	17.9	7.50	41.1	10.4	118	28.5	10062	0.651	25.2	67.4	692
A2-25	<80.57	4.27	0.423	401	0.0169	12.5	0.0302	0.462	1.23	0.506	6.41	2.21	29.6	12.3	65.2	15.6	174	40.9	10083	1.73	111	188	701
A2-34	<77.65	3.32	0.390	353	<0.0045	8.33	0.0224	0.376	1.04	0.464	5.34	1.85	24.8	10.4	57.2	14.6	164	39.0	10585	0.997	37.9	111	680
A2-26	<74.30	4.80	0.369	306	0.0249	6.51	0.0293	0.410	0.859	0.413	4.90	1.66	21.7	9.34	50.6	12.8	144	34.9	9677	0.727	32.8	83.1	711
A2-36	<74.75	3.20	0.401	341	<0.0040	8.10	0.0160	0.344	0.920	0.387	4.98	1.77	23.8	10.2	56.9	14.4	164	39.6	10371	0.912	37.4	107	677
A2-28	<76.86	4.66	0.372	431	<0.0046	8.88	0.0210	0.571	1.21	0.612	6.80	2.30	30.9	13.0	70.8	17.9	202	48.1	9481	0.970	46.7	119	709
A2-48	<72.63	4.84	0.374	501	0.0044	10.2	0.0484	1.06	1.85	0.794	9.07	2.89	37.4	15.5	81.6	20.0	224	52.2	9555	1.16	61.6	138	712

A2-42	<77.73	4.20	0.361	406	<0.0050	11.3	0.0216	0.413	0.982	0.460	6.14	2.17	28.7	12.4	68.1	17.2	192	45.8	9651	1.20	54.7	136	700
A2-60	<70.20	3.42	0.389	457	<0.0039	11.4	0.0207	0.419	1.14	0.483	6.57	2.33	32.0	13.7	77.4	19.4	219	52.1	9970	1.10	50.5	137	682
A2-45	<76.17	4.20	0.323	208	<0.0047	6.86	0.0155	0.288	0.603	0.321	3.30	1.17	15.1	6.28	33.3	8.24	92.2	21.6	9585	0.755	50.3	100	700
A2-54	<72.18	4.12	0.350	319	0.0048	8.07	0.0191	0.403	0.864	0.399	5.00	1.66	22.6	9.60	52.5	13.1	151	36.0	9882	0.804	34.7	90.3	698
A2-64	<83.71	3.81	0.306	341	<0.0054	7.18	0.0184	0.351	0.929	0.413	5.03	1.75	23.7	10.2	56.1	13.9	154	38.7	9635	0.788	34.6	90.7	691
A2-29	<76.62	5.11	0.335	467	0.0055	9.36	0.0285	0.538	1.30	0.599	6.87	2.43	32.4	14.1	76.0	19.0	209	50.8	9489	1.20	49.0	130	717
A2-12	<78.19	2.66	0.413	346	<0.0060	6.79	0.0197	0.291	0.922	0.446	5.11	1.76	24.2	10.3	57.0	14.3	167	39.5	10372	0.862	33.1	103	662

**AntaKori porphyry PF.
Sample Anta-PF**

A4-3	<61.51	3.84	0.453	510	0.0053	42.6	0.0799	1.40	2.08	0.821	9.23	2.80	34.7	14.4	78.5	20.1	235	57.1	11989	13.5	1690	1711	692
A4-6	<66.01	2.64	0.459	309	<0.0039	15.9	0.0088	0.315	0.831	0.350	4.51	1.51	20.5	8.88	50.1	13.2	152	37.4	11982	1.38	71.5	193	661
A4-11	<58.62	1.87	0.472	264	0.0047	11.1	0.0105	0.291	0.530	0.282	3.42	1.22	16.9	7.49	43.3	11.6	139	37.2	13355	2.33	95.7	310	635
A4-13	<59.51	5.19	0.399	231	0.1390	15.5	0.0591	0.506	0.896	0.353	4.33	1.37	17.2	6.91	36.9	9.13	102	23.0	10870	1.30	85.2	190	718
A4-18	<63.37	3.99	0.533	602	0.0233	20.8	0.0862	1.58	2.96	1.04	13.1	4.06	48.2	18.7	95.7	22.6	239	54.9	11620	1.99	167	270	695
A4-22	<64.52	3.96	0.350	240	0.0053	13.1	0.0162	0.367	0.728	0.309	3.95	1.33	17.1	7.15	38.5	9.50	105	24.5	11273	1.49	89.8	222	695
A4-27	<60.78	4.12	0.305	190	<0.0037	10.2	0.0117	0.229	0.529	0.214	3.03	1.03	13.5	5.69	30.5	7.64	86.8	19.8	10805	0.790	43.5	123	698
A4-29	<62.78	2.47	0.469	438	0.0635	13.2	0.0603	0.908	1.68	0.638	7.69	2.45	31.2	12.9	71.2	17.8	210	53.8	12827	2.55	145	365	656
A4-36	<61.01	6.92	0.317	189	<0.0037	8.16	0.0202	0.348	0.765	0.270	3.39	1.14	14.1	5.75	30.5	7.48	81.2	18.3	9983	0.563	30.8	72.0	744
4A-40	<58.88	3.86	0.370	222	<0.0037	11.9	0.0205	0.355	0.772	0.309	3.84	1.27	16.6	6.84	35.6	8.82	98.6	21.7	10868	0.904	54.8	126	692
4A-53	<59.74	3.42	0.394	429	0.0041	17.4	0.0255	0.609	1.54	0.591	7.64	2.55	32.7	13.4	70.2	16.9	178	40.8	10752	1.76	134	238	682
4A-54	<58.65	3.84	0.335	326	<0.0035	16.4	0.0247	0.481	1.18	0.410	5.93	1.91	24.2	9.96	52.0	12.8	138	31.0	10804	1.64	99.7	210	692
4A-66	<55.46	4.74	0.367	300	<0.0033	14.6	0.0246	0.434	1.16	0.418	5.43	1.82	22.9	9.11	47.1	11.5	124	28.0	10697	1.15	67.0	164	710
4-A92	<56.61	9.17	0.339	518	0.0044	7.58	0.0474	0.801	1.37	0.679	6.60	2.36	33.4	15.1	85.8	20.9	227	54.2	7902	0.838	48.5	101	771
4A-116	<57.21	6.18	0.374	199	0.0143	9.47	0.0168	0.305	0.702	0.267	3.44	1.14	14.8	6.22	31.8	8.15	91.5	20.9	11081	0.932	48.5	118	734

Cerro Jesus. Sample CJ

CJ3	<61.36	1.54	0.489	647	0.0136	4.38	0.0420	0.860	2.21	1.24	12.0	4.22	51.5	19.8	97.4	23.4	253	48.1	11138	1.78	22.8	182	621
CJ5	<57.79	2.63	0.593	892	<0.0028	7.25	0.0166	0.424	1.46	0.940	11.9	4.65	65.2	27.4	143	35.6	400	80.7	10684	2.88	38.3	300	661
CJ6	<55.14	5.12	0.536	690	0.0085	17.1	0.0553	1.04	2.16	1.13	13.1	4.37	56.0	21.5	107	25.3	282	55.3	9003	1.76	76.5	147	717

CJ12	<53.88	2.97	0.635	940	<0.0022	12.8	0.0263	0.710	2.19	1.32	14.0	5.29	71.4	27.8	147	37.0	432	76.6	9061	2.76	56.9	305	671
CJ15	<56.69	3.81	0.684	1241	0.0171	11.0	0.0234	0.529	1.93	1.28	16.3	6.64	95.0	40.3	208	51.2	544	102	10196	3.95	52.1	425	691
CJ24	<62.15	3.71	0.532	565	0.0037	8.79	0.0370	0.750	1.80	0.870	10.9	3.62	48.0	18.1	93.0	21.4	227	44.6	8821	3.62	61.0	167	689
CJ18	<53.38	5.49	0.483	767	0.0041	21.0	0.0539	1.35	2.94	1.51	16.6	5.38	66.4	23.3	119	27.5	298	55.9	7887	1.92	98.6	205	723

**Cerro Choro Blanco.
Sample CB**

CHCB45	73.2	4.12	0.634	836	0.0236	20.3	0.0324	0.850	2.15	1.01	12.3	4.65	62.0	24.9	131	33.1	381	76.3	9763	3.66	140	413	698
CHCB33	<61.33	3.42	0.553	592	<0.0035	15.0	0.0286	0.500	1.64	0.797	9.57	3.26	43.6	18.1	95.4	25.4	305	58.9	9221	2.40	74.1	271	682
CHCB43	<63.53	3.98	0.530	614	<0.0030	15.8	0.0483	1.03	2.05	0.924	10.8	3.57	45.9	18.7	97.2	25.2	292	58.5	9587	2.16	81.6	252	695
CHCB59	<61.16	2.97	0.571	748	0.0281	17.9	0.0454	0.910	2.01	0.980	11.6	4.16	54.2	22.3	117	31.0	365	69.4	9374	2.98	92.2	331	671
CHCB60	<60.37	3.37	0.583	656	0.0230	19.9	0.0266	0.611	1.69	0.769	9.90	3.87	48.6	19.5	104	26.5	307	61.6	9583	3.45	140	394	681
CHCB64	<61.89	3.11	0.455	453	<0.0030	17.1	0.0315	0.624	1.30	0.637	7.55	2.68	34.2	13.7	71.9	18.6	209	42.5	9677	2.28	109	261	674
CHCB67	69.6	3.06	0.535	841	0.0066	20.4	0.0318	0.750	2.00	1.01	12.5	4.60	61.1	25.3	136	35.2	399	79.5	9768	3.74	121	417	673
CHCB69	<55.41	3.47	0.552	766	<0.00197	20.8	0.0347	0.758	1.81	0.942	11.5	4.22	55.1	22.9	120	31.0	347	72.3	9202	3.58	147	403	683
CHCB73	<61.02	4.96	0.511	451	0.0044	10.3	0.0263	0.671	1.37	0.622	7.17	2.61	33.7	13.6	75.3	19.4	230	44.9	8536	1.21	48.1	147	714
CHCB82	<56.84	4.13	0.490	608	0.0034	16.1	0.0221	0.664	1.68	0.768	8.83	3.30	44.2	18.3	99.2	26.4	303	62.1	9238	2.21	61.0	237	698
CHCB85	<61.86	4.56	0.633	1024	0.0109	30.6	0.0563	1.20	2.78	1.31	16.8	6.11	79.3	31.6	161	40.7	461	86.6	9483	4.39	253	534	707
CHCB97	<58.35	3.46	0.511	551	<0.0030	14.3	0.0450	0.870	1.75	0.836	9.34	3.22	43.0	17.3	89.6	24.0	282	55.8	8935	2.22	67.1	238	683
CHCB103	<55.25	3.18	0.542	497	0.0050	16.3	0.0263	0.609	1.44	0.662	8.01	2.80	36.5	15.5	78.4	21.3	249	48.1	8707	2.54	104	307	676
CHCB105	<54.70	4.18	0.530	761	0.0493	17.4	0.0530	0.787	2.33	1.03	14.1	4.94	61.2	26.4	127	33.3	343	59.1	7630	2.28	105	253	699
CHCB106	<59.22	2.12	0.470	441	0.0140	9.67	0.0191	0.369	1.05	0.520	6.01	2.40	31.0	14.0	70.4	19.0	221	45.5	9910	1.77	43.2	196	644
CHCB112	<54.14	3.05	0.543	725	0.0038	16.5	0.0236	0.624	1.69	0.939	10.7	3.94	51.3	21.1	112	29.7	350	69.6	9274	2.71	79.5	307	673

**Cerro Caballerisa. Sample
CAB**

CAB1	<53.61	1.97	0.697	886	0.1284	17.3	0.0729	0.862	1.99	0.938	12.4	4.81	64.1	27.1	145	36.1	421	80.7	10259	2.53	69.5	295	639
CAB12	<51.16		0.538	481	0.0402	14.0	0.0407	0.618	1.29	0.643	7.45	2.64	34.8	14.6	78.2	19.4	227	48.4	9888	1.52	67.9	169	
CAB23	<50.88	2.86	0.594	776	0.0148	18.1	0.0328	0.693	1.86	0.912	11.4	4.24	55.8	23.8	125	31.0	357	72.1	10467	3.84	129	433	668
CAB25	<44.01	3.66	0.489	400	0.0581	11.6	0.0500	0.833	1.61	0.712	7.13	2.46	30.4	12.4	63.8	17.3	224	38.2	8084	1.64	55.4	192	688

CAB30	<50.33	2.67	0.603	650	0.0033	12.5	0.0250	0.584	1.56	0.765	9.84	3.64	47.2	20.3	104	27.0	302	63.7	10014	2.30	75.0	261	662
CAB32	<51.40	3.56	0.697	1089	<0.00122	31.4	0.0390	0.855	2.67	1.28	16.3	5.84	75.6	32.1	171	43.8	511	104	9746	5.47	299	615	686
CAB47	<56.83	4.35	0.697	517	0.1450	11.3	0.0823	0.841	1.53	0.631	7.92	2.86	36.5	15.7	83.9	21.2	234	55.2	9658	1.77	66.5	178	703
CAB58	<50.62	2.43	0.544	639	0.0127	20.3	0.0267	0.730	1.79	0.842	10.2	3.66	48.4	19.9	106	26.0	296	59.8	9690	3.46	155	386	655
CAB59	<48.58		0.384	436	0.0019	13.9	0.0259	0.527	1.26	0.548	7.18	2.51	31.7	13.7	69.0	18.4	204	43.6	8894	2.09	99.5	220	
CAB66	<52.08	3.38	0.628	832	<0.00189	18.7	0.0369	0.741	2.17	1.00	13.0	4.66	63.1	26.5	134	35.7	377	82.1	9996	3.85	126	405	681
CAB76	<48.58	3.81	0.596	680	0.0522	20.4	0.0488	0.991	2.37	0.939	13.3	4.12	55.4	22.1	112	30.1	306	71.5	8362	3.41	152	327	691
CAB85	<52.10	2.98	0.588	801	<0.0029	18.8	0.0226	0.631	1.87	0.934	12.3	4.29	65.2	24.5	148	35.3	416	85.8	9250	3.14	73.9	366	671
CAB94	<47.82	3.22	0.556	645	0.0036	15.8	0.0421	0.633	1.62	0.772	8.78	3.69	40.5	21.1	91.6	26.8	284	56.6	9663	2.10	115	236	677
CAB105	<47.57	3.37	0.568	682	0.0022	15.7	0.0225	0.591	1.78	0.739	10.8	3.65	54.6	22.3	116	34.1	325	79.4	8798	2.94	66.8	277	681
CAB116	<50.59	2.95	0.532	782	0.0051	13.4	0.0214	0.632	1.90	0.778	11.3	4.33	57.3	24.3	126	31.6	345	71.9	9499	2.61	76.3	286	670

**Cerro Las Gordas. Sample
LG**

SG3	<64.86	4.91	0.526	655	<0.0026	18.7	0.0340	0.810	1.66	0.750	9.89	3.60	47.2	19.7	108	27.4	341	63.1	8925	2.26	84.7	277	713
SG18	<63.39	1.92	0.486	528	<0.0022	12.9	0.0181	0.509	1.43	0.690	8.92	3.28	39.4	16.6	81.3	22.6	249	46.1	9658	3.50	116	370	637
SG41	<54.31	4.61	0.493	302	<0.0020	8.31	0.0333	0.640	1.33	0.660	6.29	1.93	25.9	9.30	49.4	13.2	159	27.7	7318	0.870	34.4	114	708
SG43	<65.22	3.38	0.570	747	0.0472	15.2	0.0630	1.00	2.44	1.12	11.8	4.47	52.3	22.9	112	29.3	341	63.1	9304	2.86	95.3	323	681
SG47	<72.34	4.27	0.566	527	0.0045	16.9	0.0332	0.720	1.43	0.720	8.82	3.04	41.0	15.9	89.3	22.1	279	50.7	8795	2.31	91.8	284	701
SG54	<68.31	2.93	0.525	529	0.0255	12.1	0.0531	0.890	1.97	0.780	8.71	3.18	38.0	15.6	82.0	21.3	248	47.6	8914	1.58	61.5	189	670
SG59	<63.08	3.32	0.546	689	<0.0021	19.4	0.0288	0.760	1.86	1.01	10.8	4.02	48.6	21.0	105	27.6	334	61.0	9259	3.13	124	366	680
SG60	<69.62	4.01	0.535	406	0.0558	11.1	0.0469	0.700	1.41	0.690	7.17	2.40	32.5	12.7	70.8	18.0	234	44.5	8922	1.62	53.8	182	696
SG71	<67.24	4.34	0.506	444	0.0042	10.8	0.0410	0.990	1.69	0.710	8.28	2.62	36.3	12.7	77.5	17.7	218	43.4	8811	1.38	50.0	162	702
SG74	<74.38	4.73	0.653	651	0.0980	16.9	0.0590	1.02	1.68	0.880	8.82	3.61	45.1	18.2	102	23.2	332	56.6	11006	1.99	85.2	248	710
SG78	<73.45	4.88	0.506	566	0.0046	14.7	0.0408	1.12	1.80	0.860	9.42	3.20	43.9	16.6	96.1	22.0	295	54.4	8889	1.82	66.0	221	713
SG90	<60.69	3.84	0.435	436	0.0093	13.9	0.0285	0.600	1.31	0.610	7.18	2.43	34.6	13.3	72.6	18.6	242	44.9	8012	1.64	46.8	187	692
SG99	<52.49	3.90	0.566	488	0.0317	13.4	0.0402	0.610	1.45	0.610	6.76	2.70	32.9	14.0	73.4	20.2	287	42.5	8622	1.81	57.1	226	693
SG100	<72.18	2.38	0.550	956	0.0069	16.7	0.0900	2.27	4.23	2.12	20.0	6.41	81.0	27.7	153	33.1	434	69.1	9999	3.05	103	398	653
SG105	<55.63	2.19	0.505	504	0.0212	8.79	0.0250	0.360	1.11	0.580	6.62	2.80	32.9	16.1	74.0	22.6	253	48.0	9289	1.99	47.2	207	647

**Sill Coymolache. Sample
CD**

CD13	<49.96	3.74	0.400	240	0.0075	6.93	0.0155	0.350	0.701	0.339	3.82	1.32	17.8	7.23	39.5	9.97	116	25.7	9059	0.866	40.7	93.8	690
CD18	<52.97	3.58	0.398	285	<0.00256	7.44	0.0151	0.323	0.886	0.420	4.58	1.58	21.8	8.74	48.8	12.7	157	31.7	8934	0.798	27.7	98.9	686
CD24	<51.92	4.95	0.400	333	0.0073	6.85	0.0214	0.452	1.05	0.464	5.21	1.86	24.0	10.3	56.0	14.7	176	37.3	8373	0.783	33.5	90.8	714
CD27	<54.44	4.59	0.411	381	0.0028	7.23	0.0283	0.650	1.20	0.611	6.26	2.21	28.3	11.5	62.5	15.5	186	39.4	8939	0.863	44.0	96.7	707
CD37	<53.51	4.49	0.470	527	0.0052	14.2	0.0372	0.793	1.58	0.713	8.36	3.02	39.5	16.2	86.2	21.2	243	51.8	8855	1.66	115	198	705
CD38	<56.64	3.97	0.401	319	0.0036	7.64	0.0180	0.361	0.775	0.371	4.58	1.64	22.7	9.60	53.9	13.8	160	36.0	9204	0.861	36.8	95.6	695
CD51	<56.64	3.51	0.391	265	0.0163	6.53	0.0151	0.353	0.750	0.333	3.82	1.42	18.9	7.94	44.0	11.5	136	30.7	9389	0.847	31.7	89.8	684
CD68	<57.13	4.60	0.323	188	<0.00156	5.92	0.0109	0.261	0.599	0.270	3.16	1.08	14.0	5.50	31.0	7.70	91.1	19.5	9053	0.767	32.1	84.5	707
CD80	<54.83	4.14	0.341	182	<0.00210	7.26	0.0100	0.244	0.531	0.300	3.03	0.979	13.5	5.42	30.4	7.61	93.8	18.9	8826	0.879	37.7	99.9	698
CD84	<54.09	3.89	0.458	423	0.0181	10.2	0.0369	0.746	1.33	0.614	7.16	2.42	32.8	12.7	71.6	17.6	206	43.4	8881	1.26	53.5	147	693
CD103	<55.67	3.83	0.431	457	0.0034	9.27	0.0298	0.663	1.31	0.638	6.93	2.46	34.1	14.3	76.3	19.7	229	49.4	9439	1.35	50.5	152	692
CD104	<53.63	4.15	0.476	341	0.0210	6.57	0.0487	0.699	1.16	0.503	5.95	2.08	25.8	10.7	55.9	14.4	164	36.2	8885	0.824	40.5	88.8	699
CD119	<42.62	3.96	0.410	432	0.0158	8.60	0.0388	0.741	1.44	0.602	6.44	2.58	29.8	13.3	64.9	17.7	217	41.1	8192	1.08	56.9	137	695
CD121	<59.36	4.83	0.317	374	<0.0024	12.9	0.0143	0.656	1.07	0.670	6.46	1.99	34.2	10.4	73.9	15.9	268	38.7	8200	1.33	39.7	176	712
CD125	<51.64	5.07	0.458	375	0.0043	10.3	0.0313	0.643	1.28	0.557	7.09	2.21	31.5	12.0	65.8	16.4	180	41.5	7932	1.54	80.9	167	716

**Sill Coymolache. Sample
161025-5**

I2-9	<74.70	3.84	0.284	349	0.0163	7.66	0.0505	0.545	1.20	0.531	5.65	1.98	24.6	10.2	55.7	13.7	155	35.9	10872	0.807	37.8	87.6	692
I2-10	<68.22	8.13	0.230	226	0.0231	5.15	0.0351	0.558	1.18	0.549	4.74	1.55	17.8	6.80	34.4	8.67	98.2	21.2	8199	0.318	17.4	32.2	760
I2-11	<72.11	8.48	0.357	837	0.0147	8.84	0.153	2.59	5.01	1.60	21.6	6.65	77.3	28.0	128	27.9	271	51.9	9255	0.446	39.7	55.9	764
I2-12	<67.18	3.07	0.349	383	0.0055	9.04	0.0218	0.347	1.01	0.442	5.60	2.04	26.6	11.4	62.4	16.2	185	42.1	11175	1.02	40.2	123	673
I2-16	<84.09	3.38	0.347	362	0.0204	12.0	0.0496	0.413	0.911	0.413	5.37	1.97	25.9	10.8	60.1	15.1	174	39.3	12267	0.813	58.7	97.5	681
I2-22	<71.88	3.70	0.325	398	0.0298	7.95	0.0180	0.525	1.14	0.492	5.95	2.18	28.3	12.0	64.6	16.6	194	43.8	10717	0.990	39.3	103	689
I2-23	<71.18	3.30	0.347	356	0.0086	8.62	0.0408	0.292	0.913	0.442	5.29	1.87	25.8	10.6	59.0	15.4	181	39.8	11066	0.833	35.8	95.9	679
I2-28	<71.89	5.35	0.356	293	0.0127	6.30	0.0643	0.474	0.949	0.462	5.01	1.69	20.9	8.48	46.2	11.7	134	31.3	10136	0.536	28.9	65.6	721
I2-29	<69.33	4.38	0.293	309	<0.0030	7.01	0.0289	0.653	1.18	0.479	5.65	1.86	23.3	9.39	49.6	12.8	142	31.2	10354	0.684	35.7	84.3	703
I2-35	<69.99	3.98	0.318	321	<0.0043	5.81	0.0169	0.380	0.890	0.401	4.80	1.75	21.9	9.56	52.4	13.3	152	35.5	10132	0.651	29.0	75.4	695

I2-37	<68.51	3.99	0.328	383	0.0051	9.12	0.0245	0.419	0.952	0.472	5.56	1.99	27.6	11.4	62.7	16.2	193	40.8	9852	0.987	43.2	111	695
I2-39-1	<71.32	4.63	0.371	378	0.0288	8.36	0.0526	0.426	1.20	0.547	6.08	2.08	27.6	11.7	63.5	16.1	184	40.8	10648	0.866	41.6	99.4	708
I2-39-2	<68.71	4.46	0.336	363	0.0145	7.57	0.0403	0.529	1.24	0.533	6.40	2.20	28.5	11.3	60.7	15.4	184	40.3	10461	0.718	38.0	92.1	705
I2-40	<72.91	3.67	0.395	413	0.0210	9.14	0.0312	0.405	1.17	0.525	6.22	2.13	28.3	12.1	67.1	17.0	196	44.8	10687	1.05	41.2	106	688
I2-54	<73.31	4.02	0.272	291	0.0053	7.07	0.0170	0.312	0.692	0.392	4.56	1.59	20.7	8.69	47.6	11.9	140	31.9	10586	0.758	33.5	82.9	696
I2-60	<65.15	5.82	0.272	283	<0.0028	5.86	0.0182	0.462	0.900	0.428	5.05	1.59	20.5	8.45	44.8	11.4	132	30.1	9335	0.511	29.8	66.6	728
I2-61	<67.88	6.82	0.235	339	0.0039	6.17	0.0802	1.13	1.66	0.794	7.07	2.20	26.3	10.2	53.4	13.5	152	32.5	8339	0.450	28.8	49.0	743
I2-105	<72.76	3.45	0.249	250	<0.0023	7.20	0.0123	0.296	0.666	0.310	3.70	1.33	17.8	7.23	39.5	10.2	118	26.5	10812	0.870	40.9	103	683

San Miguel. Sample SCO-1

I4-3	<65.34	3.13	0.403	719	<0.0039	15.9	0.0187	0.496	1.52	0.782	10.4	3.99	51.4	22.0	117	28.5	317	69.3	11993	2.82	98.0	307	675
I4-4	<64.74	3.35	0.399	612	0.0057	19.0	0.0281	0.718	1.88	0.763	10.2	3.51	42.8	17.6	93.2	22.6	238	54.7	11058	2.89	194	349	681
I4-11	<64.09	2.61	0.429	741	<0.0032	14.8	0.0201	0.542	1.48	0.698	10.0	3.57	49.6	21.0	116	29.3	325	75.5	11596	2.25	72.0	246	660
I4-19	<63.42	3.10	0.339	457	0.0027	14.7	0.0253	0.483	1.29	0.567	7.50	2.72	33.4	13.9	73.5	18.0	192	44.7	11662	2.21	130	254	674
I4-35	<65.50	3.16	0.390	770	<0.0026	19.9	0.0286	0.815	1.69	1.04	12.2	4.39	56.7	23.2	117	28.6	298	68.1	11224	3.09	134	345	676
I4-43	<66.71	3.38	0.387	810	<0.0030	16.5	0.0584	0.980	2.23	0.895	12.0	4.14	54.4	23.0	124	30.5	343	78.7	10921	1.98	83.6	236	681
I12-1	<103.26	2.56	0.366	611	0.0165	13.9	0.0493	0.980	2.08	1.03	10.6	3.59	44.8	19.0	100	25.4	279	61.8	10263	2.24	76.0	250	659
I12-2-1	<98.07	4.83	0.338	460	<0.0039	14.0	0.0243	0.553	1.41	0.635	8.06	2.69	34.8	14.2	74.5	17.6	192	43.3	9623	2.05	152	233	712
I12-2-2	<111.61	3.93	0.378	479	<0.0077	12.5	0.0383	0.449	1.44	0.570	7.36	2.48	33.1	13.9	75.3	18.8	205	47.9	10159	1.66	83.0	193	694
I12-3	<87.70	4.59	0.426	575	<0.0063	14.7	0.0360	0.413	1.53	0.561	8.67	3.20	39.4	17.4	94.2	21.8	247	57.1	10881	1.76	95.1	199	707
I12-4	<99.95	2.96	0.379	472	0.0080	8.98	0.0572	1.17	2.22	0.961	10.7	3.18	38.7	14.7	74.9	18.2	206	43.3	9705	0.992	49.2	127	670
I12-5-1	<95.81	3.82	0.595	705	0.1250	13.9	0.0718	0.753	1.85	0.786	10.6	3.83	47.3	19.2	107	27.4	297	68.1	11137	2.72	81.8	307	692
I12-5-3	<101.03	2.58	0.416	582	<0.0046	18.5	0.0269	0.543	1.51	0.735	9.76	3.45	42.8	17.9	90.8	22.6	257	53.9	10543	3.92	193	461	660
I12-6	<101.98	2.99	0.384	413	<0.0057	14.6	0.0312	0.568	1.30	0.590	7.24	2.47	31.5	12.4	63.6	15.4	162	36.8	10212	1.97	149	242	671
I12-7	108	4.42	0.389	447	<0.0070	8.74	0.0367	0.747	1.45	0.677	7.75	2.51	31.7	13.3	68.8	17.3	181	42.6	10049	1.13	46.7	114	704
I12-8	<103.46	4.16	0.415	527	<0.0049	16.2	0.0333	0.567	1.31	0.712	8.62	2.85	37.1	15.3	81.4	21.4	231	51.9	9624	2.40	116	272	699
I12-9	<98.20	3.89	0.454	456	<0.0073	10.1	0.0296	0.558	1.19	0.538	6.79	2.53	31.5	13.4	73.9	18.4	210	49.0	10330	1.31	48.0	139	693
I12-10	<101.46	2.98	0.341	442	<0.0048	15.1	0.0309	0.544	1.20	0.576	6.94	2.47	31.4	13.0	66.7	16.7	182	41.2	10119	2.65	139	291	671
I12-11	<104.12	3.12	0.331	395	<0.0058	12.1	0.0173	0.466	1.04	0.500	6.03	2.10	28.0	11.7	63.4	16.1	177	40.0	10584	1.56	74.1	180	675

I12-12	<100.13	2.82	0.386	519	<0.0056	13.3	0.0283	0.514	1.28	0.631	7.54	2.60	35.3	15.0	82.0	21.6	242	55.2	10553	1.51	48.8	189	667
I12-13	<112.62	2.94	0.451	435	<0.0056	9.18	0.0196	0.432	1.17	0.521	6.41	2.33	31.0	12.9	69.1	18.1	201	47.1	10314	1.18	42.3	138	670
I12-14	<108.43	3.40	0.326	372	<0.0067	11.8	0.0247	0.449	1.04	0.483	6.19	2.11	27.2	10.9	57.1	14.1	152	34.0	10347	1.71	104	198	682
I12-16	<109.21	2.96	0.460	740	<0.0046	18.5	0.0397	0.679	1.80	0.863	10.8	3.96	50.9	21.7	117	29.7	322	75.0	10854	2.19	79.8	261	670
I12-17	<103.95	3.39	0.432	524	<0.0068	10.3	0.0692	1.04	2.05	0.899	10.2	3.21	39.3	15.5	80.8	20.2	217	51.9	10072	1.54	61.7	181	682
I12-18	<108.10	3.41	0.434	405	<0.0060	9.85	0.0162	0.476	1.07	0.507	6.20	2.30	28.3	12.6	65.9	17.4	200	47.2	10335	1.30	41.6	132	682
I12-19	<111.10	3.01	0.308	467	<0.0065	8.99	0.0436	0.894	1.62	0.710	8.46	2.71	34.2	13.7	70.1	18.4	201	46.0	10086	1.24	47.7	137	672

San Miguel. Sample SCO-2

I5-17	<64.91	4.78	0.333	512	0.0017	11.7	0.0335	0.607	1.30	0.620	7.57	2.69	35.2	15.2	81.1	19.5	209	49.7	10870	1.39	71.4	162	711
I5-23	<64.53	3.08	0.251	315	0.0021	9.40	0.0186	0.355	0.930	0.355	4.79	1.71	22.4	9.40	50.7	12.5	137	33.0	11244	1.37	51.0	145	674
I5-25	<74.03	3.32	0.410	545	<0.0037	10.3	0.0320	0.410	1.32	0.560	8.90	3.05	38.5	15.5	87.1	21.4	243	55.2	11568	1.40	61.7	193	680
I5-26	76.2	3.00	0.394	730	<0.0034	14.9	0.0328	0.560	1.43	0.754	9.85	3.62	49.7	21.7	119	29.3	319	77.4	11238	2.16	74.9	240	672
I5-29	<64.08	3.98	0.346	348	<0.0037	10.0	0.0181	0.414	0.990	0.459	5.60	1.87	24.0	9.94	53.6	13.3	144	33.9	10597	1.58	86.2	175	695
I5-30-1	<68.50	3.73	0.455	513	0.0806	9.61	0.0410	0.619	1.29	0.619	7.56	2.70	35.6	15.3	84.3	20.7	233	57.0	11071	1.19	51.0	143	690
I5-30-2	<64.85	3.55	0.357	507	0.0522	14.7	0.0435	0.669	1.45	0.581	8.25	2.84	35.5	15.0	82.0	19.2	206	48.2	10964	2.36	115	241	685
I5-33	<70.25	3.28	0.429	843	<0.0024	18.0	0.0291	0.686	1.91	0.861	11.8	4.28	59.5	25.2	138	34.8	381	88.7	12127	2.67	93.3	313	679
I5-34	<62.42	4.29	0.310	383	0.0027	8.25	0.0313	0.398	1.07	0.519	5.53	2.01	27.1	11.1	60.7	15.3	175	40.9	10721	1.03	44.6	122	701
I5-63	<70.10	3.02	0.426	923	<0.0027	21.6	0.0309	0.595	1.85	0.930	12.9	4.80	63.1	26.8	146	35.4	388	91.1	11827	2.70	109	318	672
I5-65	<65.87	2.91	0.276	414	<0.0022	9.12	0.0109	0.333	0.870	0.423	5.74	2.19	28.6	12.0	65.1	16.2	179	42.7	12122	1.39	47.1	157	669
I5-67	<67.73	3.82	0.531	349	0.0136	12.6	0.0199	0.333	0.920	0.483	5.59	2.02	25.4	10.5	55.4	13.4	148	34.6	12145	1.81	87.9	195	692
I5-70	<68.62	3.23	0.449	675	0.0896	12.6	0.3290	1.90	3.16	1.38	15.1	4.59	53.4	20.7	104	24.4	264	57.3	10996	1.48	81.6	178	678
I5-74	<71.42	3.50	0.441	789	0.0036	14.7	0.0293	0.558	1.52	0.804	10.2	3.86	53.2	23.1	126	32.4	357	81.9	12738	2.45	67.7	282	684
I5-90	<66.35	5.02	0.352	486	<0.0031	11.6	0.0307	0.616	1.36	0.611	7.30	2.65	34.8	14.6	79.3	20.6	244	50.2	10380	1.44	61.2	169	715
I5-127	<62.11	3.20	0.415	568	0.0031	12.3	0.0236	0.512	1.31	0.604	7.97	2.86	38.9	16.7	91.6	23.3	268	61.4	11386	1.60	58.4	198	677
I5-154-1	<70.05	3.54	0.332	413	<0.0024	9.14	0.0183	0.348	0.920	0.474	6.12	2.21	28.6	12.2	67.7	17.4	198	45.8	11312	1.08	38.9	124	685
I5-154-2	<76.24	3.72	0.388	582	<0.0033	12.5	0.0268	0.493	1.53	0.727	8.90	3.16	41.8	17.4	95.5	25.0	289	64.9	11689	1.65	57.0	195	689
I5-174	<61.39	3.26	0.369	415	<0.0026	9.38	0.0192	0.415	1.07	0.488	5.71	2.14	27.8	11.9	66.5	16.8	188	44.7	11780	1.23	50.0	155	678

San Miguel. Sample SCO-3

I3-11	<65.20	4.35	0.394	537	0.0043	11.5	0.0289	0.567	1.31	0.618	7.72	2.83	37.0	15.8	85.8	21.4	247	54.7	10282	1.24	57.2	149	703
I3-14	<66.29	4.79	0.372	541	0.0085	11.5	0.0408	0.847	1.95	0.855	8.86	3.13	40.1	16.4	85.5	21.5	252	52.2	10510	1.35	60.4	144	711
I3-15	<65.15	3.93	0.356	557	0.0052	9.75	0.0869	1.71	3.05	1.23	12.4	3.97	45.1	17.1	86.1	20.9	234	47.2	9693	1.13	64.2	133	694
I3-22	<55.16	2.84	0.282	323	0.0019	8.20	0.0147	0.436	0.943	0.486	5.40	1.81	23.2	9.70	52.0	13.6	169	33.5	8403	0.759	31.6	103	667
I3-26	<74.13	3.11	0.450	697	0.0133	15.0	0.0251	0.560	1.57	0.681	9.49	3.47	45.0	19.4	107	26.9	301	70.8	12568	1.90	60.5	223	674
I3-35	<67.83	4.12	0.428	769	<0.0031	18.2	0.0292	0.593	1.81	0.770	11.1	4.03	54.4	22.4	121	29.6	329	73.7	11446	2.27	92.0	252	698
I3-37-1	<65.40	3.38	0.396	675	<0.0026	13.6	0.0278	0.643	1.61	0.665	9.71	3.78	48.2	20.0	105	25.5	273	59.6	10803	1.92	91.8	225	681
I3-37-2	<59.97	3.68	0.351	569	0.0058	9.92	0.0222	0.577	1.33	0.645	8.32	3.06	41.1	16.8	89.9	22.6	251	55.0	10935	1.62	62.1	181	688
I3-41	<66.57	4.39	0.444	658	<0.0025	14.9	0.0288	0.657	1.54	0.733	9.68	3.43	46.3	19.7	107	26.6	294	67.6	10870	1.78	72.5	201	703
I3-42	<67.08	2.92	0.340	427	<0.0027	9.82	0.0227	0.396	1.09	0.499	6.40	2.26	29.8	12.4	66.1	16.6	187	43.6	11089	1.05	47.0	119	669
I3-43	<65.04	3.21	0.308	333	0.0174	10.1	0.0241	0.389	0.918	0.429	5.16	1.78	23.7	9.82	52.4	13.4	155	34.2	10982	1.26	50.9	149	677
I3-44	<64.52	2.32	0.326	391	<0.0021	7.37	0.0156	0.330	1.06	0.406	5.34	1.92	26.0	11.1	61.8	16.0	183	44.5	11015	0.998	31.9	116	651
I3-45	67.2	2.84	0.448	394	0.0918	9.88	0.0827	0.571	1.16	0.462	6.05	2.12	28.0	11.5	62.0	16.5	194	40.9	10537	1.03	36.4	126	667
I3-46	<63.76	3.90	0.429	667	0.0023	17.4	0.0295	0.624	1.54	0.688	9.08	3.34	45.3	19.5	105	26.4	290	67.2	10974	1.95	87.0	233	693
I3-68	<63.66	3.33	0.430	496	0.0614	16.3	0.0483	0.895	1.32	0.617	8.03	2.68	34.9	14.4	76.3	18.5	204	45.4	11152	2.37	128	286	680
I3-73-1	<67.86	2.49	0.418	735	0.0037	11.9	0.0167	0.442	1.47	0.713	9.43	3.60	49.8	21.4	120	29.7	332	73.8	11700	2.10	56.7	245	657
I3-73-2	<62.68	3.25	0.299	329	<0.0025	8.32	0.0106	0.289	0.770	0.347	4.76	1.73	22.5	9.50	52.7	13.3	150	35.5	11067	0.894	30.2	93.2	678
I3-81	<69.15	2.48	0.404	341	0.0053	8.15	0.0104	0.271	0.714	0.359	5.06	1.72	23.2	9.76	55.5	14.1	160	37.1	11608	0.833	31.6	99.0	656
I3-82	<65.38	5.06	0.383	678	<0.0024	13.6	0.0312	0.673	1.69	0.792	9.33	3.47	47.2	20.0	111	27.8	311	67.3	9715	1.70	74.4	187	716
I3-88	<68.30	4.27	0.296	306	<0.00203	7.89	0.0202	0.351	0.892	0.420	4.86	1.68	21.6	8.97	48.7	12.1	140	30.9	9785	0.946	45.4	110	701
I3-90	<74.88	4.56	0.406	563	<0.0036	12.5	0.0327	0.515	1.47	0.628	7.92	2.96	39.3	16.7	91.1	22.9	264	57.5	11022	1.34	58.7	156	707
I3-93	<65.39	2.59	0.281	378	0.0033	12.9	0.0255	0.466	1.03	0.479	5.96	2.14	27.2	10.9	57.5	13.8	148	34.4	10858	2.27	129	265	660

San Nicolas. Sample SN

SN5	<66.56	13.5	0.428	456	0.0059	9.11	0.0620	1.15	1.90	0.780	7.71	2.55	33.8	13.1	75.2	17.6	231	42.1	7777	0.650	33.8	75.2	811
SN11	<62.56	10.1	0.408	322	<0.0034	10.7	0.0177	0.510	1.26	0.470	6.50	2.20	24.9	10.3	47.5	11.3	123	21.3	9130	0.380	31.8	48.5	781
SN29	<62.29	11.1	0.431	518	<0.0030	10.3	0.0930	1.94	3.15	1.03	12.1	4.04	42.8	16.6	77.5	17.1	190	31.9	8884	0.450	42.7	60.1	791
SN35	<70.75	7.78	0.341	275	0.0047	7.68	0.0245	0.470	0.960	0.410	5.33	1.56	23.7	8.18	49.9	12.4	135	31.9	7980	0.820	34.3	86.8	755

SN37	<61.48	6.27	0.392	372	<0.0035	10.0	0.0510	0.870	1.44	0.650	6.99	2.27	29.8	11.3	63.3	14.8	181	35.1	8285	0.860	55.4	117	735
SN39	<56.21	8.89	0.468	207	0.0147	7.57	0.0284	0.490	0.940	0.440	3.67	1.32	15.3	6.63	31.2	8.90	110	18.8	9217	0.540	32.9	71.5	768
SN47	<55.78	13.3	0.416	497	0.0039	10.3	0.0760	1.36	2.77	0.780	11.7	3.44	45.2	16.9	83.3	19.9	202	40.6	7070	0.410	31.0	55.5	810
SN48	<57.08	2.81	0.489	499	<0.0038	12.0	0.0420	0.910	1.64	0.750	8.30	2.79	37.4	14.3	82.7	17.9	254	46.1	9228	1.48	56.9	193	666
SN56	<62.68	3.48	0.412	229	0.0043	8.78	0.0127	0.313	0.600	0.388	3.48	1.30	15.4	6.62	36.0	8.71	116	21.7	10195	0.720	34.3	85.2	684
SN61	<60.74	5.38	0.403	334	<0.0031	7.08	0.0312	0.510	1.12	0.450	5.14	1.85	22.9	10.4	51.5	13.4	165	33.3	9161	0.750	43.0	97.8	721
SN64	<62.04	6.57	0.414	193	0.0219	8.02	0.0238	0.370	0.720	0.347	3.52	1.14	14.4	5.41	30.2	7.36	94.8	18.0	9176	0.600	32.2	75.3	739
SN70	<62.94	8.51	0.406	444	0.0269	6.52	0.110	1.70	2.45	1.12	10.4	3.01	43.6	14.8	79.0	20.0	221	44.3	6849	0.570	38.9	69.7	764
SN77	<53.58	8.27	0.375	564	<0.0034	7.84	0.109	2.18	4.09	1.48	15.8	4.71	48.8	19.4	79.9	19.8	198	34.6	7694	0.450	40.2	53.0	761
SN96	<52.57	5.18	0.378	357	0.0036	6.05	0.0600	0.960	1.75	0.750	7.27	2.51	26.6	11.4	52.5	14.4	164	31.9	8550	0.740	43.5	82.5	718

**Calipuy andesite. Sample
Anta-6**

A6-6	<76.48	5.05	0.403	376	<0.0041	12.0	0.0282	0.468	1.11	0.450	6.74	2.17	28.1	11.4	60.7	14.9	163	36.8	10534	0.725	55.9	107	716
A6-12	<101.93	7.66	0.396	533	0.0082	15.0	0.108	1.98	3.68	1.16	15.1	4.24	47.6	17.2	80.5	17.9	177	36.4	9723	0.719	62.4	80.5	754
A6-69	<101.81	6.96	0.288	344	0.0080	10.4	0.0558	1.12	2.02	0.700	9.09	2.58	28.5	10.7	51.7	12.1	121	26.8	9070	0.539	38.6	59.0	745
A6-70	<102.92	5.26	0.373	211	0.0057	9.51	0.0169	0.255	0.593	0.281	3.31	1.16	15.0	6.16	33.9	8.27	91.9	22.1	10569	0.726	46.4	95.2	719
A6-72	<124.50	3.97	0.374	367	<0.0046	8.69	0.0261	0.431	0.970	0.470	5.58	1.96	25.2	10.8	58.5	14.8	166	40.5	9604	1.27	51.7	128	695

**Calipuy rhyolite. Sample
Anta-8**

A8-13	<93.72	2.51	0.459	310	<0.0051	11.4	0.0225	0.320	0.651	0.342	4.39	1.53	20.8	8.85	51.1	13.3	145	37.0	10895	1.28	57.3	158	657
A8-15	<100.66	3.50	0.368	274	<0.0049	12.5	0.0141	0.269	0.787	0.330	4.47	1.48	18.9	7.86	43.1	10.7	116	27.6	10269	0.704	44.6	94.4	684
A8-18	<95.34	1.93	0.362	285	<0.0053	13.7	0.0178	0.362	0.784	0.353	4.46	1.46	18.6	8.01	43.7	10.9	122	31.6	11280	1.89	112	256	637
A8-25	<90.82	2.33	0.799	1553	0.0099	14.8	0.0122	0.310	1.62	0.506	14.9	6.72	107	47.6	258	64.0	680	137	14100	17.6	403	2650	652
A8-20	<100.89	2.03	0.394	208	<0.0050	9.17	0.0082	0.195	0.472	0.228	2.69	0.956	13.0	5.87	34.2	9.11	111	30.4	12322	1.37	47.9	152	641
A8-21	<89.22	9.18	0.246	462	<0.0049	3.50	0.0243	0.532	1.49	0.996	9.62	3.31	39.5	14.6	68.3	14.6	140	26.1	7843	0.265	15.3	48.8	772
A8-35	<97.45	1.76	0.294	172	0.0062	10.7	0.0108	0.181	0.455	0.174	2.51	0.811	10.8	5.01	27.6	7.67	94.3	25.3	11816	1.43	62.6	184	630
A8-42	<100.23	3.14	0.378	446	<0.0047	18.0	0.0284	0.508	1.20	0.554	6.63	2.30	30.2	13.3	72.2	18.5	208	48.7	10825	1.71	96.5	236	675
A8-31	<90.74	0.96	0.418	144	<0.0038	7.03	0.0054	0.097	0.165	0.131	1.09	0.408	6.43	3.34	23.8	7.53	111	36.7	13179	1.75	67.2	260	588

A8-38	<97.11	1.40	0.507	237	0.0047	5.64	<0.0053	0.095	0.240	0.200	2.16	0.799	12.2	6.10	39.0	12.3	179	52.3	16065	4.82	133	768	614
A8-40	<96.97	2.92	0.413	466	<0.0058	12.7	0.0145	0.379	1.05	0.474	6.40	2.34	30.9	13.7	74.0	18.5	208	45.6	10674	2.23	69.8	297	669
A8-55	<92.07	1.46	0.361	166	<0.0040	9.79	<0.0051	0.147	0.333	0.135	2.13	0.752	10.5	4.72	27.1	7.19	87.1	20.3	11694	1.26	40.5	169	617
A8-53	<78.41	3.40	0.327	228	<0.0043	13.9	0.0140	0.351	0.733	0.303	3.80	1.25	16.2	6.72	35.9	9.41	106	23.3	10296	0.854	50.5	125	682
A8-64	<85.60	4.55	0.297	282	<0.0047	10.7	0.0217	0.329	0.887	0.335	4.82	1.60	20.5	8.46	44.9	11.5	130	27.8	9681	0.919	51.8	148	706
A8-61	<78.76	5.33	0.311	287	0.0126	10.6	0.0263	0.493	1.03	0.428	5.20	1.76	21.6	8.74	46.3	11.8	129	27.8	9081	0.801	55.6	116	720

**Hualgayoc rhyodacite.
Sample 25-6**

I1-4	<72.16	8.80	0.245	631	0.0028	5.97	0.0232	0.498	1.66	1.065	12.5	4.28	53.4	19.9	91.6	20.3	199	35.3	8351	1.472	107	262	767
I1-5	<75.05	2.55	0.325	376	0.0078	7.63	0.0244	0.408	1.41	0.631	7.58	2.57	30.3	11.6	57.0	13.1	139	27.4	10643	0.458	32.0	84.8	659
I1-7	<72.75	1.76	0.484	727	0.0034	14.0	0.0134	0.247	0.977	0.595	7.89	3.17	45.1	20.2	114	31.2	380	83.1	12581	3.46	142	620	630
I1-10	<76.93	1.32	0.504	434	<0.0042	11.8	0.0136	0.219	0.529	0.303	3.65	1.363	20.4	10.7	70.1	21.1	278	71.7	13585	3.13	134	571	610
I1-11	<72.28	3.65	0.389	626	0.0046	44.4	0.0552	1.2	2.61	1.028	11.4	3.87	46.0	18.9	97.6	25.7	312	59.5	11627	6.17	636	890	688
I1-12	<124.10	1.82	0.659	472	0.0960	16.5	0.129	1.22	1.53	0.808	6.74	2.37	30.2	13.6	71.4	19.1	218	57.3	13057	4.26	209	555	633
I1-13	<96.03	2.96	0.395	340	0.0200	17.1	0.0227	0.407	0.868	0.369	5.47	1.83	24.5	10.3	53.2	12.5	141	32.2	11314	1.43	89.4	184	670
I1-14	<55.76	3.65	0.714	1060	0.0664	13.5	0.183	2.42	4.31	1.341	22.3	7.42	90.9	34.4	172	37.8	393	78.1	10399	4.76	191	347	688
I1-15	<55.81	3.50	0.501	822	0.0274	30.0	0.174	2.79	4.08	1.245	17.1	5.35	63.4	25.1	129	31.2	344	75.2	12175	3.49	334	464	684
I1-16	<51.98	4.66	0.325	527	<0.0034	7.31	0.0377	0.815	2.1	0.912	11.8	3.94	45.1	17.1	79.0	16.5	163	31.6	10467	0.939	42.6	152	709
I1-17	<52.52	2.97	0.555	649	0.0846	27.7	0.0792	1.04	1.73	0.798	9.77	3.09	40.9	17.5	97.3	24.8	290	74.1	13208	6.65	539	1198	671
I1-21	<90.37	4.59	0.681	1061	0.0285	21.0	0.224	1.46	2.78	1.44	16.8	6.12	83.8	33.2	160	38.4	394	81.4	12251	3.36	163	568	707

Table A1-6. Metadata for LA-ICPMS analysis

Metadata for LA-ICP-MS Trace element analysis.

Session 1, 2 & 3

Date	30/05/17 (session 1 & 2) and 01/06/17 (session 3)				
Run parameters	Machine models	Photon Machines Analyte Excite 193 nm excimer laser + Agilent 7700x ICP-MS			
			Internal Std	SiO ₂	
	Mineral(s) analyzed	Zircon	29Si	31.57	
	Number of analysis	188 unknowns and 69 standards			
	Beam size	42 microns (session 1 & 2) and 32 microns (session 3)			
	Repetition Rate	10Hz			
	Energy	5.9mJ/cm2			
	Background—Analysis—Flush	30 - 50 -30 seconds			
Calibration Summary	Calibration using	SiO ₂	<i>Si entered as SiO₂ and Glitter converts to Si</i>		
	Internal standard	NIST612	29Si	72.01	n=32
	Secondary standards	GSE1G	29Si	54.4	n=9
		Zircon 91500	29Si	31.57	n=15
		BCR2G	29Si	53.7	n=13
Elements analyzed	²⁹ Si, ³¹ P, ⁴² Ca, ⁴⁹ Ti, ⁵⁴ Fe, ⁸⁸ Sr, ⁸⁹ Y, ⁹¹ Zr, ⁹³ Nb, ⁹⁶ Mo, ¹³⁷ Ba, ¹³⁹ La, ¹⁴⁰ Ce, ¹⁴¹ Pr, ¹⁴⁶ Nd, ¹⁴⁷ Sm, ¹⁵¹ Eu, ¹⁵⁷ Gd, ¹⁵⁹ Tb, ¹⁶³ Dy, ¹⁶⁵ Ho, ¹⁶⁷ Er, ¹⁶⁹ Tm, ¹⁷³ Yb, ¹⁷⁵ Lu, ¹⁷⁷ Hf, ²⁰² Hg, ²⁰⁴ Pb, ²⁰⁶ Pb, ²⁰⁷ Pb, ²⁰⁸ Pb, ²³² Th, ²³⁵ U, ²³⁸ U				

Session 4

Date	27/09/18				
Run parameters	Machine models	Photon Machines Analyte Excite 193 nm excimer laser + Agilent 7700x ICP-MS			
			Internal Std	SiO ₂	
	Mineral(s) analyzed	Zircon	29Si	32.7	

Calibration Summary	Number of analysis	62 unknowns and 25 standards			
	Beam size	42 microns			
	Repetition Rate	10Hz			
	Energy	5.9mJ/cm2			
	Background—Analysis—Flush	30 - 50 -30 seconds			
	Calibration using	SiO ₂ wt%	<i>Si entered as SiO₂ and Glitter converts to Si</i>		
	Internal standard	NIST612	29Si	72.1	n=9
	Secondary standards	Zircon 91500	29Si	32.7	n=8
		BCR2G	29Si	54.12	n=4
		GSD1G	29Si	53.19	n=4
²⁹ Si, ³¹ P, ⁴² Ca, ⁴⁵ Sc, ⁴⁹ Ti, ⁵⁶ Fe, ⁸⁸ Sr, ⁸⁹ Y, ⁹¹ Zr, ¹³⁹ La, ¹⁴⁰ Ce, ¹⁴¹ Pr, ¹⁴⁶ Nd, ¹⁴⁷ Sm, ¹⁵¹ Eu, ¹⁵⁷ Gd, ¹⁵⁹ Tb, ¹⁶³ Dy, ¹⁶⁵ Ho, ¹⁶⁷ Er, ¹⁶⁹ Tm, ¹⁷³ Yb, ¹⁷⁵ Lu, ¹⁷⁷ Hf, ²⁰⁶ Pb, ²³² Th, ²³⁸ U					

Session 5

Date	25/10/18				
Run					
parameters	Machine models	Photon Machines Analyte Excite 193 nm excimer laser + Agilent 7700x ICP-MS			
			Internal Std	SiO ₂	
	Mineral(s) analyzed	Zircon	29Si	32.7	
	Number of analysis	52 unknowns and 21 standards			
	Beam size	49			
	Repetition Rate	12Hz			
	Energy	5.9mJ/cm2			
	Background—Analysis—Flush	30 - 50 -30 seconds			
Calibration Summary	Calibration using	SiO ₂ wt%	<i>Si entered as SiO₂ and Glitter converts to Si</i>		
	Internal standard	NIST612	29Si	72.1	n=9

	Secondary standards	Zircon 91500	29Si	32.7	n=8
		NIST610	29Si	69.7	n=4
Elements analyzed	²⁹ Si, ³¹ P, ⁴² Ca, ⁴⁵ Sc, ⁴⁹ Ti, ⁵⁶ Fe, ⁸⁸ Sr, ⁸⁹ Y, ⁹¹ Zr, ⁹³ Nb, ¹³⁹ La, ¹⁴⁰ Ce, ¹⁴¹ Pr, ¹⁴⁶ Nd, ¹⁴⁷ Sm, ¹⁵¹ Eu, ¹⁵⁷ Gd, ¹⁵⁹ Tb, ¹⁶³ Dy, ¹⁶⁵ Ho, ¹⁶⁷ Er, ¹⁶⁹ Tm, ¹⁷³ Yb, ¹⁷⁵ Lu, ¹⁷⁷ Hf, ²⁰⁶ Pb, ²³² Th, ²³⁸ U				

Session 6					
Date	01/11/18				
Run					
parameters	Machine models	Photon Machines Analyte Excite 193 nm excimer laser + Agilent 7700x ICP-MS			
			Internal Std	SiO ₂	
	Mineral(s) analyzed	Zircon	29Si	32.7	
	Number of analysis	34 unknowns and 23 standards			
	Beam size	32			
	Repetition Rate	12Hz			
	Energy	5.9mJ/cm2			
	Background—Analysis—Flush	30 - 50 -30 seconds			
Calibration Summary					
	Calibration using	SiO ₂ wt%	<i>Si entered as SiO₂ and Glitter converts to Si</i>		
	Internal standard	NIST612	29Si	72.1	n=9
	Secondary standards	Zircon 91500	29Si	32.7	n=9
Elements analyzed		NIST610	29Si	69.7	n=5
	²⁹ Si, ³¹ P, ⁴² Ca, ⁴⁵ Sc, ⁴⁹ Ti, ⁵⁶ Fe, ⁸⁸ Sr, ⁸⁹ Y, ⁹¹ Zr, ⁹³ Nb, ¹³⁹ La, ¹⁴⁰ Ce, ¹⁴¹ Pr, ¹⁴⁶ Nd, ¹⁴⁷ Sm, ¹⁵¹ Eu, ¹⁵⁷ Gd, ¹⁵⁹ Tb, ¹⁶³ Dy, ¹⁶⁵ Ho, ¹⁶⁷ Er, ¹⁶⁹ Tm, ¹⁷³ Yb, ¹⁷⁵ Lu, ¹⁷⁷ Hf, ²⁰⁶ Pb, ²³² Th, ²³⁸ U				

Metadata for LA-ICP-MS U-Pb analysis

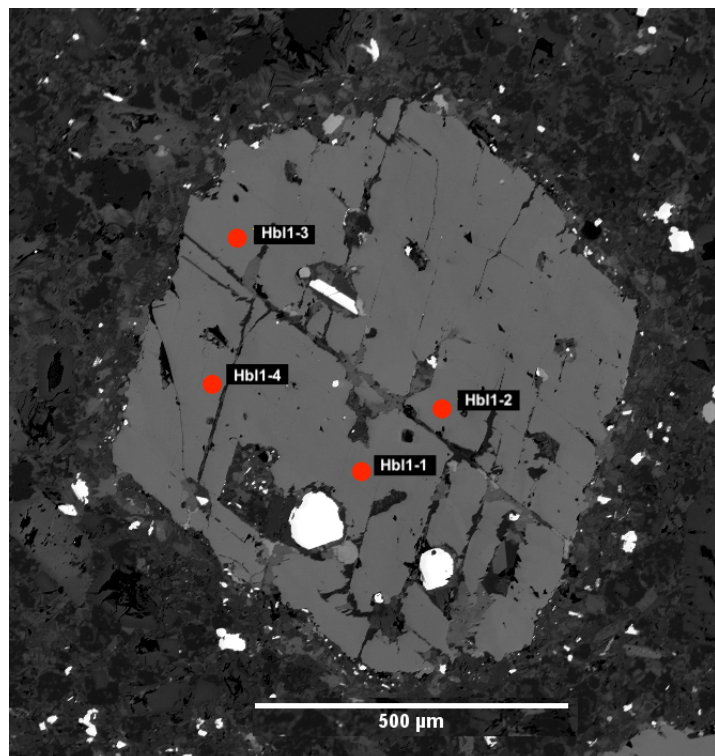
Sessions 1 to 6		
Date	21/12/17 (session 1); 22/01/18 (session 2); 26/01/18 (session 3); 13/02/18 (session 4); 23/08/18 (session 5); 12/12/2018 (session 6)	
Run		
parameters	Machine models	Photon Machines Analyte Excite 193 nm excimer laser + Agilent 7700x ICP-MS
	Beam size	32 microns

	Repetition Rate	11 Hz
	Energy	5.7mJ/cm ²
	Background—Analysis—Flush	30-40-30 seconds
	He Carrier flow rate	0.985 L/min
	Ar carrier gas	0.75 L/min
Calibration Summary	Internal standard	Zircon 91500
	Secondary standards	Zircon 91500, Zircon Plesovice
Elements analyzed	¹⁴⁰ Ce, ²⁰⁶ Pb, ²⁰⁷ Pb, ²⁰⁸ Pb, ²³² Th, ²³⁵ Pb, ²³⁸ U	

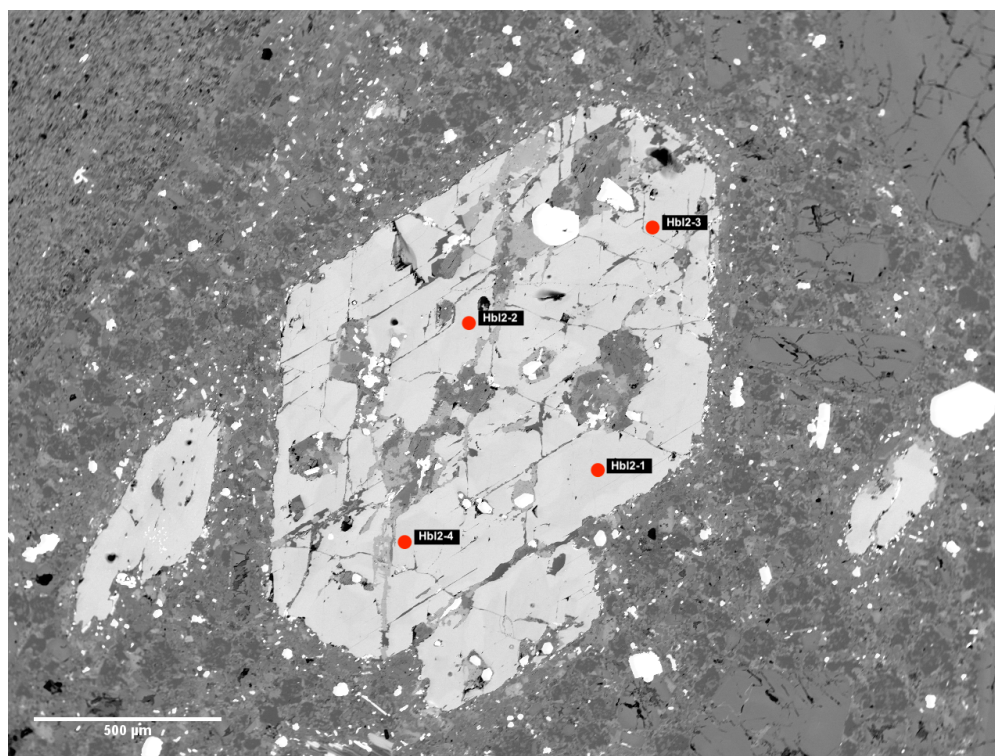
A1.2. SEM-CL images and areas of analysis of amphiboles from sample CD of the Coymolache sill and from sample SN of San Nicolas intrusion

Figure A1-26. SEM-CL images of selected amphiboles from the Coymolache Sill. Sample CD. Red dots correspond to the areas of analysis.

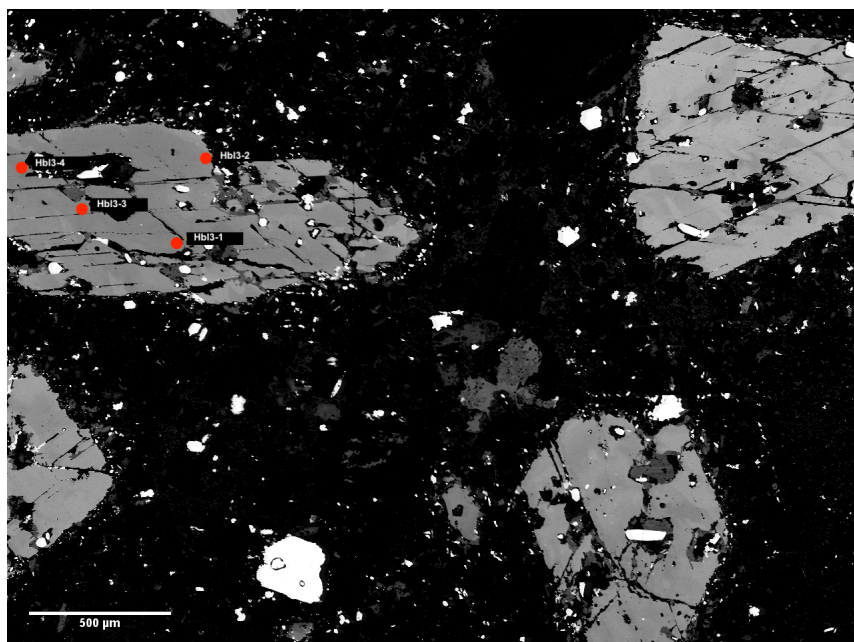
Grain Hbl1



Grain Hbl2



Grain Hbl-3



Grain Hbl-4

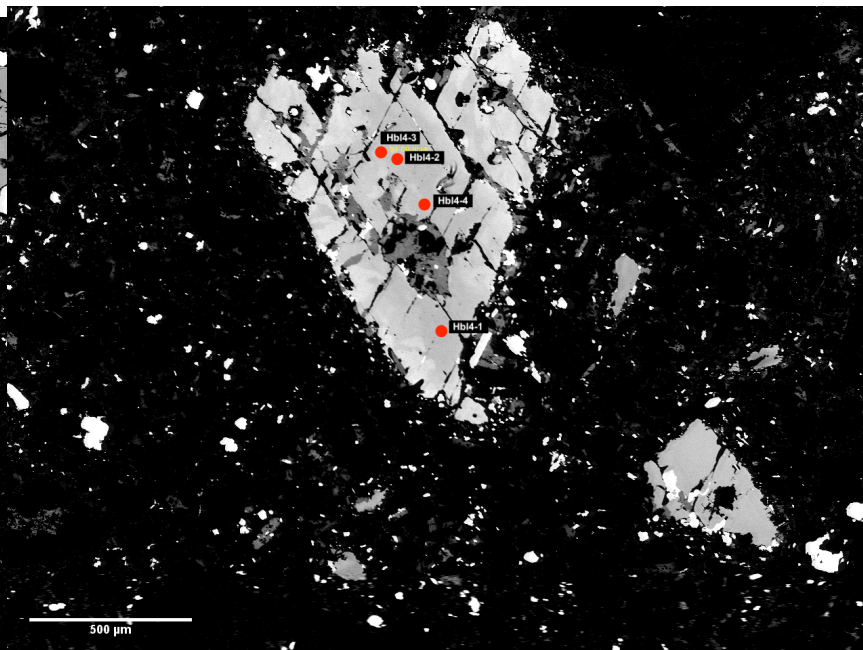
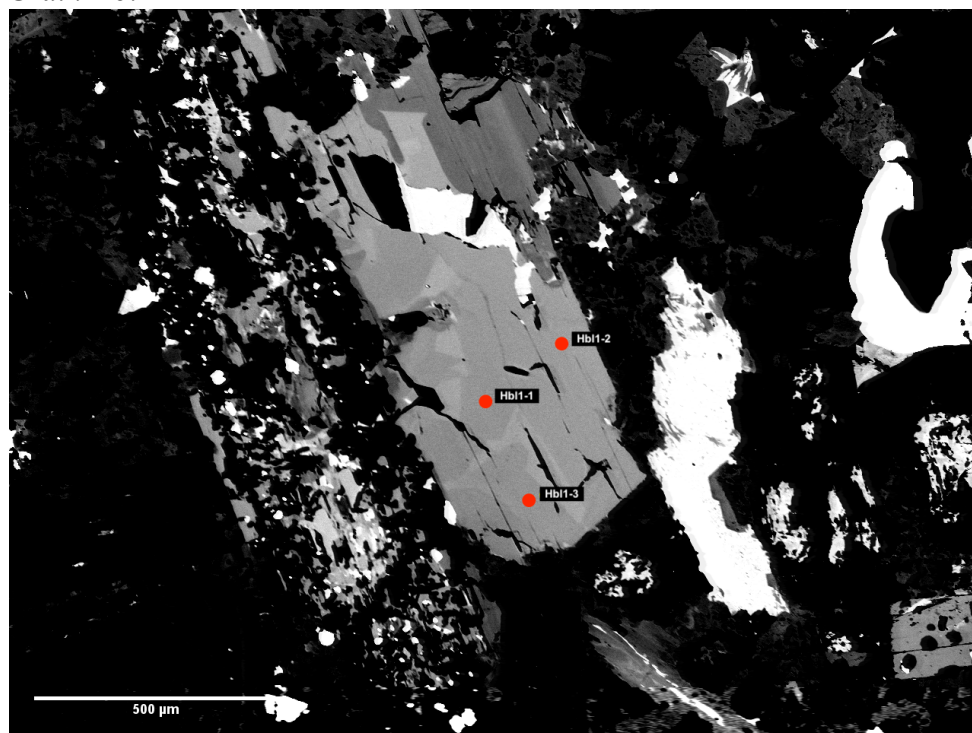
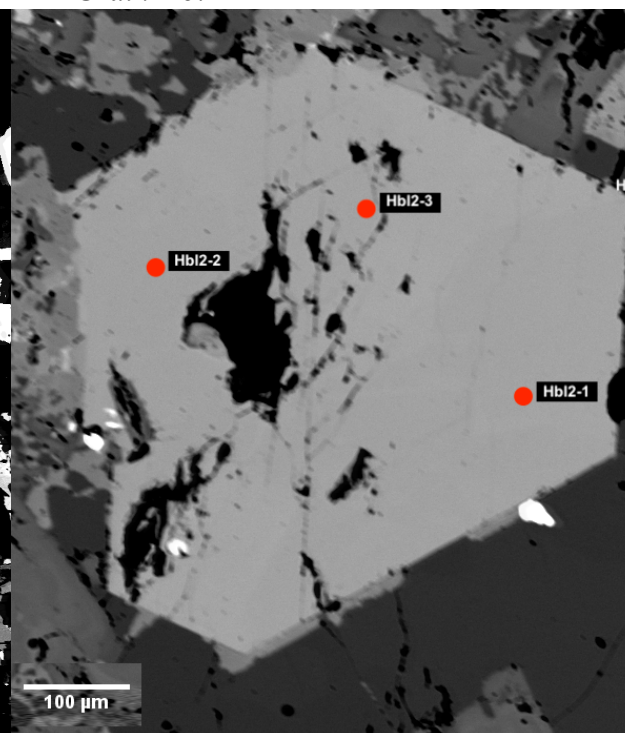


Figure A1-27. SEM-CL images of selected amphiboles from the San Nicolas intrusion. Sample SN. Red dots correspond to areas of analysis.

Grain Hbl-1



Grain Hbl-2



Grain Hbl-3

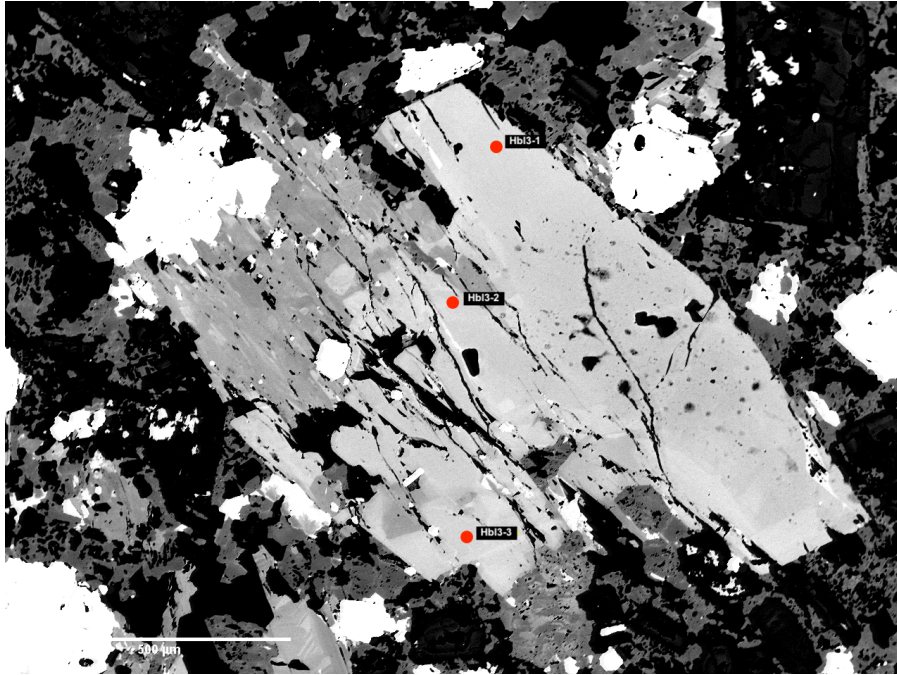


Table A1-7. Results of EPMA analysis of amphibole composition

For fO_2 , P and T calculations based on Ridolfi et al. (2009)

bdl: below detection limit

1: Total Fe expressed as FeO

Analytical error on Cr and F are very high, these measurements are not considered for calculations

Coymolache Sill. sample CD																			
Grain	spot	SiO ₂ wt%	TiO ₂ wt%	Al ₂ O ₃ wt%	¹ FeO wt%	MnO wt%	MgO wt%	CaO wt%	Na ₂ O wt%	K wt% ₂ O	Cr ₂ O ₃ wt%	F wt%	Cl wt%	TOTAL %	Species	T (°C)	fO_2	ΔFMQ	P (Mpa)
Hbl1	1	45.81	1.52	8.61	14.35	0.43	13.47	11.13	1.63	0.58	0.03	0.18	0.12	97.85					
Hbl1	2	44.56	1.49	9.37	14.93	0.41	12.69	11.25	1.65	0.83	0.00	0.12	0.18	97.49					
Hbl1	3	44.48	1.51	9.60	15.87	0.48	12.50	11.24	1.68	0.82	bdl	0.09	0.17	98.45					
Hbl1	4	44.48	1.49	9.51	15.26	0.46	12.54	11.31	1.58	0.80	0.02	0.20	0.19	97.83					
Average		44.83	1.50	9.27	15.10	0.45	12.80	11.23	1.64	0.76	0.01	0.15	0.17	97.91	Magnesio- Hornblende	862	-11.6	1.56	191
Hbl2	1	45.97	1.17	8.46	15.13	0.54	13.09	11.55	1.37	0.69	0.02	0.08	0.14	98.21					
Hbl2	2	46.37	1.10	8.26	15.21	0.45	12.91	11.34	1.41	0.71	0.01	0.19	0.14	98.11					
Hbl2	3	45.93	1.18	8.60	15.23	0.49	12.96	11.42	1.38	0.68	0.02	0.09	0.14	98.12					
Hbl2	4	45.61	1.10	8.49	15.25	0.46	12.86	11.46	1.36	0.73	0.01	0.05	0.15	97.51					
Average		45.97	1.14	8.45	15.20	0.49	12.95	11.44	1.38	0.70	0.01	0.10	0.14	97.99	Magnesio- Hornblende	834	-12.0	1.76	155
Hbl3	1	46.27	1.36	8.46	13.64	0.56	13.97	11.19	1.52	0.60	bdl	0.22	0.13	97.90					
Hbl3	2	46.55	1.32	8.08	13.52	0.41	14.46	11.14	1.50	0.51	0.01	0.20	0.10	97.80					
Hbl3	3	46.39	1.34	8.23	13.76	0.50	13.87	11.23	1.51	0.52	0.01	0.16	0.11	97.64					
Hbl3	4	46.48	1.42	8.22	13.52	0.44	14.11	11.22	1.54	0.52	0.00	0.18	0.11	97.76					
Average		46.42	1.36	8.25	13.61	0.48	14.10	11.20	1.52	0.54	0.01	0.19	0.11	97.78	Magnesio- Hornblende	835	-11.7	2.05	145

Hbl4	1	46.79	1.29	7.85	13.91	0.46	14.14	11.17	1.43	0.53	0.01	0.20	0.11	97.89					
Hbl4	2	46.14	1.38	8.21	14.06	0.48	13.74	11.13	1.57	0.57	bdl	0.01	0.13	97.41					
Hbl4	3	46.44	1.37	8.28	13.84	0.44	13.88	11.32	1.57	0.58	0.02	0.10	0.13	97.97					
Hbl4	4	46.57	1.28	7.85	13.59	0.52	14.05	11.27	1.56	0.51	bdl	0.11	0.12	97.43					
Average		46.49	1.33	8.05	13.85	0.48	13.95	11.22	1.53	0.55	0.01	0.10	0.12	97.67	Magnesio-Hornblende	830	-11.9	2.02	139

San Nicolas. sample SN																			
Grain	Spot	SiO2 wt%	TiO2 wt%	Al2O3 wt%	FeO wt%	MnO wt%	MgO wt%	CaO wt%	Na2O wt%	K wt%2O	Cr2O3 wt%	F wt%	Cl wt%	TOTAL %		T (°C)	f _{O2}	ΔFMQ	P (Mpa)
Hbl1	1	48.88	1.65	5.80	9.89	0.21	17.09	11.59	1.58	0.58	bdl	0.69	0.12	98.09					
Hbl1	2	48.85	1.53	5.74	9.90	0.32	17.08	11.49	1.70	0.54	0.01	0.86	0.13	98.14					
Hbl1	3	49.15	1.43	5.64	9.86	0.33	17.14	11.38	1.60	0.55	0.03	0.79	0.17	98.07					
Average		48.96	1.54	5.73	9.88	0.29	17.11	11.48	1.63	0.56	0.01	0.78	0.14	98.10	Magnesio-Hornblende	810	-11.4	2.96	77

Hbl2	1	49.72	1.38	5.40	9.67	0.31	17.37	11.68	1.52	0.51	0.01	0.80	0.13	98.51					
Hbl2	2	49.85	1.25	5.29	10.14	0.40	17.62	11.39	1.53	0.51	0.02	0.64	0.13	98.76					
Hbl2	3	49.97	1.36	5.49	10.00	0.25	17.49	11.64	1.49	0.52	bdl	0.82	0.13	99.14					
Average		49.84	1.33	5.39	9.94	0.32	17.50	11.57	1.51	0.52	0.01	0.75	0.13	98.81	Magnesio-Hornblende	802	-11.4	3.15	70

Hbl3	1	49.62	1.42	5.35	9.75	0.32	17.39	11.61	1.51	0.54	bdl	0.87	0.11	98.50					
Hbl3	2	49.33	1.35	5.57	9.77	0.31	17.18	11.62	1.58	0.55	0.02	0.78	0.13	98.16					
Hbl3	3	49.99	1.38	5.09	9.67	0.30	17.36	11.62	1.49	0.50	0.03	0.68	0.13	98.23					
Average		49.65	1.38	5.34	9.73	0.31	17.31	11.61	1.53	0.53	0.01	0.78	0.12	98.30	Magnesio-Hornblende	795	-11.6	3.05	70

Analytical conditions

Element/Line	Standard	Detection Limit (99%)	Precision (%)
K ka	Sanidine	0.012	96.9
Ca ka	Diopside #1	0.016	99.4
Na ka	Albite	0.016	97.8

Al ka	Sanidine	0.009	99.2
Fe ka	Hematite	0.037	98.7
Mn ka	Tephroite	0,038	89,2
Ti ka	Rutile	0,013	98,5
Si ka	Sanidine	0,009	99,8
Mg ka	Diopside #1	0.010	99.5
Cr ka	Chromite	0.016	N/A
F ka	Fluorite	0,117	N/A
Cl ka	Tugtupite	0.006	96.1

Appendix 2. Supplementary material for Chapter 4

Table A2-1. Lithology, mineralogy, alteration, mineralization and sample location of intrusions and volcanic rocks in the Hualgayoc district.

Abbreviations: Aln: alunite; Anh: anhydrite; Bt: biotite; Ccp: chalcopryite; Chl: chlorite; Dsp: diaspore; En: enargite; Ep: epidote; Hbl: hornblende; Kal: kaolinite; Kfs: potassic feldspar; Mag: magnetite; Pl: plagioclase; Prl: pyrophyllite; Py: pyrite; Qz: quartz; Ttn: titanite; WM: white mica.

¹UTM coordinates are WGS84 Zone 17.

Sample	Igneous unit	Mode of occurrence	abbreviation in the map	Sample location ¹		Lithology	Primary minerals	Alteration minerals	Metallic mineralization in sample
				Easting (m)	Northing (m)				
CC1	Cerro Corona	Plug	CC	762,812	9,252,019	Qz-diorite porphyry	Bt. Hbl. Pl. Qz. Ap. Mag. Ilm. Zrn	Weak – Bt. Kfs. Mag. Chl	Ccp disseminated
CC4				763,296	9,251,870	Qz-diorite porphyry	Bt. Hbl. Pl. Qz. Ap. Mag. Ilm. Zrn	Moderate – Bt. Kfs. Mag. Chl	Ccp disseminated
CC5				762,934	9,251,586	Qz-diorite porphyry	Bt. Hbl. Pl. Qz. Ap. Mag. Ilm. Zrn	Moderate – Bt. Kfs. Mag. Chl	Ccp disseminated
CC6				763,085	9,251,843	Qz-diorite porphyry	Bt. Hbl. Pl. Qz. Ap. Mag. Ilm. Zrn	Moderate – Bt. Kfs. Mag. Chl	Ccp disseminated
SJD-05	San Jose	Plug	SJ	764,830	9,251,099	Qz-diorite porphyry	Bt. Hbl. Pl. Qz. Ap. Mag. Ilm. Zrn	Moderate – Bt. Kfs. Mag. Chl	Ccp disseminated and in veinlets
SJD-02				765,137	9,251,308	Altered Qz-diorite porphyry	Bt. Hbl. Pl. Qz. Zrn	Intense – WM. clay minerals	Not observed
25-4				765,119	9,251,258	Altered Qz-diorite porphyry	Bt. Hbl. Pl. Qz. Zrn	Intense – WM. clay minerals	Not observed
Tanta-351	Tantahuatay	Plug	TA	757,213	9,255,245	Altered porphyry	Qz (residual). Zrn	High to intense – Aln±Prl	En
Tanta-352				757,458	9,255,461	Altered porphyry	Qz (residual). Zrn	High to intense – Aln±Prl	Not observed
Tanta-355				758,118	9,255,898	Altered porphyry	Qz (residual). Zrn	High to intense – Aln±Prl	Not observed
Tanta-356				758,015	9,255,942	Altered porphyry	Qz (residual). Zrn	High to intense – Aln±Prl	Not observed
Tanta-357				758,008	9,255,855	Altered porphyry	Qz (residual). Zrn	High to intense – Aln±Prl	Not observed
Anta-PK	AntaKori PK	Plug	AK	758,093	9,256,788	Altered Pl-Qz porphyry	Pl. Qz. Zrn	High – WM	Not observed
Anta-PF	AntaKori PF	Plug		758,116	9,256,564	Altered Pl-Qz-Bt porphyry	Pl. Qz. Bt. Ttn. Zrn	High – WM	Not observed

CJ	Cerro Jesus	Plug	JE	764,114	9,252,182	Qz-diorite porphyry	Pl. Hbl. Qz. Zrn	High – WM	Not observed
CB	Cerro Choro Blanco	Plug	CB	760,586	9,251,265	Diorite porphyry	Pl. Hbl. Qz. Zrn	None	Not observed
CAB	Cerro Caballerisa	Plug	CAB	760,244	9,251,364	Diorite porphyry	Pl. Hbl. Qz. Zrn	None	Not observed
LG	Las Gordas	Plug	LG	760,081	9,252,023	Porphyritic rock	Qz (residual). Zrn	Intense – Qz. WM.	Not observed
CD	Coymolache	Sill	CO	761,877	9,249,776	Qz-diorite porphyry	Pl. Hbl. Bt. Qz. Kfs. Mag. Zrn	Weak – Chl	Not observed
25-5				763,733	9,249,006	Qz-diorite porphyry	Pl. Hbl. Bt. Qz. Kfs. Mag. Zrn	Weak – Chl	Not observed
SCO-1	San Miguel	Sill or lacolith	SM	759,532	9,256,283	Qz-diorite porphyry	Pl. Hbl. Bt. Qz. Kfs. Mag. Ilm. Zrn	Weak to moderate – Chl. Ep	Not observed
SCO-2				759,214	9,256,907	Qz-diorite porphyry	Pl. Hbl. Bt. Qz. Kfs. Mag. Ilm. Zrn	Weak to moderate – Chl. Ep	Not observed
SCO-3				758,993	9,257,411	Qz-diorite porphyry	Pl. Hbl. Bt. Qz. Kfs. Mag. Ilm. Zrn	Weak to moderate – Chl. Ep	Not observed
SN	San Nicolas	Plug	SN	760,473	9,253,673	Qz-diorite porphyry	Pl. Hbl. Bt. Mag. Zrn	Weak – Chl. Ep	Not observed
Anta-6	Calipuy	Volcanic flows/dome s	AK	757,858	9,256,301	Andesite	Bt. Pl. Qz. Hbl. Zrn	Intense – Prl. Kal. Dsp	Not observed
Anta-8				758,236	9,256,684	Rhyolite	Bt. Pl. Qz. Kfs. Hbl. Zrn	Moderate – WM	Not observed
25-6	Hualgayoc	Volcanic dome	HG	764,213	9,253,208	Rhyodacite	Bt. Pl. Kfs. Qz. Zrn	None	Not observed

Table A2-2. Trace element abundance (ppm) in zircon.

SD: Standard deviation

Avg: average

$$\text{Eu/Eu}^* = [\text{Eu}_{\text{cn}}]/[(\text{Sm}_{\text{cn}} * \text{Gd}_{\text{cn}})^{0.5}]$$

$$\text{Ce/Ce}^* = [\text{Ce}_{\text{cn}}]/[(\text{Nd}_{\text{cn}}^2)/\text{Sm}_{\text{cn}}]$$

Analysis	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Y	Eu/Eu*	Ce/Ce*	Th/U
Cerro Corona phase 1. Sample CC1																		
CC1-1-1	0.006	15.7	0.02	0.48	1.64	0.78	9.54	3.52	49.1	20.7	105	26.9	333	63.8	628	0.60	253	0.22
CC1-1-2	<0.002	11.9	0.05	0.99	2.39	1.12	12.4	4.20	52.9	20.2	104	26.2	299	57.8	651	0.63	66.4	0.25
CC1-5-1	0.018	11	0.04	0.82	2.11	0.96	11.1	3.82	49.9	20.3	106	26.3	301	63.3	645	0.61	79.5	0.24
CC1-6-1	<0.002	15.1	0.09	1.91	3.82	1.73	18.0	5.97	71.9	27.2	138	32.4	357	71.5	859	0.63	36.3	0.32
CC1-6-2	<0.002	12.7	0.02	0.47	1.35	0.68	9.03	3.38	46.1	19.7	106	27.7	323	66.0	654	0.59	182	0.23
CC1-10-1	0.003	14.8	0.03	0.46	1.37	0.71	8.01	2.86	41.3	17.5	92.7	24.2	298	59.2	564	0.65	224	0.23
CC1-11-1	<0.002	17.2	0.04	0.63	1.77	0.88	9.78	3.71	48.7	20.8	116	29.8	349	70.4	692	0.64	179	0.24
CC1-11-2	0.060	13.4	0.07	1.34	2.90	1.22	13.4	4.52	54.7	21.5	113	28.4	326	65.0	709	0.59	49.6	0.28
CC1-113-1	<0.002	16.2	0.03	0.58	1.87	0.88	11.2	4.23	58.1	24.5	125	31.5	381	78.3	773	0.58	209	0.28
CC1-113-2	0.093	12.9	0.04	0.69	1.26	0.68	9.09	3.29	42.6	18.4	101	23.8	264	59.5	607	0.61	78.8	0.26
CC1-12-1	<0.002	14.8	0.02	0.63	1.46	0.85	10.6	4.02	54.6	23.3	121	30.3	324	71.5	738	0.66	125	0.26
CC1-13-1	0.064	19.4	0.05	0.65	1.86	0.84	11.2	4.01	51.3	21.2	108	26.7	313	60.1	662	0.56	194	0.32
CC1-13-2	<0.002	16.7	0.03	0.53	1.55	0.84	9.69	3.57	46.0	19.0	99.8	25.0	301	57.3	625	0.66	211	0.33
CC1-30-1	<0.002	13.7	0.02	0.39	1.60	0.81	9.33	3.40	48.7	20.9	109	27.2	311	69.6	660	0.64	337	0.25
CC1-30-2	<0.002	18.6	0.02	0.77	1.91	1.03	11.2	4.32	55.8	22.4	115	29.5	329	68.2	749	0.68	140	0.35
CC1-39-1	<0.002	12.1	0.02	0.50	1.23	0.69	9.10	3.45	46.7	20.4	111	28.9	329	69.4	689	0.63	136	0.22
CC1-39-2	<0.002	12.6	0.02	0.47	1.47	0.71	9.13	3.41	46.2	19.5	106	27.0	321	66.6	653	0.59	190	0.20
CC1-44-1	0.112	13.9	0.06	0.66	1.59	0.79	9.52	3.53	47.8	19.9	105	27.8	327	60.7	647	0.62	118	0.26
CC1-83-1	0.010	21.2	0.05	0.83	2.16	1.05	13.8	4.90	65.4	26.6	141	34.3	391	85.3	896	0.59	154	0.33

CC1-84-1	0.047	15.9	0.03	0.58	1.48	0.83	9.87	3.22	46.7	19.7	101	22.9	277	62.2	605	0.66	163	0.31
CC1-86-1	0.058	15.9	0.04	0.72	1.85	0.91	11.4	4.29	58.0	23.5	121	31.2	357	75.0	788	0.60	131	0.27
CC1-87-1	0.005	10.1	0.04	1.09	2.68	1.01	14.2	4.57	63.3	26.5	135	31.4	349	71.9	793	0.50	52.6	0.18
CC1-89-1	0.031	16	0.03	0.54	1.52	0.84	11.1	3.93	49.5	22.2	123	30.5	319	70.1	753	0.62	196	0.30
CC1-89-2	0.005	18.6	0.03	0.59	1.59	0.95	11.8	4.33	55.5	24.4	134	33.3	358	76.8	812	0.67	194	0.29
CC1-90-1	0.007	21.3	0.03	0.85	2.04	1.03	12.5	4.58	56.5	23.3	124	31.1	329	72.3	777	0.62	140	0.45
CC1-95-1	0.007	14.6	0.05	1.14	2.44	1.28	13.1	4.17	52.2	21.5	109	25.2	290	64.9	689	0.69	63.2	0.30
Avg																0.62	147	0.27
SD																0.04	71.4	0.06

Cerro Corona phase 4. Sample CC4

CC4-4-1	0.003	8.75	0.01	0.34	0.93	0.50	5.55	2.03	26.6	11.5	63.7	17.4	221	42.2	386	0.68	158	0.18
CC4-4-2	0.004	14.4	0.03	0.56	1.41	0.69	7.73	2.80	39.4	16.3	87.5	23.9	293	56.8	532	0.63	151	0.25
CC4-12	0.003	20.9	0.03	0.91	2.32	1.09	14.6	5.15	66.3	27.4	145	35.2	382	83.0	922	0.57	136	0.43
CC4-13-1	0.008	17.1	0.04	0.84	1.80	0.79	9.52	3.44	43.8	18.3	97.8	24.6	279	59.5	633	0.59	100	0.43
CC4-13-2	0.061	21.2	0.07	0.95	2.03	0.99	10.9	4.00	53.8	22.3	119	30.3	348	73.3	751	0.64	111	0.41
CC4-18	0.003	10.2	0.02	0.49	1.20	0.62	6.47	2.39	30.1	12.8	70.0	18.9	240	45.9	419	0.67	115	0.22
CC4-20	<0.002	20.4	0.04	0.76	2.12	0.96	12.9	4.52	57.6	24.0	128	32.2	358	72.2	799	0.56	173	0.36
CC4-23	0.013	11.7	0.06	1.16	2.37	1.00	11.5	3.76	46.7	18.2	95.4	23.9	270	57.2	609	0.58	47.2	0.30
CC4-24-1	0.002	15.9	0.03	0.63	1.80	0.89	10.9	4.16	55.3	23.1	129	33.8	387	75.7	764	0.61	169	0.21
CC4-24-2	<0.002	10.4	0.02	0.37	1.37	0.67	8.56	3.23	43.1	18.5	101.0	26.1	308	62.9	624	0.59	237	0.19
CC4-26	0.018	16.1	0.04	0.90	1.90	0.93	11.6	4.13	52.6	22.0	116	30.1	345	70.4	729	0.60	86.9	0.30
CC4-47	0.001	13.2	0.02	0.56	1.36	0.76	6.66	2.56	34.0	13.5	69.7	20.5	289	39.6	431	0.76	133	0.17
CC4-49	0.006	24.2	0.04	0.89	2.73	1.28	16.1	5.85	77.0	31.8	163	41.8	482	89.6	1041	0.59	193	0.32
CC4-60	0.008	17.2	0.03	0.73	1.44	0.73	9.57	3.51	45.7	19.6	107	26.8	291	65.2	666	0.60	105	0.34
CC4-69	<0.002	10.5	0.02	0.49	1.15	0.57	6.94	2.43	32.0	13.5	74.1	20.3	249	48.6	446	0.61	117	0.21
CC4-86	0.021	28.9	0.06	1.22	3.03	1.45	16.6	5.57	71.4	27.5	133	36.2	440	71.9	877	0.62	136	0.36
CC4-93	0.030	15.6	0.05	0.76	1.67	0.86	10.8	3.72	47.7	19.4	107	28.3	344	64.0	656	0.62	103	0.27
CC4-94	0.005	25.6	0.04	0.92	2.19	1.02	13.8	4.57	56.9	22.7	117	28.7	315	68.3	772	0.56	154	0.49
CC4-96	<0.002	18.2	0.04	0.98	2.45	1.15	13.8	4.76	62.4	24.9	127	33.5	393	72.1	813	0.60	106	0.28
CC4-98-1	<0.002	25.2	0.04	1.02	2.23	1.18	14.8	5.12	65.9	26.5	141	34.8	393	81.5	903	0.62	125	0.41

CC4-98-2	0.015	16.9	0.04	0.79	1.94	0.97	11.4	4.17	52.9	22.2	118	29.2	337	72.8	756	0.63	120	0.44
CC4-103	0.003	7.52	0.01	0.27	1.00	0.44	5.77	2.23	30.8	13.2	74.1	19.7	228	49.6	449	0.56	245	0.18
CC4-105	<0.002	14.6	0.02	0.62	1.54	0.79	9.19	3.39	44.7	18.5	99.9	25.9	309	59.4	614	0.64	134	0.23
CC4-109	0.015	22.9	0.05	1.13	2.90	1.45	17.3	5.95	73.4	29.1	148	37.2	420	79.5	949	0.62	121	0.39
Avg																0.61	123	0.31
SD																0.04	46.1	0.10

Cerro Corona phase 4. Sample CC4b

CC4b-37-2	<0.002	12	0.02	0.52	1.22	0.68	9.63	3.47	45.1	19.3	106	27.8	318	68.8	669	0.60	127	0.22
CC4b-60	0.086	10.9	0.06	0.82	1.54	0.69	8.59	3.03	38.6	15.7	86.5	21.7	246	58.8	547	0.58	56.6	0.34
CC4b-66	<0.002	19.2	0.02	0.72	2.01	0.94	12.1	4.45	59.9	24.9	134	35.3	416	77.7	873	0.58	169	0.23
CC4b-77	0.004	9.78	0.05	1.00	1.99	0.82	9.59	3.25	39.9	16.5	87.2	21.2	233	56.5	549	0.57	44.7	0.34
CC4b-78	0.005	31.4	0.04	1.15	3.28	1.51	18.5	6.37	78.0	31.3	158	40.2	453	84.9	1033	0.59	180	0.40
CC4b-82	0.063	19	0.05	0.89	2.16	1.11	13.4	5.19	66.9	27.6	142	36.2	405	80.9	911	0.63	118	0.31
CC4b-83	0.014	13	0.06	1.22	2.73	1.24	13.6	4.60	58.8	23.0	118	30.5	357	69.7	759	0.62	54.7	0.26
CC4b-95-1	0.027	9.43	0.02	0.37	1.05	0.53	6.53	2.57	34.9	14.9	81.8	21.9	263	53.3	494	0.61	169	0.20
CC4b-95-2	0.023	11.6	0.04	0.97	2.41	1.03	12.7	4.18	52.1	20.1	104	26.1	302	59.9	666	0.57	68.9	0.26
CC4b-97-3	0.012	25.7	0.05	0.98	2.36	1.20	15.1	5.63	75.5	31.4	165	40.8	443	97.1	1042	0.61	147	0.34
CC4b-104	0.014	9.64	0.02	0.41	1.05	0.53	5.85	2.24	29.6	12.2	65.7	18.4	225	44.7	420	0.65	138	0.24
CC4b-107	<0.002	17.1	0.02	0.67	1.76	0.83	10.5	3.79	50.6	21.5	117	30.6	363	72.9	729	0.59	156	0.24
CC4b-115	<0.002	22.6	0.03	0.76	2.32	1.06	13.1	4.62	56.7	22.8	115	28.2	306	64.9	757	0.58	210	0.42
CC4b-117-1	0.002	16.2	0.03	0.59	1.33	0.70	8.98	3.14	39.6	16.0	83.8	21.3	241	48.7	546	0.62	140	0.38
CC4b-117-2	0.014	13.1	0.02	0.51	1.42	0.70	9.14	3.41	44.9	19.4	107	27.0	306	74.0	679	0.59	164	0.28
CC4b-126	<0.002	22.1	0.04	0.82	2.36	1.16	13.2	4.67	59.7	23.0	116	30.4	356	61.8	754	0.63	177	0.32
Avg																0.60	143	0.30
SD																0.02	50.7	0.07

Cerro Corona phase 5. Sample CC5

CC5-3-1	0.010	19.1	0.03	0.68	1.96	0.94	11.5	4.23	57.0	23.2	122	31.9	371	69.1	781	0.61	185	0.26
CC5-3-2	0.003	16.7	0.04	0.67	1.83	0.81	10.2	3.69	48.7	20.3	112	29.0	345	68.3	686	0.57	158	0.28
CC5-27	0.057	16.8	0.05	1.11	2.14	0.94	11.0	3.99	51.0	20.6	109	28.0	333	63.0	686	0.59	67.5	0.31

CC5-51	<0.002	13.2	0.02	0.56	1.23	0.63	7.98	2.81	39.0	16.4	88.6	23.1	271	59.2	554	0.61	122	0.29
CC5-60	0.022	19.9	0.04	0.77	2.27	1.18	12.7	4.83	62.4	25.1	129	34.0	429	70.5	813	0.67	176	0.24
CC5-69	0.016	16.4	0.03	0.69	1.50	0.87	9.60	3.38	44.6	18.2	94.7	25.5	304	56.5	617	0.70	118	0.24
CC5-70	0.042	21.1	0.05	0.96	2.46	1.06	14.1	5.06	65.6	26.6	138	34.6	390	80.4	888	0.55	131	0.31
CC5-71-1	<0.002	16.7	0.03	0.64	1.52	0.81	9.29	3.40	46.5	19.7	106	28.5	340	67.6	651	0.65	142	0.30
CC5-71-2	0.020	17.9	0.04	0.81	2.10	1.03	12.5	4.71	63.2	25.8	138	36.1	436	80.9	840	0.61	131	0.26
CC5-73	0.035	26	0.13	2.86	6.28	3.05	32.3	9.87	109	40.5	188	41.3	416	85.7	1273	0.65	46.0	0.53
CC5-93	<0.002	21.6	0.04	0.81	2.15	1.03	12.1	4.40	56.5	23.2	118	31.1	381	65.2	732	0.61	162	0.29
CC5-111-1	0.003	16.3	0.02	0.60	1.67	0.86	10.5	3.80	51.2	21.2	111	30.1	371	62.6	686	0.63	175	0.21
CC5-111-2	0.013	12	0.02	0.66	1.50	0.70	8.14	2.93	37.7	15.4	83.0	22.1	274	51.7	527	0.61	94.2	0.24
CC5-111-3	<0.002	11.1	0.02	0.42	1.15	0.57	6.37	2.24	28.9	12.1	64.5	18.1	239	41.6	380	0.65	166	0.23
CC5-114-1	0.006	8.95	0.02	0.40	1.03	0.53	6.32	2.38	31.6	13.3	73.5	20.2	247	48.0	434	0.64	136	0.19
CC5-114-2	<0.002	7.57	0.02	0.44	1.06	0.49	5.54	2.06	25.6	10.6	55.9	16.1	211	34.9	330	0.62	96.0	0.22
CC5-115	0.005	21.1	0.03	0.86	2.26	1.08	12.7	4.55	62.3	25.6	135	34.7	408	73.6	845	0.61	148	0.23
Avg																0.61	136	0.26
SD																0.04	39	0.08

Cerro Corona phase 5. Sample CC5n

CC5n-3-1	0.004	12.5	0.02	0.40	1.31	0.62	7.13	2.51	33.7	14.1	75.5	18.9	219	48.5	469	0.61	230	0.37
CC5n-4-1	0.004	18	0.02	0.67	1.64	0.87	11.5	4.02	54.8	22.5	117	29.6	332	71.1	741	0.61	150	0.31
CC5n-7-1	0.004	20.4	0.04	0.88	2.17	0.88	11.3	4.44	57.6	23.6	121	30.8	361	76.2	761	0.55	132	0.32
CC5n-15-1	0.039	13.6	0.05	0.73	1.44	0.73	8.19	2.83	38.5	15.4	79.5	20.4	243	52.6	504	0.65	84.8	0.34
CC5n-16-1	0.036	11.4	0.04	0.81	1.79	0.74	8.91	3.10	40.1	16.2	86.6	21.9	257	57.4	542	0.57	72.4	0.30
CC5n-20-1	0.011	24.1	0.05	1.00	2.51	1.24	14.5	5.37	70.4	28.9	149	39.3	458	89.0	959	0.63	139	0.29
CC5n-23-1	<0.002	14.9	0.02	0.49	1.42	0.63	7.17	2.63	37.3	15.6	82.1	22.2	294	53.6	502	0.60	204	0.26
CC5n-26-1	0.010	16.1	0.03	0.56	1.22	0.71	7.70	2.88	37.9	15.3	81.1	22.5	255	48.7	526	0.70	145	0.28
CC5n-26-2	0.025	7.87	0.03	0.41	0.77	0.37	4.62	1.67	22.2	9.32	51.6	13.3	156	35.0	310	0.59	82.2	0.31
CC5n-30-1	0.007	16.3	0.03	0.59	1.68	0.83	9.81	3.63	50.8	21.3	111	27.9	339	67.4	690	0.62	182	0.27
CC5n-30-2	0.005	15.5	0.03	0.48	1.43	0.66	8.81	3.11	41.5	17.4	92.9	25.1	291	58.3	592	0.57	224	0.28
CC5n-31-1	0.038	19.3	0.04	0.63	1.36	0.73	7.45	2.49	33.5	12.9	63.3	15.3	200	33.7	375	0.70	154	0.48
CC5n-33-1	0.028	16.2	0.05	1.04	2.37	1.03	12.2	4.22	55.6	21.2	109	28.0	343	64.6	699	0.59	81.2	0.36

CC5n-34-1	<0.002	12.7	0.03	0.58	1.50	0.76	8.22	2.92	39.4	15.4	83.5	22.0	268	51.7	523	0.66	129	0.27
CC5n-35-1	0.015	25.7	0.03	0.82	2.15	0.95	11.2	3.93	50.1	18.6	91.3	23.1	283	48.7	585	0.59	190	0.47
CC5n-42-1	0.025	15.5	0.03	0.55	1.35	0.70	8.04	2.74	34.4	14.0	74.1	18.8	233	43.5	457	0.65	160	0.31
CC5n-69-1	0.043	19.6	0.05	0.88	2.01	0.93	10.0	3.50	46.4	17.8	91.0	25.9	318	53.1	584	0.63	117	0.31
CC5n-70-1	0.014	17.3	0.05	1.15	2.21	1.14	12.8	4.54	58.8	22.9	119	30.6	364	69.6	769	0.65	66.7	0.30
CC5n-76-1	0.004	31.2	0.05	1.19	2.72	1.25	16.2	5.92	76.9	33.4	177	43.8	518	111	1088	0.57	138	0.36
CC5n-78-1	0.009	16	0.02	0.63	1.33	0.64	9.70	3.34	47.8	21.1	112	27.3	325	74.0	702	0.54	123	0.29
CC5n-100-1	0.009	17.2	0.02	0.65	2.09	0.88	10.2	3.75	56.1	22.8	114	29.7	377	70.8	688	0.58	196	0.22
CC5n-104-1	0.017	10.2	0.04	1.10	2.21	0.97	9.09	3.05	39.3	15.5	74.0	18.3	220	49.0	470	0.66	43.1	0.39
CC5n-109-1	0.005	6.76	0.03	0.55	1.08	0.47	5.59	1.94	25.5	11.0	54.9	13.9	168	38.7	331	0.58	56.1	0.35
Avg																0.61	138	0.31
SD																0.04	53.9	0.06

Cerro Corona phase 6. Sample CC6

CC6-9-1	0.006	18.6	0.03	0.70	2.03	0.99	13.7	4.95	67.8	28.2	150	36.6	410	90.6	939	0.57	179	0.26
CC6-13-1	0.004	14	0.03	0.61	1.35	0.62	7.03	2.76	36.0	15.4	84.2	21.7	255	53.4	515	0.61	117	0.29
CC6-18-1	0.007	42.1	0.04	0.91	3.00	1.69	23.9	10.2	151	66.1	364	89.4	969	191	2235	0.61	348	0.40
CC6-19-1	0.015	28.2	0.05	1.06	3.16	1.32	18.8	6.28	80.7	32.4	167	38.6	407	93.5	1065	0.52	183	0.47
CC6-27-1	0.003	7.76	0.02	0.45	1.09	0.55	6.32	2.27	30.1	12.6	66	17.1	204	43.5	420	0.63	97.4	0.23
CC6-32-1	0.120	17.7	0.08	0.87	1.82	0.95	10.1	3.64	48.3	19.6	103	26.1	313	64.0	639	0.67	99.1	0.31
CC6-38-1	<0.002	11.1	0.02	0.46	1.28	0.55	6.50	2.31	31.7	13.7	73.1	18.5	218	48.0	452	0.58	157	0.26
CC6-38-2	0.056	12	0.09	1.31	2.65	1.23	13.6	4.37	53.9	20.6	106	25.5	290	61.6	671	0.62	43.1	0.31
CC6-43-1	0.040	13.6	0.03	0.75	1.70	0.78	9.15	3.37	44.2	18.2	99.4	25.6	300	65.9	630	0.60	95.3	0.29
CC6-45-1	0.003	14.4	0.02	0.64	1.32	0.65	8.07	2.80	36.2	15.5	82.5	20.8	240	52.7	510	0.61	108	0.37
CC6-45-2	0.026	15.3	0.05	0.82	1.88	0.87	10.8	3.78	50.0	20.7	109	27.8	317	68.9	699	0.59	97.4	0.31
CC6-48-1	<0.002	7.72	0.01	0.48	1.17	0.53	5.47	1.88	26.3	10.9	58.1	15.1	195	38.6	347	0.63	91.0	0.29
CC6-50-1	0.084	16.4	0.06	0.76	1.45	0.70	8.87	3.08	38.8	15.5	80.9	21.4	252	51.1	515	0.60	93.8	0.27
CC6-52-1	0.022	12.6	0.04	0.40	1.14	0.53	6.92	2.49	32.2	14.1	76.2	18.8	218	50.4	467	0.57	206	0.32
CC6-58-1	0.005	20.2	0.04	0.82	1.82	0.95	10.7	4.06	52.9	21.8	115	29.3	336	68.3	724	0.66	125	0.35
CC6-65-1	0.004	16.7	0.03	0.70	1.52	0.77	9.11	3.45	46.6	20.6	109	27.9	327	72.7	666	0.63	121	0.26
CC6-65-2	0.002	12.8	0.02	0.47	1.18	0.58	6.18	2.23	30.5	13.0	67.7	18.1	214	44.4	421	0.65	156	0.31

CC6-65-3	0.006	9.63	0.01	0.40	1.24	0.56	6.54	2.56	34.7	14.1	76.6	21.0	261	50.3	472	0.60	174	0.19
CC6-76-1	0.005	18.7	0.03	0.70	1.45	0.73	8.21	2.91	38.3	14.9	79.3	20.3	230	46.3	501	0.64	128	0.39
CC6-90-1	<0.002	16.1	0.05	0.90	1.95	0.90	10.5	3.76	47.1	19.3	100	26.2	297	57.3	652	0.61	90.1	0.31
CC6-90-2	0.006	16.5	0.03	0.70	1.65	0.91	9.53	3.54	46.1	19.4	106	27.3	325	63.5	663	0.70	129	0.28
CC6-125-1	0.009	13.9	0.02	0.57	1.66	0.79	11.0	4.08	52.9	23.4	131	32.3	346	73.5	791	0.56	165	0.23
CC6-127-1	<0.002	19.9	0.02	0.54	1.46	0.88	9.52	2.98	38.9	18.1	91.5	20.9	235	54.2	533	0.72	233	0.42
Avg																0.61	125	0.31
SD																0.04	63.3	0.07

San Jose. Sample SJD-02

SJD-1	0.005	13.6	0.02	0.50	1.55	0.76	9.99	3.72	50.9	21.4	114	27.9	301	69.8	740	0.59	197	0.25
SJD-2	0.007	18	0.09	1.74	3.93	1.63	20.1	6.66	79.6	31.3	160	37.8	394	86.8	1077	0.56	53.9	0.34
SJD-3-1	<0.002	17.9	0.02	0.60	1.93	0.94	13.3	5.01	67.9	28.8	154	37.5	398	91.6	984	0.57	222	0.28
SJD-3-2	<0.002	20.5	0.03	0.76	2.19	1.08	14.9	5.62	75.5	32.2	168	40.8	427	98.5	1081	0.58	181	0.31
SJD-4	0.002	15.5	0.03	0.65	1.74	0.87	11.3	4.26	56.3	24.2	128	32.1	345	78.6	812	0.60	147	0.25
SJD-5	<0.002	16.5	0.02	0.58	1.71	0.87	11.2	4.16	55.8	23.5	127	32.3	355	76.9	791	0.61	195	0.26
SJD-6	<0.002	15.6	0.03	0.58	1.95	0.91	12.1	4.46	60.9	25.5	139	34.6	377	84.2	874	0.57	212	0.25
SJD-7	0.016	13.4	0.03	0.60	1.71	0.87	10.7	3.94	53.4	22.5	119	28.9	310	73.4	757	0.62	147	0.28
SJD-8	0.005	22.6	0.03	0.69	2.34	1.09	15.6	5.72	77.9	32.7	169	40.4	428	96.3	1096	0.55	253	0.30
SJD-9	0.038	17.7	0.05	0.67	1.91	0.89	13.0	4.67	63.7	27.5	144	35.5	386	86.5	931	0.54	172	0.25
SJD-10-1	0.024	17.4	0.03	0.82	2.09	0.91	13.9	5.23	69.3	29.5	161	38.6	403	94.5	1054	0.51	126	0.29
SJD-10-2	0.003	16.9	0.03	0.68	1.87	0.89	12.7	4.70	63.8	27.3	147	35.8	384	89.4	939	0.56	157	0.27
SJD-11	0.004	16.1	0.02	0.62	1.93	0.86	12.2	4.57	61.5	25.7	135	33.5	358	79.9	879	0.54	188	0.26
SJD-12	<0.002	11.7	0.03	0.58	1.43	0.72	8.25	2.86	34.9	14.0	70.3	16.5	171	38.7	461	0.64	116	0.63
SJD-13	<0.002	22.8	0.03	0.87	2.62	1.08	16.0	5.95	82.4	34.4	180	44.0	464	103.8	1146	0.51	183	0.30
SJD-14	<0.002	20.1	0.04	0.65	1.94	0.97	12.4	4.44	57.6	23.7	124	30.4	321	72.7	790	0.60	210	0.35
SJD-15	0.026	12	0.07	1.05	2.67	1.09	14.5	4.89	60.0	24.4	124	29.8	317	71.3	834	0.53	67.2	0.30
Avg																0.57	181	0.28
SD																0.04	53.0	0.09

San Jose. Sample 161025-4

25-4-1	<0.002	26.9	0.04	1.03	2.89	1.42	19.5	6.41	86.2	35.1	173	43.7	478	92.3	1127	0.58	167	0.34
25-4-2	0.005	14.8	0.02	0.47	1.83	0.84	12.5	4.80	64.1	26.1	135	31.6	327	71.3	875	0.53	277	0.28
25-4-3	<0.002	13.5	0.02	0.53	1.55	0.74	9.66	3.54	47.7	20.4	108	26.8	291	67.4	706	0.58	173	0.28
25-4-4	0.005	20.9	0.04	0.85	2.41	1.07	15.9	5.80	78.8	33.4	177	41.8	450	102	1112	0.53	162	0.29
25-4-5	<0.002	16.7	0.02	0.57	1.80	0.88	11.7	4.74	62.2	25.8	134	32.7	363	68.7	870	0.59	212	0.27
25-4-6	<0.002	17.7	0.03	0.59	1.99	0.91	11.6	4.32	58.2	24.3	129	32.0	349	77.2	840	0.58	236	0.34
25-4-7-1	0.047	21.2	0.05	0.69	1.89	0.91	11.7	4.09	51.9	20.3	104	24.4	258	56.8	676	0.59	195	0.47
25-4-7-2	<0.002	22.5	0.01	0.75	2.19	0.91	14.7	5.29	70.7	29.7	152	36.2	383	85.7	1003	0.49	201	0.39
25-4-8	<0.002	14.8	0.02	0.58	1.62	0.85	11.0	4.17	56.2	23.7	128	31.5	338	79.9	814	0.62	164	0.26
25-4-9	<0.002	12.6	0.02	0.37	1.15	0.62	7.82	2.73	36.8	15.4	83.6	20.9	222	50.2	524	0.63	240	0.26
25-4-10	<0.002	14	0.02	0.53	1.51	0.81	9.99	3.67	49.7	20.8	112	26.2	282	67.3	708	0.64	172	0.26
25-4-11	<0.002	4.93	0.01	0.17	0.52	0.29	3.79	1.41	18.9	8.44	46.3	11.6	130	31.8	286	0.64	194	0.18
25-4-12	<0.002	15.6	0.02	0.47	1.47	0.66	10.1	3.63	47.2	19.9	105	25.6	278	62.7	662	0.52	242	0.33
25-4-13	<0.002	19.8	0.03	0.54	1.94	0.91	12.9	4.76	60.8	25.2	131	32.3	347	74.0	845	0.56	300	0.31
Avg																0.58	198	0.29
SD																0.05	43.8	0.07

Tantahuatay Complex. Sample Tanta-351

351-19-1	0.008	29.9	0.18	2.80	4.81	1.28	20.9	6.24	71.8	26.7	126	27.2	261	52.6	808	0.39	42.2	1.18
351-19-2	0.005	34.3	0.15	2.28	4.35	1.13	20.0	6.68	82.7	32.9	163	35.5	350	69.7	1014	0.37	66.1	1.01
351-19-3	<0.002	26.3	0.08	1.52	3.25	0.85	16.0	5.28	66.8	26.3	129	28.1	275	54.9	806	0.36	84.9	0.91
351-19-4	0.030	23.3	0.36	5.43	9.57	2.47	40.3	11.7	130	45.5	205	42.5	403	77.1	1339	0.38	17.4	1.34
351-33-1	0.045	50	0.50	7.89	20.4	5.50	92.3	26.6	289	99.4	438	90.1	836	156	3010	0.39	37.7	1.62
351-33-2	0.012	64.3	0.18	3.05	5.79	1.55	30.2	10.9	146	60.1	294	62.3	594	116	1858	0.36	92.1	1.52
351-33-3	0.012	61.4	0.17	3.01	5.88	1.40	28.9	10.1	127	50.8	250	53.6	516	100	1578	0.33	91.8	1.22
351-33-4	0.017	62.7	0.18	3.21	6.01	1.47	30.1	10.3	135	54.5	269	58.4	556	109	1713	0.33	84.2	1.28
351-6	0.020	22	0.34	5.63	8.81	2.05	35.7	10.4	115	41.0	185	38.0	358	68.0	1208	0.35	14.1	1.37
351-17	0.014	59	0.15	2.84	5.32	1.21	25.7	9.27	121	49.7	248	54.4	530	105	1559	0.32	89.5	1.26
Avg																0.36	75.2	1.27
SD																0.03	31.4	0.21

Tantahuatay Complex. Sample Tanta-352

352-17	0.009	11.1	0.15	2.28	3.59	1.13	13.4	3.77	43.2	15.82	77.4	16.9	167	36.5	485	0.50	17.7	0.66
352-22	0.007	10.5	0.12	2.25	3.88	1.04	15.6	4.57	51.0	18.43	85.7	18.7	182	36.2	550	0.41	18.5	0.87
352-24	0.048	7.06	0.03	0.47	1.21	0.21	7.59	2.82	37.7	15.36	75.6	17.0	166	32.9	446	0.21	89.8	0.23
352-29	<0.002	10.7	0.06	1.12	2.27	0.74	9.91	3.08	35.5	13.70	67.6	15.6	157	33.3	415	0.47	45.1	0.58
352-30	0.015	65.2	0.21	3.59	6.25	1.85	30.2	9.76	123	50.01	262	63.6	688	144	1624	0.41	72.7	0.98
352-35	<0.002	8.47	0.05	0.84	1.75	0.61	7.97	2.39	27.7	10.31	49.5	11.5	118	24.6	315	0.50	48.5	0.61
Avg																0.44	46.8	0.64
SD																0.11	28.8	0.26

Tantahuatay Complex. Sample Tanta-355

355-5-1	<0.002	8.97	0.02	0.33	0.65	0.28	4.29	1.44	18.1	7.38	38.9	9.0	97	22.0	237	0.51	126	0.50
355-5-2	<0.002	9.98	0.05	0.98	2.07	0.68	8.60	2.97	35.6	13.7	67.6	15.7	168	36.2	426	0.49	49.2	0.65
355-22-1	<0.002	6.76	0.02	0.41	0.90	0.38	4.27	1.48	18.4	7.40	39.0	9.6	105	23.7	236	0.59	84.6	0.60
355-22-2	<0.002	7.79	0.04	0.65	1.13	0.38	5.46	2.01	24.4	9.82	52.0	12.3	138	30.9	313	0.46	47.9	0.53
355-23	<0.002	10.3	0.07	1.39	2.50	0.87	9.99	2.99	34.3	12.8	59.6	13.1	134	27.7	384	0.53	30.7	0.67
355-74-1	<0.002	9.95	0.08	1.60	2.87	0.93	11.2	3.25	36.1	13.4	64.6	14.4	153	31.7	411	0.50	25.7	0.74
355-74-2	<0.002	9.70	0.08	1.51	2.91	0.91	11.1	3.33	36.9	13.4	65.2	14.2	151	31.3	414	0.49	28.5	0.73
355-89-1	<0.002	9.04	0.04	0.71	1.29	0.54	5.77	1.87	22.1	8.47	43.5	10.7	123	27.4	277	0.60	53.1	0.58
355-89-2	<0.002	9.28	0.06	0.81	1.62	0.61	6.87	2.05	24.0	9.05	45.9	10.7	119	26.2	291	0.56	52.9	0.61
355-92-1	0.009	13.8	0.08	1.59	3.25	1.09	14.7	4.38	49.9	18.0	87.4	19.2	196	40.5	564	0.48	40.9	0.82
355-92-2	<0.002	11.0	0.03	0.50	1.19	0.39	5.92	2.02	25.1	9.87	51.8	12.1	131	28.8	321	0.45	119	0.57
355-105-1	<0.002	6.16	0.02	0.16	0.49	0.24	2.69	0.93	11.8	5.10	27.3	6.8	78	18.7	166	0.65	275	0.42
355-105-2	<0.002	10.0	0.03	0.56	1.21	0.55	6.45	2.42	32.2	14.1	76.9	19.1	211	51.7	466	0.60	89.7	0.43
355-120	<0.002	17.6	0.03	0.49	1.69	0.54	11.4	5.14	78.0	34.2	190	47.2	513	108	1114	0.38	283	0.23
355-122	<0.002	6.95	0.02	0.38	0.79	0.34	4.18	1.40	17.9	7.28	37.7	9.1	103	23.7	233	0.57	88.0	0.51
355-138	<0.002	9.95	0.02	0.41	0.93	0.32	4.29	1.41	18.1	7.64	43.4	11.5	138	34.4	265	0.49	126	0.47
355-142	<0.002	12.8	0.03	0.55	1.18	0.39	6.54	2.31	27.5	11.1	57.1	13.5	146	31.3	358	0.43	115	0.54
355-173	<0.002	10.2	0.02	0.56	1.30	0.50	6.25	2.10	24.8	9.63	47.3	10.5	114	24.0	302	0.54	96.5	0.62
355-201-1	0.009	32.7	0.03	0.56	1.64	0.55	10.7	3.71	51.8	22.9	135	35.2	431	114	794	0.40	397	0.45
355-201-2	<0.002	18.3	0.05	1.06	2.26	0.65	10.2	3.64	45.7	19.2	107	27.6	331	84.3	660	0.41	84.7	0.46

355-214	<0.002	14	0.01	0.23	0.48	0.24	2.44	0.85	11.4	5.56	34.0	9.7	130	36.6	210	0.68	289	0.46
355-250	<0.002	43.1	0.05	0.87	1.91	1.00	11.1	4.04	54.7	23.3	127	31.4	364	83.7	767	0.66	251	0.57
Avg																0.51	88.9	0.56
SD																0.09	104	0.13

Tantahuatay igneous rock. Sample Tanta-356

356-9-1	<0.002	10.6	0.05	0.81	1.73	0.58	8.23	2.63	30.7	11.5	56.9	12.6	131	27.1	365	0.47	64.7	0.58
356-9-2	<0.002	12.5	0.08	1.75	3.81	1.20	14.2	4.13	46.7	16.4	75.3	16.1	159	32.1	493	0.49	35.7	0.79
356-9-3	<0.002	12.7	0.06	1.32	2.81	0.90	11.5	3.47	39.0	14.3	67.5	14.4	142	29.1	428	0.48	47.0	0.74
356-10-1	0.008	10.9	0.05	1.20	2.07	0.66	8.76	2.74	31.9	11.7	56.5	12.6	127	25.7	361	0.47	36.1	0.66
356-10-2	<0.002	11.9	0.07	1.28	2.64	0.99	11.7	3.57	40.0	14.5	67.5	14.7	146	29.6	437	0.54	44.0	0.74
356-11-1	<0.002	9.19	0.02	0.31	0.80	0.34	4.03	1.46	19.0	8.14	45.7	11.8	134	32.4	272	0.58	176	0.47
356-11-2	0.017	9.4	0.19	2.65	3.58	1.45	13.7	3.98	45.0	17.2	88.2	20.2	219	49.4	554	0.63	11.0	0.78
356-19-1	<0.002	10.8	0.03	0.54	1.35	0.45	6.31	2.06	25.7	10.2	51.6	12.0	122	26.7	327	0.47	116	0.54
356-19-2	<0.002	14.4	0.04	0.79	1.53	0.57	7.19	2.42	30.8	12.9	69.0	16.5	183	42.2	419	0.52	82.1	0.49
356-18-1	<0.002	8.27	0.03	0.42	0.98	0.42	4.39	1.47	18.4	7.41	40.3	9.7	111	25.8	250	0.61	106	0.51
356-18-2	<0.002	7.47	0.03	0.40	0.80	0.35	3.42	1.15	14.6	6.11	37.6	10.9	129	29.6	214	0.63	85.5	0.58
356-29-1	<0.002	7.31	0.02	0.35	0.84	0.39	4.39	1.45	19.1	8.08	46.1	11.2	126	30.8	272	0.62	117	0.37
356-29-2	0.006	5.59	0.03	0.43	1.01	0.42	4.77	1.69	21.6	9.00	49.9	12.2	139	33.9	299	0.59	71.1	0.34
356-77	<0.002	8.88	0.02	0.35	0.73	0.38	4.46	1.64	21.3	8.81	48.8	12.1	136	32.6	299	0.64	125	0.38
356-95-1	<0.002	9.38	0.13	2.15	3.70	1.24	14.7	4.34	49.0	17.9	85.0	17.9	178	37.8	543	0.51	17.3	0.70
356-95-2	<0.002	6.99	0.02	0.28	0.97	0.41	5.04	1.72	20.6	8.40	43.4	9.88	107	23.5	268	0.57	194	0.48
356-135	<0.002	7.93	0.03	0.43	0.86	0.42	5.04	1.77	22.4	9.74	54.6	13.4	151	36.9	331	0.61	86.8	0.39
356-155-1	<0.002	12.5	0.02	0.46	1.11	0.38	5.16	1.76	21.1	8.20	43.4	10.0	109	25.4	274	0.48	154	0.55
356-155-2	0.007	11.5	0.03	0.61	1.49	0.48	7.32	2.43	29.2	11.4	60.6	14.2	155	35.7	375	0.45	107	0.52
356-156-1	<0.002	12.5	0.09	1.82	3.43	1.18	14.3	4.22	46.0	16.5	77.3	16.7	168	33.7	493	0.51	29.7	0.80
356-156-2	<0.002	12.7	0.09	2.20	3.88	1.29	15.4	4.42	47.8	16.8	81.0	17.1	169	34.3	524	0.51	23.5	0.82
Avg																0.52	82.1	0.55
SD																0.06	52.3	0.16

Tantahuatay igneous rock. Sample Tanta-357

357-2	<0.002	13.3	0.10	2.01	3.65	1.17	14.9	4.35	49.9	18.1	88.9	19.8	210	45.1	580	0.48	27.6	0.55
357-3	<0.002	10.5	0.05	0.78	1.63	0.60	8.15	2.50	30.8	12.1	59.6	13.8	146	31.9	374	0.50	65.2	0.57
357-11	<0.002	14.4	0.11	2.47	4.89	1.57	19.0	5.34	59.2	21.0	95.8	21.0	215	44.2	636	0.50	26.5	0.87
357-44	<0.002	10.5	0.01	0.22	0.49	0.18	2.73	0.91	12.7	5.46	32.2	8.3	102	27.6	190	0.47	244	0.39
357-64	<0.002	9.93	0.01	0.25	0.41	0.19	1.89	0.66	9.0	3.95	22.8	5.8	73	18.1	132	0.67	150	0.38
Avg																0.50	65.2	0.55
SD																0.08	93.5	0.20

AntaKori porphyry 1. Sample Anta-PK

A2-2	<0.002	12	0.02	0.41	1.22	0.64	8.27	3.09	42.9	18.7	105.0	27.1	315	80.9	655	0.62	197	0.23
A2-3	<0.002	7.10	0.02	0.32	0.76	0.36	4.27	1.57	20.7	8.88	48.7	12.2	139	33.5	298	0.60	122	0.39
A2-13	<0.002	5.86	0.01	0.24	0.52	0.24	2.83	0.97	13.0	5.43	29.2	7.5	85	19.7	179	0.60	119	0.37
A2-8	<0.002	8.09	0.02	0.44	0.95	0.48	5.80	2.03	27.6	11.6	63.8	16.0	177	43.1	394	0.62	93.2	0.40
A2-29	<0.002	6.96	0.01	0.22	0.68	0.28	3.35	1.14	15.5	6.39	35.4	9.0	101	24.6	220	0.56	220	0.31
A2-32	<0.002	5.66	0.01	0.35	0.69	0.36	4.19	1.55	20.8	8.60	47.5	12.1	137	33.6	289	0.64	73.8	0.34
A2-23	0.008	6.30	0.01	0.25	0.60	0.29	3.74	1.30	17.9	7.50	41.1	10.4	118	28.5	254	0.59	144	0.37
A2-25	0.017	12.5	0.03	0.46	1.23	0.51	6.41	2.21	29.6	12.3	65.2	15.6	174	40.9	401	0.55	166	0.59
A2-34	<0.002	8.33	0.02	0.38	1.04	0.46	5.34	1.85	24.8	10.4	57.2	14.6	164	39.0	353	0.60	141	0.34
A2-26	0.025	6.51	0.03	0.41	0.86	0.41	4.90	1.66	21.7	9.34	50.6	12.8	144	34.9	306	0.61	76.6	0.39
A2-36	<0.002	8.10	0.02	0.34	0.92	0.39	4.98	1.77	23.8	10.2	56.9	14.4	164	39.6	341	0.55	145	0.35
A2-28	<0.002	8.88	0.02	0.57	1.21	0.61	6.80	2.30	30.9	13.0	70.8	17.9	202	48.1	431	0.65	76.1	0.39
A2-48	0.004	10.2	0.05	1.06	1.85	0.79	9.07	2.89	37.4	15.5	81.6	20.0	224	52.2	501	0.59	39.0	0.45
A2-42	<0.002	11.3	0.02	0.41	0.98	0.46	6.14	2.17	28.7	12.4	68.1	17.2	192	45.8	406	0.57	150	0.40
A2-60	<0.002	11.4	0.02	0.42	1.14	0.48	6.57	2.33	32.0	13.7	77.4	19.4	219	52.1	457	0.54	171	0.37
A2-45	<0.002	6.86	0.02	0.29	0.60	0.32	3.30	1.17	15.1	6.28	33.3	8.2	92	21.6	208	0.69	115	0.50
A2-54	0.005	8.07	0.02	0.40	0.86	0.40	5.00	1.66	22.6	9.60	52.5	13.1	151	36.0	319	0.59	98.8	0.38
A2-64	<0.002	7.18	0.02	0.35	0.93	0.41	5.03	1.75	23.7	10.2	56.1	13.9	154	38.7	341	0.58	125	0.38
A2-29	0.006	9.36	0.03	0.54	1.30	0.60	6.87	2.43	32.4	14.1	76.0	19.0	209	50.8	467	0.61	96.7	0.38
A2-12	<0.002	6.79	0.02	0.29	0.92	0.45	5.11	1.76	24.2	10.3	57.0	14.3	167	39.5	346	0.63	170	0.32
Avg																0.60	124	0.38
SD																0.04	45.2	0.07

AntaKori porphyry 2. Sample Anta-PF

A4-3	0.005	42.6	0.08	1.40	2.08	0.82	9.23	2.80	34.7	14.4	78.5	20.1	235	57.1	510	0.57	104	0.99
A4-6	<0.002	15.9	0.01	0.32	0.83	0.35	4.51	1.51	20.5	8.88	50.1	13.2	152	37.4	309	0.55	306	0.37
A4-11	0.005	11.1	0.01	0.29	0.53	0.28	3.42	1.22	16.9	7.49	43.3	11.6	139	37.2	264	0.64	160	0.31
A4-13	0.139	15.5	0.06	0.51	0.90	0.35	4.33	1.37	17.2	6.91	36.9	9.1	102	23.0	231	0.55	125	0.45
A4-18	0.023	20.8	0.09	1.58	2.96	1.04	13.1	4.06	48.2	18.7	95.7	22.6	239	54.9	602	0.51	56.4	0.62
A4-22	0.005	13.1	0.02	0.37	0.73	0.31	3.95	1.33	17.1	7.15	38.5	9.5	105	24.5	240	0.56	163	0.40
A4-27	<0.002	10.2	0.01	0.23	0.53	0.21	3.03	1.03	13.5	5.69	30.5	7.6	87	19.8	190	0.52	237	0.35
A4-29	0.064	13.2	0.06	0.91	1.68	0.64	7.69	2.45	31.2	12.9	71.2	17.8	210	53.8	438	0.54	62.0	0.40
A4-36	<0.002	8.16	0.02	0.35	0.77	0.27	3.39	1.14	14.1	5.75	30.5	7.5	81	18.3	189	0.51	119	0.43
A4-40	<0.002	11.9	0.02	0.36	0.77	0.31	3.84	1.27	16.6	6.84	35.6	8.8	99	21.7	222	0.55	168	0.43
A4-53	0.004	17.4	0.03	0.61	1.54	0.59	7.64	2.55	32.7	13.4	70.2	16.9	178	40.8	429	0.53	166	0.56
A4-54	<0.002	16.4	0.02	0.48	1.18	0.41	5.93	1.91	24.2	9.96	52.0	12.8	138	31.0	326	0.47	193	0.47
A4-66	<0.002	14.6	0.02	0.43	1.16	0.42	5.43	1.82	22.9	9.11	47.1	11.5	124	28.0	300	0.51	207	0.41
A4-92	0.004	7.58	0.05	0.80	1.37	0.68	6.60	2.36	33.4	15.1	85.8	20.9	227	54.2	518	0.69	37.2	0.48
A4-116	0.014	9.47	0.02	0.31	0.70	0.27	3.44	1.14	14.8	6.22	31.8	8.2	92	20.9	199	0.52	164.5	0.41
Avg																0.54	163	0.43
SD																0.05	71.2	0.16

Cerro Jesus. Sample CJ

CJ3	0.014	4.38	0.04	0.86	2.21	1.24	12.0	4.22	51.5	19.8	97.4	23.4	253	48.1	647	0.74	30.1	0.13
CJ5	<0.002	7.25	0.02	0.42	1.46	0.94	11.9	4.65	65.2	27.4	143	35.6	400	80.7	892	0.69	136	0.13
CJ6	0.009	17.1	0.06	1.04	2.16	1.13	13.1	4.37	56.0	21.5	107	25.3	282	55.3	690	0.65	78.6	0.52
CJ12	<0.002	12.8	0.03	0.71	2.19	1.32	14.0	5.29	71.4	27.8	147	37.0	432	76.6	940	0.73	128	0.19
CJ15	0.017	11	0.02	0.53	1.93	1.28	16.3	6.64	95.0	40.3	208	51.2	544	101.9	1241	0.70	175	0.12
CJ18	0.004	21	0.05	1.35	2.94	1.51	16.6	5.38	66.4	23.3	119	27.5	298	55.9	767	0.66	78.1	0.48
CJ24	0.004	8.79	0.04	0.75	1.80	0.87	10.9	3.62	48.0	18.1	93.0	21.4	227	44.6	565	0.60	64.8	0.36
Avg																0.69	79	0.19
SD																0.05	50	0.17

Cerro Choro Blanco. Sample CB

CHCB33	<0.002	15	0.03	0.50	1.64	0.80	9.57	3.26	43.6	18.1	95.4	25.4	305	58.9	592	0.61	226	0.27
CHCB43	<0.002	15.8	0.05	1.03	2.05	0.92	10.8	3.57	45.9	18.7	97.2	25.2	292	58.5	614	0.60	70.1	0.32
CHCB45	0.024	20.3	0.03	0.85	2.15	1.01	12.3	4.65	62.0	24.9	131	33.1	381	76.3	836	0.60	139	0.34
CHCB59	0.028	17.9	0.05	0.91	2.01	0.98	11.6	4.16	54.2	22.3	117	31.0	365	69.4	748	0.62	100	0.28
CHCB60	0.023	19.9	0.03	0.61	1.69	0.77	9.90	3.87	48.6	19.5	104	26.5	307	61.6	656	0.57	207	0.35
CHCB64	<0.002	17.1	0.03	0.62	1.30	0.64	7.55	2.68	34.2	13.7	71.9	18.6	209	42.5	453	0.62	131	0.42
CHCB67	0.007	20.4	0.03	0.75	2.00	1.01	12.5	4.60	61.1	25.3	136	35.2	399	79.5	841	0.61	167	0.29
CHCB69	<0.002	20.8	0.03	0.76	1.81	0.94	11.5	4.22	55.1	22.9	120	31.0	347	72.3	766	0.63	151	0.36
CHCB73	0.004	10.3	0.03	0.67	1.37	0.62	7.17	2.61	33.7	13.6	75.3	19.4	230	44.9	451	0.60	72.2	0.33
CHCB82	0.003	16.1	0.02	0.66	1.68	0.77	8.83	3.30	44.2	18.3	99.2	26.4	303	62.1	608	0.61	141	0.26
CHCB85	0.011	30.6	0.06	1.20	2.78	1.31	16.8	6.11	79.3	31.6	161	40.7	461	86.6	1024	0.58	136	0.47
CHCB97	<0.002	14.3	0.05	0.87	1.75	0.84	9.34	3.22	43.0	17.3	89.6	24.0	282	55.8	551	0.63	76.1	0.28
CHCB103	0.005	16.3	0.03	0.61	1.44	0.66	8.01	2.80	36.5	15.5	78.4	21.3	249	48.1	497	0.59	146	0.34
CHCB105	0.049	17.4	0.05	0.79	2.33	1.03	14.1	4.94	61.2	26.4	127	33.3	343	59.1	761	0.55	151	0.41
CHCB106	0.014	9.67	0.02	0.37	1.05	0.52	6.01	2.40	31.0	14.0	70.4	19.0	221	45.5	441	0.63	172	0.22
CHCB112	0.004	16.5	0.02	0.62	1.69	0.94	10.7	3.94	51.3	21.1	112	29.7	350	69.6	725	0.67	165	0.26
Avg																0.61	144	0.33
SD																0.03	44.6	0.07

Cerro Caballerisa. Sample CAB

CAB1	0.128	17.3	0.07	0.86	1.99	0.94	12.4	4.81	64.1	27.1	145	36.1	421	80.7	886	0.58	107	0.24
CAB12	0.040	14	0.04	0.62	1.29	0.64	7.45	2.64	34.8	14.6	78.2	19.4	227	48.4	481	0.63	109	0.40
CAB23	0.015	18.1	0.03	0.69	1.86	0.91	11.4	4.24	55.8	23.8	125	31.0	357	72.1	776	0.60	162	0.30
CAB25	0.058	11.6	0.05	0.83	1.61	0.71	7.13	2.46	30.4	12.4	63.8	17.3	224	38.2	400	0.64	62.1	0.29
CAB30	0.003	12.5	0.03	0.58	1.56	0.77	9.84	3.64	47.2	20.3	104	27.0	302	63.7	650	0.60	132	0.29
CAB32	<0.002	31.4	0.04	0.86	2.67	1.28	16.3	5.84	75.6	32.1	171	43.8	511	104	1089	0.59	264	0.49
CAB47	0.145	11.3	0.08	0.84	1.53	0.63	7.92	2.86	36.5	15.7	83.9	21.2	234	55.2	517	0.55	56.3	0.37
CAB58	0.013	20.3	0.03	0.73	1.79	0.84	10.2	3.66	48.4	19.9	106	26.0	296	59.8	639	0.60	157	0.40
CAB59	0.002	13.9	0.03	0.53	1.26	0.55	7.18	2.51	31.7	13.7	69.0	18.4	204	43.6	436	0.55	146	0.45
CAB66	<0.002	18.7	0.04	0.74	2.17	1.00	13.0	4.66	63.1	26.5	134	35.7	377	82.1	832	0.58	170	0.31

CAB76	0.052	20.4	0.05	0.99	2.37	0.94	13.3	4.12	55.4	22.1	112	30.1	306	71.5	680	0.51	113	0.47
CAB85	<0.002	18.8	0.02	0.63	1.87	0.93	12.3	4.29	65.2	24.5	148	35.3	416	85.8	801	0.59	204	0.20
CAB94	0.004	15.8	0.04	0.63	1.62	0.77	8.78	3.69	40.5	21.1	91.6	26.8	284	56.6	645	0.62	146	0.49
CAB105	0.002	15.7	0.02	0.59	1.78	0.74	10.8	3.65	54.6	22.3	116	34.1	325	79.4	682	0.51	184	0.24
CAB116	0.005	13.4	0.02	0.63	1.90	0.78	11.3	4.33	57.3	24.3	126	31.6	345	71.9	782	0.51	146	0.27
Avg																0.59	146	0.31
SD																0.04	52.7	0.10

Cerro Las Gordas. Sample LG

SG3	<0.002	18.7	0.03	0.81	1.66	0.75	9.89	3.60	47.2	19.7	108	27.4	341	63.1	655	0.56	109	0.31
SG18	<0.002	12.9	0.02	0.51	1.43	0.69	8.92	3.28	39.4	16.6	81.3	22.6	249	46.1	528	0.59	164	0.31
SG41	<0.002	8.31	0.03	0.64	1.33	0.66	6.29	1.93	25.9	9.30	49.4	13.2	159	27.7	302	0.70	62.1	0.30
SG43	0.047	15.2	0.06	1.00	2.44	1.12	11.8	4.47	52.3	22.9	112	29.3	341	63.1	747	0.64	85.3	0.30
SG47	0.005	16.9	0.03	0.72	1.43	0.72	8.82	3.04	41.0	15.9	89.3	22.1	279	50.7	527	0.62	107	0.32
SG54	0.026	12.1	0.05	0.89	1.97	0.78	8.71	3.18	38.0	15.6	82.0	21.3	248	47.6	529	0.57	69.2	0.32
SG59	<0.002	19.4	0.03	0.76	1.86	1.01	10.8	4.02	48.6	21.0	105	27.6	334	61.0	689	0.69	144	0.34
SG60	0.056	11.1	0.05	0.70	1.41	0.69	7.17	2.40	32.5	12.7	70.8	18.0	234	44.5	406	0.66	73.3	0.29
SG71	0.004	10.8	0.04	0.99	1.69	0.71	8.28	2.62	36.3	12.7	77.5	17.7	218	43.4	444	0.58	42.8	0.31
SG74	0.098	16.9	0.06	1.02	1.68	0.88	8.82	3.61	45.1	18.2	102	23.2	332	56.6	651	0.70	62.8	0.34
SG78	0.005	14.7	0.04	1.12	1.80	0.86	9.42	3.20	43.9	16.6	96.1	22.0	295	54.4	566	0.64	48.5	0.30
SG90	0.009	13.9	0.03	0.60	1.31	0.61	7.18	2.43	34.6	13.3	72.6	18.6	242	44.9	436	0.61	116	0.25
SG99	0.032	13.4	0.04	0.61	1.45	0.61	6.76	2.70	32.9	14.0	73.4	20.2	287	42.5	488	0.59	120	0.25
SG100	0.007	16.7	0.09	2.27	4.23	2.12	20	6.41	81.0	27.7	153	33.1	434	69.1	956	0.70	31.5	0.26
SG105	0.021	8.79	0.03	0.36	1.11	0.58	6.62	2.80	32.9	16.1	74.0	22.6	253	48.0	504	0.65	173	0.23
Avg																0.64	85.3	0.30
SD																0.05	43.9	0.03

Sill Coymolache. Sample CD

CD13	0.008	6.93	0.02	0.35	0.70	0.34	3.82	1.32	17.8	7.23	39.5	10.0	116	25.7	240	0.63	91.3	0.43
CD18	<0.002	7.44	0.02	0.32	0.89	0.42	4.58	1.58	21.8	8.74	48.8	12.7	157	31.7	285	0.64	145	0.28
CD24	0.007	6.85	0.02	0.45	1.05	0.46	5.21	1.86	24.0	10.3	56.0	14.7	176	37.3	333	0.61	80.8	0.37

CD27	0.003	7.23	0.03	0.65	1.20	0.61	6.26	2.21	28.3	11.5	62.5	15.5	186	39.4	381	0.68	47.1	0.46
CD37	0.005	14.2	0.04	0.79	1.58	0.71	8.36	3.02	39.5	16.2	86.2	21.2	243	51.8	527	0.60	82.0	0.58
CD38	0.004	7.64	0.02	0.36	0.78	0.37	4.58	1.64	22.7	9.60	53.9	13.8	160	36.0	319	0.60	105	0.39
CD51	0.016	6.53	0.02	0.35	0.75	0.33	3.82	1.42	18.9	7.94	44.0	11.5	136	30.7	265	0.60	90.5	0.35
CD68	<0.002	5.92	0.01	0.26	0.60	0.27	3.16	1.08	14.0	5.50	31.0	7.70	91.1	19.5	188	0.60	120	0.38
CD80	<0.002	7.26	0.01	0.24	0.53	0.30	3.03	0.98	13.5	5.42	30.4	7.61	93.8	18.9	182	0.72	149	0.38
CD84	0.018	10.2	0.04	0.75	1.33	0.61	7.16	2.42	32.8	12.7	71.6	17.6	206	43.4	423	0.61	56.1	0.36
CD103	0.003	9.27	0.03	0.66	1.31	0.64	6.93	2.46	34.1	14.3	76.3	19.7	229	49.4	457	0.64	63.7	0.33
CD104	0.021	6.57	0.05	0.70	1.16	0.50	5.95	2.08	25.8	10.7	55.9	14.4	164	36.2	341	0.58	35.9	0.46
CD119	0.016	8.60	0.04	0.74	1.44	0.60	6.44	2.58	29.8	13.3	64.9	17.7	217	41.1	432	0.60	51.9	0.41
CD121	<0.002	12.9	0.01	0.66	1.07	0.67	6.46	1.99	34.2	10.4	73.9	15.9	268	38.7	374	0.78	73.5	0.23
CD125	0.004	10.3	0.03	0.64	1.28	0.56	7.09	2.21	31.5	12.0	65.8	16.4	180	41.5	375	0.56	73.2	0.49
Avg																0.61	80.8	0.38
SD																0.06	33.8	0.09

Sill Coymolache. Sample 161025-5

12-9	0.016	7.66	0.05	0.55	1.20	0.53	5.65	1.98	24.6	10.2	55.7	13.7	155	35.9	349	0.62	71.1	0.43
12-10	0.023	5.15	0.04	0.56	1.18	0.55	4.74	1.55	17.8	6.80	34.4	8.7	98	21.2	226	0.71	45.1	0.54
12-11	0.015	8.84	0.15	2.59	5.01	1.60	21.6	6.65	77.3	28.0	128.4	27.9	271	51.9	837	0.47	15.2	0.71
12-12	0.006	9.04	0.02	0.35	1.01	0.44	5.60	2.04	26.6	11.4	62.4	16.2	185	42.1	383	0.57	174	0.33
12-16	0.020	12.0	0.05	0.41	0.91	0.41	5.37	1.97	25.9	10.8	60.1	15.1	174	39.3	362	0.57	147	0.60
12-22	0.030	7.95	0.02	0.53	1.14	0.49	5.95	2.18	28.3	12.0	64.6	16.6	194	43.8	398	0.57	76.0	0.38
12-23	0.009	8.62	0.04	0.29	0.91	0.44	5.29	1.87	25.8	10.6	59.0	15.4	181	39.8	356	0.61	212	0.37
12-28	0.013	6.30	0.06	0.47	0.95	0.46	5.01	1.69	20.9	8.48	46.2	11.7	134	31.3	293	0.65	61.3	0.44
12-29	<0.002	7.01	0.03	0.65	1.18	0.48	5.65	1.86	23.3	9.39	49.6	12.8	142	31.2	309	0.57	44.7	0.42
12-35	<0.002	5.81	0.02	0.38	0.89	0.40	4.80	1.75	21.9	9.56	52.4	13.3	152	35.5	321	0.59	82.4	0.38
12-37	0.005	9.12	0.02	0.42	0.95	0.47	5.56	1.99	27.6	11.4	62.7	16.2	193	40.8	383	0.63	114	0.39
12-39-1	0.029	8.36	0.05	0.43	1.20	0.55	6.08	2.08	27.6	11.7	63.5	16.1	184	40.8	378	0.62	127	0.42
12-39-2	0.015	7.57	0.04	0.53	1.24	0.53	6.40	2.20	28.5	11.3	60.7	15.4	184	40.3	363	0.58	77.2	0.41
12-40	0.021	9.14	0.03	0.41	1.17	0.53	6.22	2.13	28.3	12.1	67.1	17.0	196	44.8	413	0.59	149	0.39
12-54	0.005	7.07	0.02	0.31	0.69	0.39	4.56	1.59	20.7	8.69	47.6	11.9	140	31.9	291	0.67	116	0.40

I2-60	<0.002	5.86	0.02	0.46	0.90	0.43	5.05	1.59	20.5	8.45	44.8	11.4	132	30.1	283	0.61	56.9	0.45
I2-61	0.004	6.17	0.08	1.13	1.66	0.79	7.07	2.20	26.3	10.2	53.4	13.5	152	32.5	339	0.71	18.6	0.59
I2-105	<0.002	7.20	0.01	0.30	0.67	0.31	3.70	1.33	17.8	7.23	39.5	10.2	118	26.5	250	0.60	126	0.40
Avg																0.61	79.8	0.42
SD																0.06	54.1	0.10

San Miguel. Sample SCO-1

I12-1	0.017	13.9	0.05	0.98	2.08	1.03	10.6	3.59	44.8	19	100	25.4	279	61.8	611	0.67	69.2	0.30
I12-2-1	<0.002	14	0.02	0.55	1.41	0.64	8.06	2.69	34.8	14.2	74.5	17.6	192	43.3	460	0.57	148	0.66
I12-2-2	<0.002	12.5	0.04	0.45	1.44	0.57	7.36	2.48	33.1	13.9	75.3	18.8	205	47.9	479	0.53	205	0.43
I12-3	<0.002	14.7	0.04	0.41	1.53	0.56	8.67	3.20	39.4	17.4	94.2	21.8	247	57.1	575	0.47	304	0.48
I12-4	0.008	8.98	0.06	1.17	2.22	0.96	10.7	3.18	38.7	14.7	74.9	18.2	206	43.3	472	0.60	33.5	0.39
I12-5-1	0.125	13.9	0.07	0.75	1.85	0.79	10.6	3.83	47.3	19.2	107	27.4	297	68.1	705	0.54	104	0.27
I12-5-3	<0.002	18.5	0.03	0.54	1.51	0.74	9.76	3.45	42.8	17.9	90.8	22.6	257	53.9	582	0.58	219	0.42
I12-6	<0.002	14.6	0.03	0.57	1.30	0.59	7.24	2.47	31.5	12.4	63.6	15.4	162	36.8	413	0.59	135	0.62
I12-7	<0.002	8.74	0.04	0.75	1.45	0.68	7.75	2.51	31.7	13.3	68.8	17.3	181	42.6	447	0.62	52.3	0.41
I12-8	<0.002	16.2	0.03	0.57	1.31	0.71	8.62	2.85	37.1	15.3	81.4	21.4	231	51.9	527	0.65	152	0.42
I12-9	<0.002	10.1	0.03	0.56	1.19	0.54	6.79	2.53	31.5	13.4	73.9	18.4	210	49.0	456	0.58	88.7	0.35
I12-10	<0.002	15.1	0.03	0.54	1.20	0.58	6.94	2.47	31.4	13.0	66.7	16.7	182	41.2	442	0.61	141	0.48
I12-11	<0.002	12.1	0.02	0.47	1.04	0.50	6.03	2.10	28.0	11.7	63.4	16.1	177	40.0	395	0.61	133	0.41
I12-12	<0.002	13.3	0.03	0.51	1.28	0.63	7.54	2.60	35.3	15.0	82.0	21.6	242	55.2	519	0.62	148	0.26
I12-13	<0.002	9.18	0.02	0.43	1.17	0.52	6.41	2.33	31.0	12.9	69.1	18.1	201	47.1	435	0.58	132	0.31
I12-14	<0.002	11.8	0.02	0.45	1.04	0.48	6.19	2.11	27.2	10.9	57.1	14.1	152	34.0	372	0.58	141	0.52
I12-16	<0.002	18.5	0.04	0.68	1.80	0.86	10.8	3.96	50.9	21.7	117	29.7	322	75.0	740	0.60	166	0.31
I12-17	<0.002	10.3	0.07	1.04	2.05	0.90	10.2	3.21	39.3	15.5	80.8	20.2	217	51.9	524	0.60	44.9	0.34
I12-18	<0.002	9.85	0.02	0.48	1.07	0.51	6.20	2.30	28.3	12.6	65.9	17.4	200	47.2	405	0.60	107	0.32
I12-19	<0.002	8.99	0.04	0.89	1.62	0.71	8.46	2.71	34.2	13.7	70.1	18.4	201	46.0	467	0.58	42.0	0.35
I4-3	<0.002	15.9	0.02	0.50	1.52	0.78	10.4	3.99	51.4	22	117	28.5	317	69.3	719	0.60	226	0.32
I4-4	0.006	18.9	0.03	0.72	1.88	0.76	10.2	3.51	42.8	17.6	93.2	22.6	238	54.7	612	0.53	159	0.56

14-11	<0.002	14.8	0.02	0.54	1.48	0.70	10.0	3.57	49.6	21	116	29.3	325	75.5	741	0.55	172	0.29
14-19	0.003	14.7	0.03	0.48	1.29	0.57	7.50	2.72	33.4	13.9	73.5	18.0	192	44.7	457	0.56	187	0.51
14-35	<0.002	19.9	0.03	0.82	1.69	1.04	12.2	4.39	56.7	23.2	117	28.6	298	68.1	770	0.70	116	0.39
14-43	<0.002	16.5	0.06	0.98	2.23	0.90	12.0	4.14	54.4	23	124	30.5	343	78.7	810	0.53	88	0.35
Avg																0.59	138	0.39
SD																0.05	63.1	0.11

San Miguel. Sample SCO-2

15-17	0.002	11.7	0.03	0.61	1.30	0.62	7.57	2.69	35.2	15.2	81.1	19.5	209	49.7	512	0.60	94.8	0.44
15-23	0.002	9.4	0.02	0.36	0.93	0.36	4.79	1.71	22.4	9.40	50.7	12.5	137	33.0	315	0.51	160	0.35
15-25	<0.002	10.3	0.03	0.41	1.32	0.56	8.90	3.05	38.5	15.5	87.1	21.4	243	55.2	545	0.50	187	0.32
15-26	<0.002	14.9	0.03	0.56	1.43	0.75	9.85	3.62	49.7	21.7	119	29.3	319	77.4	730	0.61	156	0.31
15-29	<0.002	9.98	0.02	0.41	0.99	0.46	5.60	1.87	24.0	9.94	53.6	13.3	144	33.9	348	0.59	133	0.49
15-30-1	0.081	9.61	0.04	0.62	1.29	0.62	7.56	2.70	35.6	15.3	84.3	20.7	233	57.0	513	0.60	74.5	0.36
15-30-2	0.052	14.7	0.04	0.67	1.45	0.58	8.25	2.84	35.5	15.0	82.0	19.2	206	48.2	507	0.51	110	0.48
15-33	<0.002	18	0.03	0.69	1.91	0.86	11.8	4.28	59.5	25.2	138	34.8	381	88.7	843	0.55	168	0.30
15-34	0.003	8.25	0.03	0.40	1.07	0.52	5.53	2.01	27.1	11.1	60.7	15.3	175	40.9	383	0.65	128	0.37
15-63	<0.002	21.6	0.03	0.60	1.85	0.93	12.9	4.80	63.1	26.8	146	35.4	388	91.1	923	0.58	259	0.34
15-65	<0.002	9.12	0.01	0.33	0.87	0.42	5.74	2.19	28.6	12.0	65.1	16.2	179	42.7	414	0.58	165	0.30
15-67	0.014	12.6	0.02	0.33	0.92	0.48	5.59	2.02	25.4	10.5	55.4	13.4	148	34.6	349	0.65	240	0.45
15-70	0.090	12.6	0.33	1.90	3.16	1.38	15.1	4.59	53.4	20.7	104	24.4	264	57.3	675	0.61	25.4	0.46
15-74	0.004	14.7	0.03	0.56	1.52	0.80	10.2	3.86	53.2	23.1	126	32.4	357	81.9	789	0.62	165	0.24
15-90	<0.002	11.6	0.03	0.62	1.36	0.61	7.30	2.65	34.8	14.6	79.3	20.6	244	50.2	486	0.59	95.7	0.36
15-127	0.003	12.3	0.02	0.51	1.31	0.60	7.97	2.86	38.9	16.7	91.6	23.3	268	61.4	568	0.57	142	0.30
15-154-1	<0.002	9.14	0.02	0.35	0.92	0.47	6.12	2.21	28.6	12.2	67.7	17.4	198	45.8	413	0.61	160	0.31
15-154-2	<0.002	12.5	0.03	0.49	1.53	0.73	8.90	3.16	41.8	17.4	95.5	25.0	289	64.9	582	0.60	182	0.29
15-174	<0.002	9.38	0.02	0.42	1.07	0.49	5.71	2.14	27.8	11.9	66.5	16.8	188	44.7	415	0.60	134	0.32
Avg																0.60	156	0.34
SD																0.04	54.3	0.07

San Miguel. Sample SCO-3

I3-11	0.004	11.5	0.03	0.57	1.31	0.62	7.72	2.83	37.0	15.8	85.8	21.4	247	54.7	537	0.59	108	0.38
I3-14	0.009	11.5	0.04	0.85	1.95	0.86	8.86	3.13	40.1	16.4	85.5	21.5	252	52.2	541	0.63	72.1	0.42
I3-15	0.005	9.75	0.09	1.71	3.05	1.23	12.4	3.97	45.1	17.1	86.1	20.9	234	47.2	557	0.61	23.4	0.48
I3-22	0.002	8.20	0.01	0.44	0.94	0.49	5.40	1.81	23.2	9.70	52.0	13.6	169	33.5	323	0.66	93.6	0.31
I3-26	0.013	15	0.03	0.56	1.57	0.68	9.49	3.47	45.0	19.4	107	26.9	301	70.8	697	0.54	173	0.27
I3-35	<0.002	18.2	0.03	0.59	1.81	0.77	11.1	4.03	54.4	22.4	121	29.6	329	73.7	769	0.52	215	0.37
I3-37-1	<0.002	13.6	0.03	0.64	1.61	0.67	9.71	3.78	48.2	20.0	105	25.5	273	59.6	675	0.51	122	0.41
I3-37-2	0.006	9.92	0.02	0.58	1.33	0.65	8.32	3.06	41.1	16.8	89.9	22.6	251	55.0	569	0.59	91.2	0.34
I3-41	<0.002	14.9	0.03	0.66	1.54	0.73	9.68	3.43	46.3	19.7	107	26.6	294	67.6	658	0.58	122	0.36
I3-42	<0.002	9.82	0.02	0.40	1.09	0.50	6.40	2.26	29.8	12.4	66.1	16.6	187	43.6	427	0.58	157	0.39
I3-43	0.017	10.1	0.02	0.39	0.92	0.43	5.16	1.78	23.7	9.82	52.4	13.4	155	34.2	333	0.60	141	0.34
I3-44	<0.002	7.37	0.02	0.33	1.06	0.41	5.34	1.92	26.0	11.1	61.8	16.0	183	44.5	391	0.52	165	0.28
I3-45	0.092	9.88	0.08	0.57	1.16	0.46	6.05	2.12	28.0	11.5	62.0	16.5	194	40.9	394	0.53	80.9	0.29
I3-46	0.002	17.4	0.03	0.62	1.54	0.69	9.08	3.34	45.3	19.5	105	26.4	290	67.2	667	0.56	158	0.37
I3-68	0.061	16.3	0.05	0.90	1.32	0.62	8.03	2.68	34.9	14.4	76	18.5	204	45.4	496	0.58	61.9	0.45
I3-73-1	0.004	11.9	0.02	0.44	1.47	0.71	9.43	3.60	49.8	21.4	120	29.7	332	73.8	735	0.58	205	0.23
I3-73-2	<0.002	8.32	0.01	0.29	0.77	0.35	4.76	1.73	22.5	9.50	52.7	13.3	150	35.5	329	0.55	177	0.32
I3-81	0.005	8.15	0.01	0.27	0.71	0.36	5.06	1.72	23.2	9.76	55.5	14.1	160	37.1	341	0.58	182	0.32
I3-82	<0.002	13.6	0.03	0.67	1.69	0.79	9.33	3.47	47.2	20.0	111	27.8	311	67.3	678	0.61	117	0.40
I3-88	<0.002	7.89	0.02	0.35	0.89	0.42	4.86	1.68	21.6	8.97	48.7	12.1	140	30.9	306	0.61	132	0.41
I3-90	<0.002	12.5	0.03	0.52	1.47	0.63	7.92	2.96	39.3	16.7	91.1	22.9	264	57.5	563	0.56	159	0.38
I3-93	0.003	12.9	0.03	0.47	1.03	0.48	5.96	2.14	27.2	10.9	57.5	13.8	148	34.4	378	0.59	140	0.49
Avg																0.58	136	0.37
SD																0.04	48.3	0.07

San Nicolas. Sample SN

SN5	0.006	9.11	0.06	1.15	1.90	0.78	7.71	2.55	33.8	13.1	75.2	17.6	231	42.1	456	0.62	30.1	0.45
SN11	<0.002	10.7	0.02	0.51	1.26	0.47	6.50	2.20	24.9	10.3	47.5	11.3	123	21.3	322	0.50	120	0.66
SN29	<0.002	10.3	0.09	1.94	3.15	1.03	12.1	4.04	42.8	16.6	77.5	17.1	190	31.9	518	0.51	19.9	0.71
SN35	0.005	7.68	0.02	0.47	0.96	0.41	5.33	1.56	23.7	8.18	49.9	12.4	135	31.9	275	0.55	76.8	0.40
SN37	<0.002	9.96	0.05	0.87	1.44	0.65	6.99	2.27	29.8	11.3	63.3	14.8	181	35.1	372	0.62	43.6	0.48

SN39	0.015	7.57	0.03	0.49	0.94	0.44	3.67	1.32	15.3	6.63	31.2	8.9	110	18.8	207	0.72	68.2	0.46
SN47	0.004	10.3	0.08	1.36	2.77	0.78	11.7	3.44	45.2	16.9	83.3	19.9	202	40.6	497	0.42	35.4	0.56
SN48	<0.002	12	0.04	0.91	1.64	0.75	8.30	2.79	37.4	14.3	82.7	17.9	254	46.1	499	0.62	54.8	0.29
SN56	0.004	8.78	0.01	0.31	0.60	0.39	3.48	1.30	15.4	6.62	36.0	8.7	116	21.7	229	0.82	124	0.40
SN61	<0.002	7.08	0.03	0.51	1.12	0.45	5.14	1.85	22.9	10.4	51.5	13.4	165	33.3	334	0.57	70.2	0.44
SN64	0.022	8.02	0.02	0.37	0.72	0.35	3.52	1.14	14.4	5.41	30.2	7.4	95	18.0	193	0.66	97.1	0.43
SN70	0.027	6.52	0.11	1.70	2.45	1.12	10.4	3.01	43.6	14.8	79.0	20.0	221	44.3	444	0.68	12.7	0.56
SN77	<0.002	7.84	0.11	2.18	4.09	1.48	15.8	4.71	48.8	19.4	79.9	19.8	198	34.6	564	0.56	15.5	0.76
SN96	0.004	6.05	0.06	0.96	1.75	0.75	7.27	2.51	26.6	11.4	52.5	14.4	164	31.9	357	0.64	26.5	0.53
Avg																0.62	49.2	0.47
SD																0.10	37.3	0.13

Calipuy andesite. Sample Anta-6

A6-6	<0.002	12	0.03	0.47	1.11	0.45	6.74	2.17	28.1	11.4	60.7	14.9	163	36.8	376	0.50	140	0.52
A6-12	0.008	15	0.11	1.98	3.68	1.16	15.1	4.24	47.6	17.2	80.5	17.9	177	36.4	533	0.48	32.4	0.78
A6-69	0.008	10.4	0.06	1.12	2.02	0.70	9.09	2.58	28.5	10.7	51.7	12.1	121	26.8	344	0.50	38.1	0.65
A6-70	0.006	9.51	0.02	0.26	0.59	0.28	3.31	1.16	15.0	6.16	33.9	8.27	91.9	22.1	211	0.61	200	0.49
A6-72	<0.002	8.69	0.03	0.43	0.97	0.47	5.58	1.96	25.2	10.8	58.5	14.8	166	40.5	367	0.62	104	0.40
Avg																0.50	104	0.52
SD																0.07	70.5	0.15

Calipuy rhyolite. Sample Anta-8

A8-13	<0.002	11.4	0.02	0.32	0.65	0.34	4.39	1.53	20.8	8.85	51.1	13.3	145	37.0	310	0.62	166	0.36
A8-15	<0.002	12.5	0.01	0.27	0.79	0.33	4.47	1.48	18.9	7.86	43.1	10.7	116	27.6	274	0.54	313	0.47
A8-18	<0.002	13.7	0.02	0.36	0.78	0.35	4.46	1.46	18.6	8.01	43.7	10.9	122	31.6	285	0.58	189	0.44
A8-25	0.010	14.8	0.01	0.31	1.62	0.51	14.9	6.72	107	47.6	258	64.0	680	137	1553	0.31	574	0.15
A8-20	<0.002	9.17	0.01	0.20	0.47	0.23	2.69	0.96	13.0	5.87	34.2	9.1	111	30.4	208	0.62	262	0.31
A8-21	<0.002	3.50	0.02	0.53	1.49	1.00	9.62	3.31	39.5	14.6	68.3	14.6	140	26.1	462	0.80	42.4	0.31
A8-35	0.006	10.7	0.01	0.18	0.46	0.17	2.51	0.81	10.8	5.01	27.6	7.7	94	25.3	172	0.50	341	0.34
A8-42	<0.002	18	0.03	0.51	1.20	0.55	6.63	2.30	30.2	13.3	72.2	18.5	208	48.7	446	0.60	193	0.41
A8-31	<0.002	7.03	0.01	0.10	0.17	0.13	1.09	0.41	6.4	3.34	23.8	7.5	111	36.7	144	0.94	284	0.26

A8-38	0.005	5.64		0.10	0.24	0.20	2.16	0.80	12.2	6.10	39	12.3	179	52.3	237	0.85	345	0.17
A8-40	<0.002	12.7	0.01	0.38	1.05	0.47	6.40	2.34	30.9	13.7	74	18.5	208	45.6	466	0.56	213	0.24
A8-55	<0.002	9.79		0.15	0.33	0.14	2.13	0.75	10.5	4.72	27.1	7.2	87	20.3	166	0.49	347	0.24
A8-53	<0.002	13.9	0.01	0.35	0.73	0.30	3.80	1.25	16.2	6.72	35.9	9.4	106	23.3	228	0.55	191	0.41
A8-64	<0.002	10.7	0.02	0.33	0.89	0.34	4.82	1.60	20.5	8.46	44.9	11.5	130	27.8	282	0.49	202	0.35
A8-61	0.013	10.6	0.03	0.49	1.03	0.43	5.20	1.76	21.6	8.74	46.3	11.8	129	27.8	287	0.56	104	0.48
Avg																0.56	213	0.35
SD																0.16	126	0.13

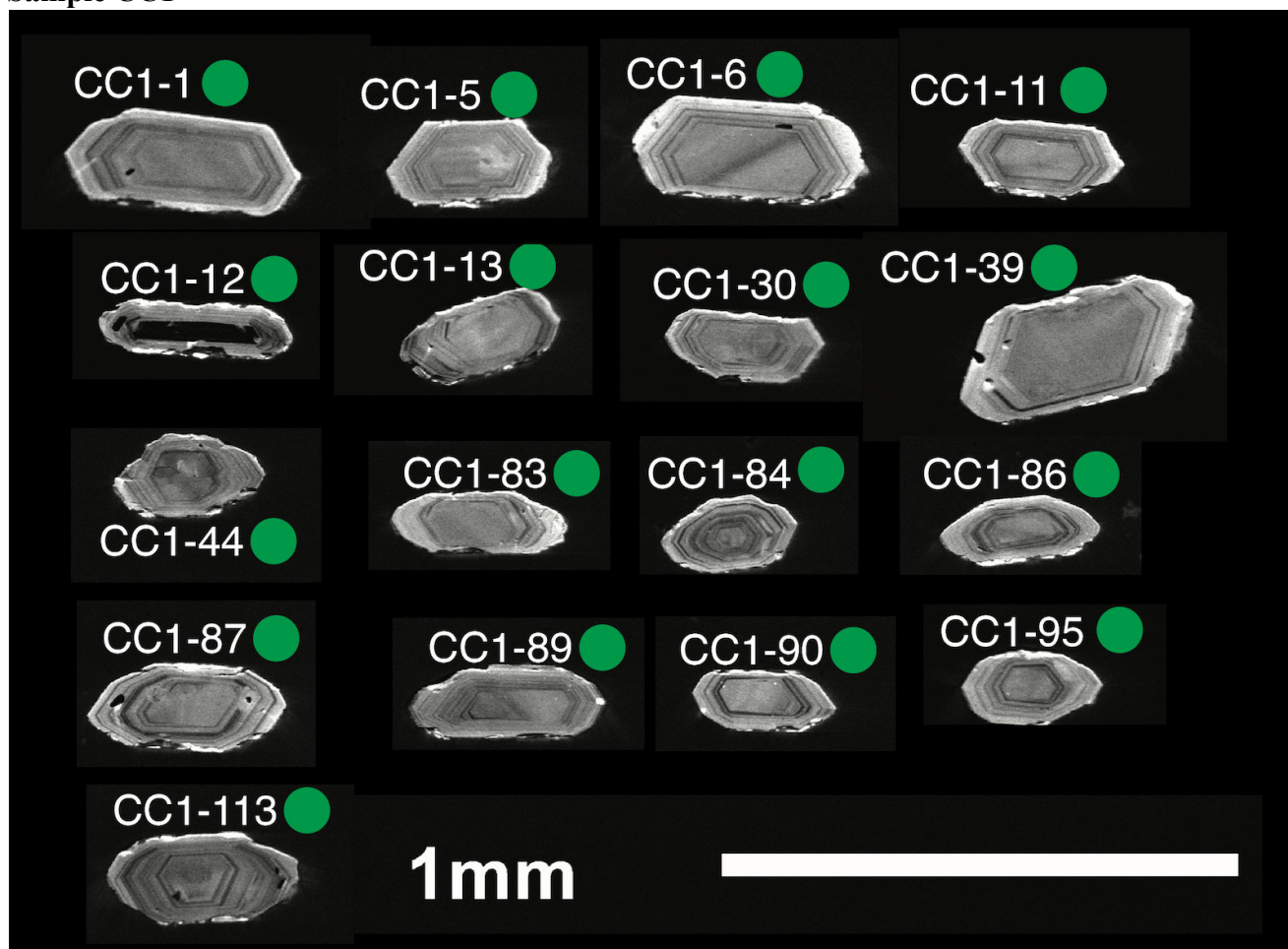
Cerro Hualgayoc. Sample 161025-6

I1-7	0.003	14	0.01	0.25	0.98	0.60	7.89	3.17	45.1	20.2	114	31.2	380	83.1	727	0.65	515	0.23
I1-4	0.003	5.97	0.02	0.50	1.66	1.07	12.5	4.28	53.4	19.9	91.6	20.3	199	35.3	631	0.71	92.0	0.41
I1-5	0.008	7.63	0.02	0.41	1.41	0.63	7.58	2.57	30.3	11.6	57.0	13.1	139	27.4	376	0.59	149	0.38
I1-10	<0.002	11.8	0.01	0.22	0.53	0.30	3.65	1.36	20.4	10.7	70.1	21.1	278	71.7	434	0.66	300	0.24
I1-11	0.005	44.4	0.06	1.20	2.61	1.03	11.4	3.87	46.0	18.9	97.6	25.7	312	59.5	626	0.58	185	0.71
I1-12	0.096	16.5	0.13	1.22	1.53	0.81	6.74	2.37	30.2	13.6	71.4	19.1	218	57.3	472	0.77	38.9	0.38
I1-13	0.020	17.1	0.02	0.41	0.87	0.37	5.47	1.83	24.5	10.3	53.2	12.5	141	32.2	340	0.52	207	0.49
I1-14	0.066	13.5	0.18	2.42	4.31	1.34	22.3	7.42	90.9	34.4	172	37.8	393	78.1	1060	0.42	22.9	0.55
I1-15	0.027	30	0.17	2.79	4.08	1.25	17.1	5.35	63.4	25.1	129	31.2	344	75.2	822	0.45	36.2	0.72
I1-16	<0.002	7.31	0.04	0.82	2.10	0.91	11.8	3.94	45.1	17.1	79.0	16.5	163	31.6	527	0.56	53.2	0.28
I1-17	0.085	27.7	0.08	1.04	1.73	0.80	9.77	3.09	40.9	17.5	97.3	24.8	290	74.1	649	0.59	102	0.45
I1-21	0.029	21	0.22	1.46	2.78	1.44	16.8	6.12	83.8	33.2	160	38.4	394	81.4	1061	0.64	62.9	0.29
Avg																0.59	97	0.40
SD																0.10	143	0.17

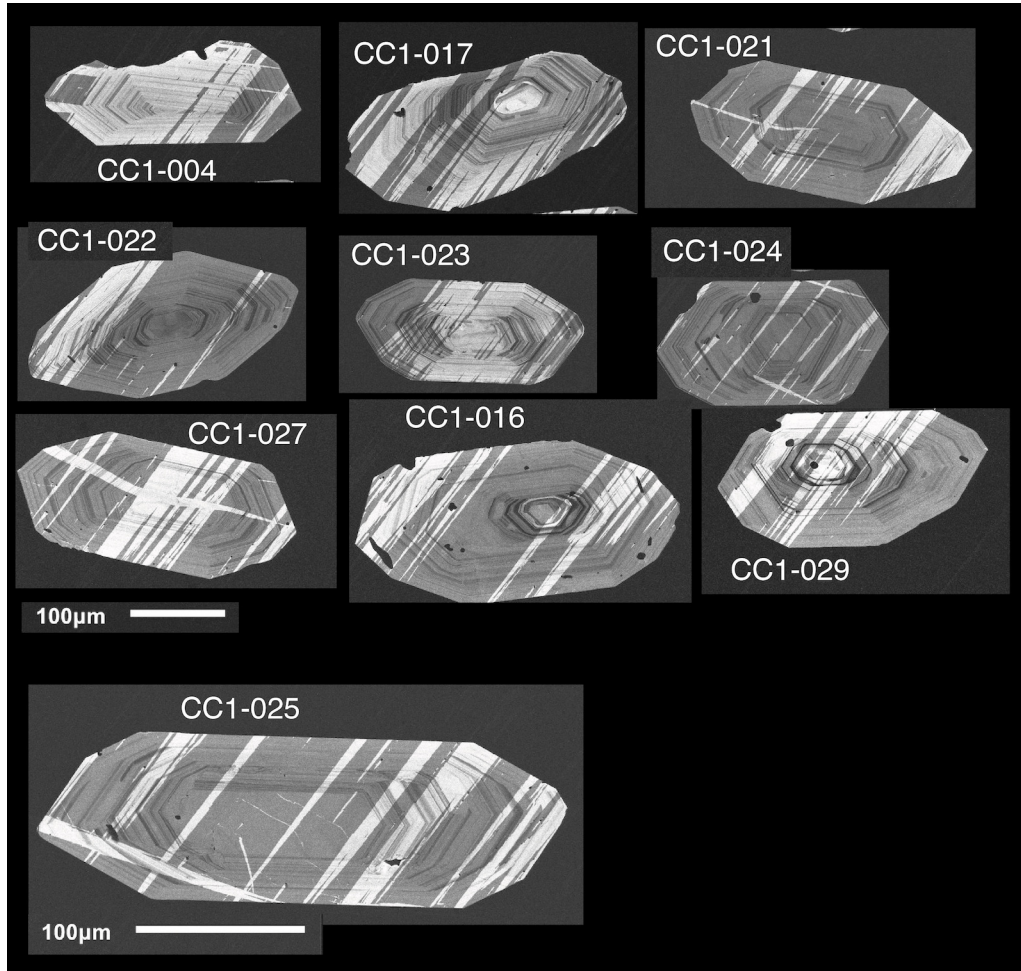
Appendix 3. SEM-CL images of analyzed zircon grains

Below are all zircons analyzed for this study. Grains with a green circle were used for trace-element analysis. Grains with a red circle were used for U-Pb dating. Grains with no circle were used for SHRIMP U-Pb dating. Some larger grains were analyzed in multiple spots.

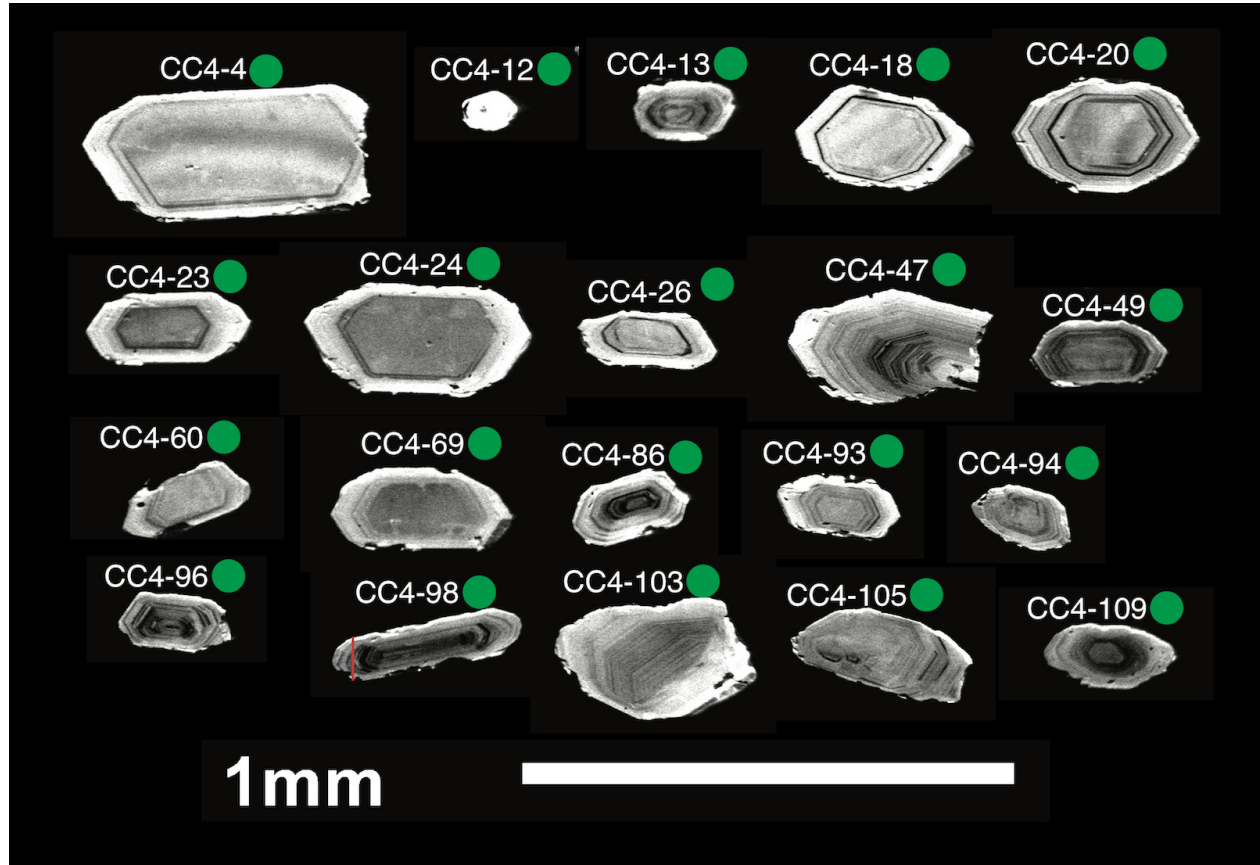
Sample CC1



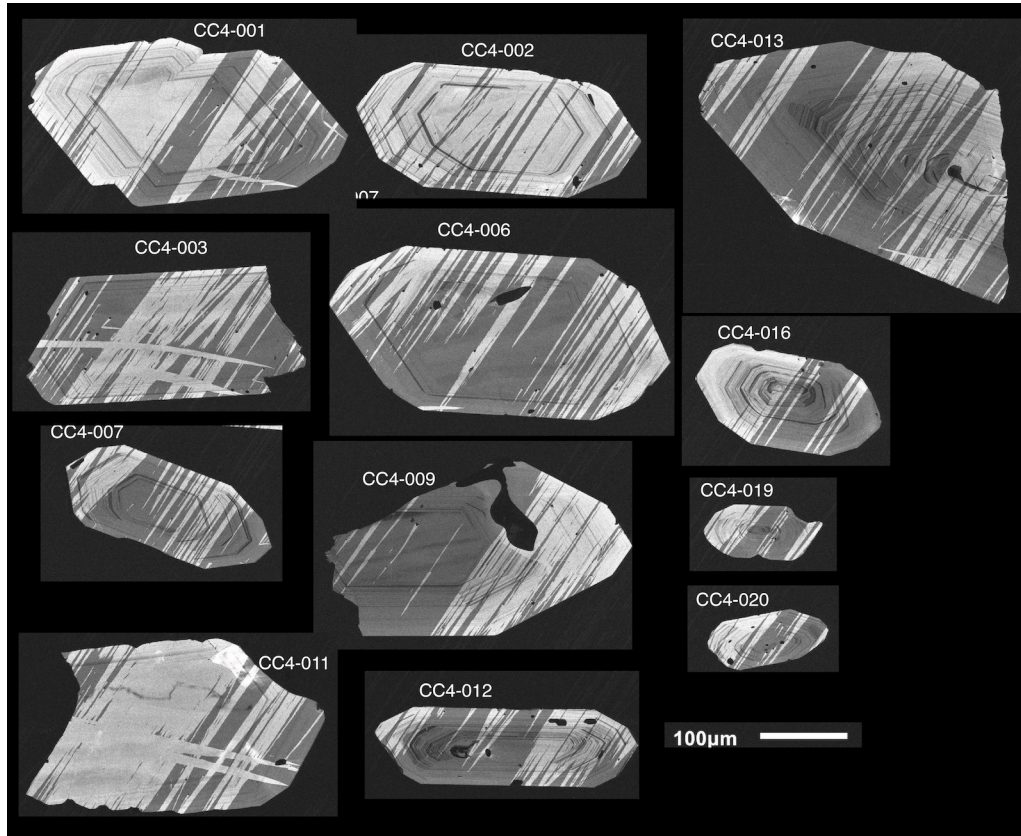
Sample CC1 (cont.)



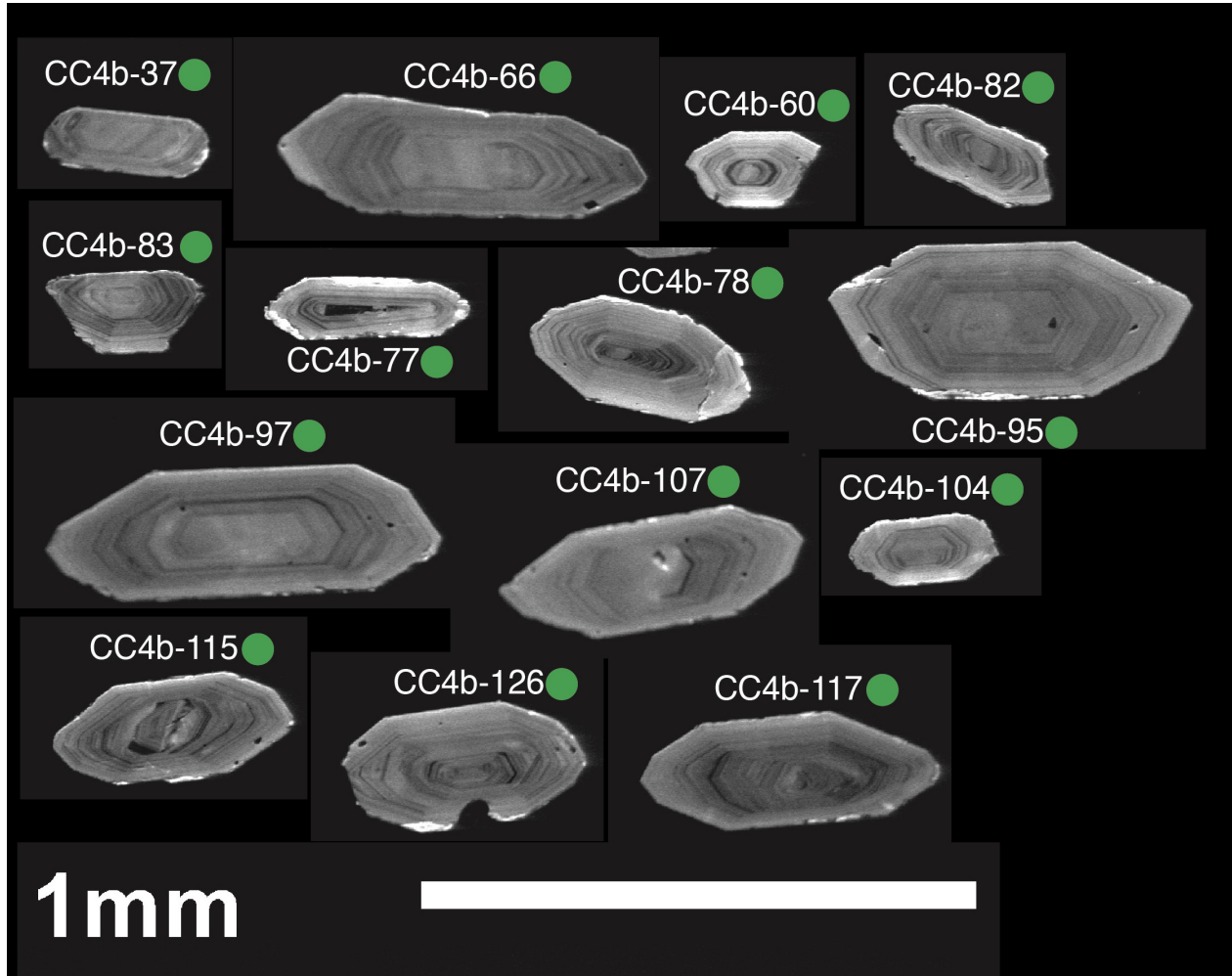
Sample CC4



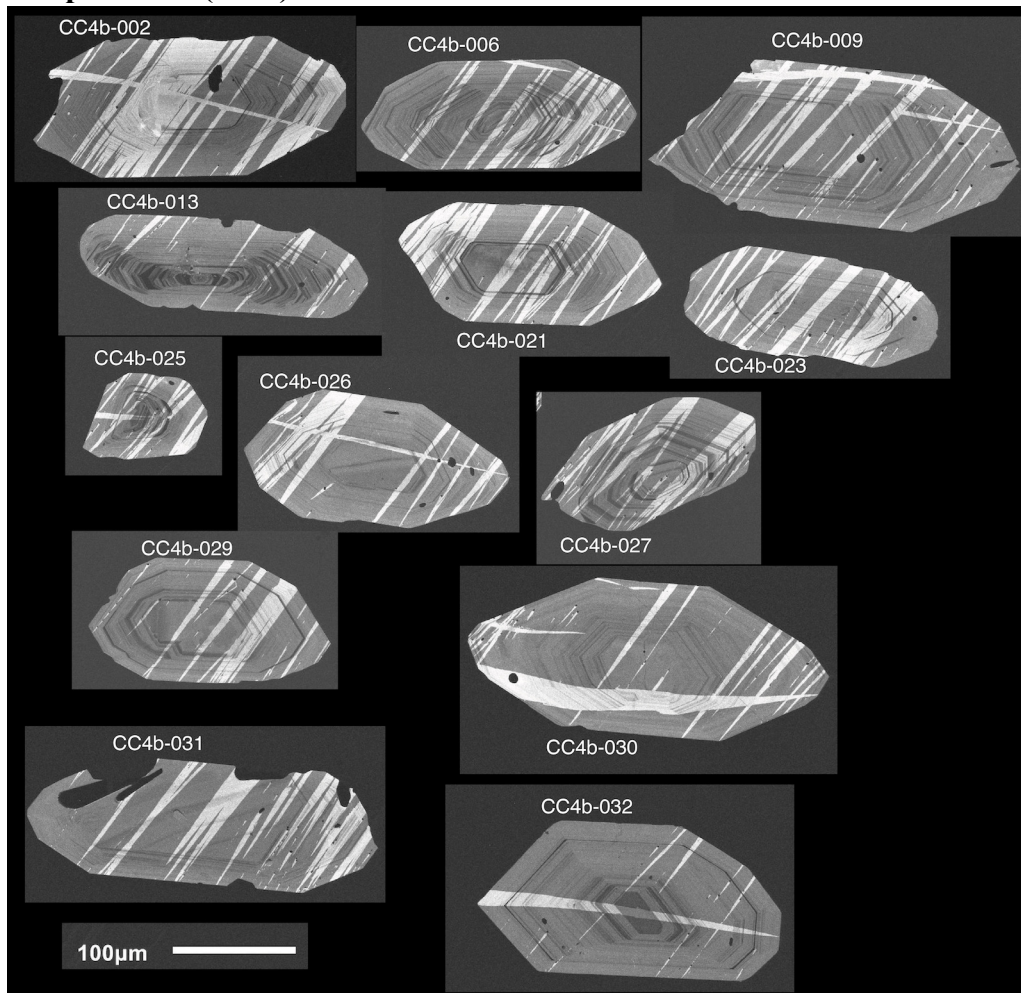
Sample CC4 (cont.)



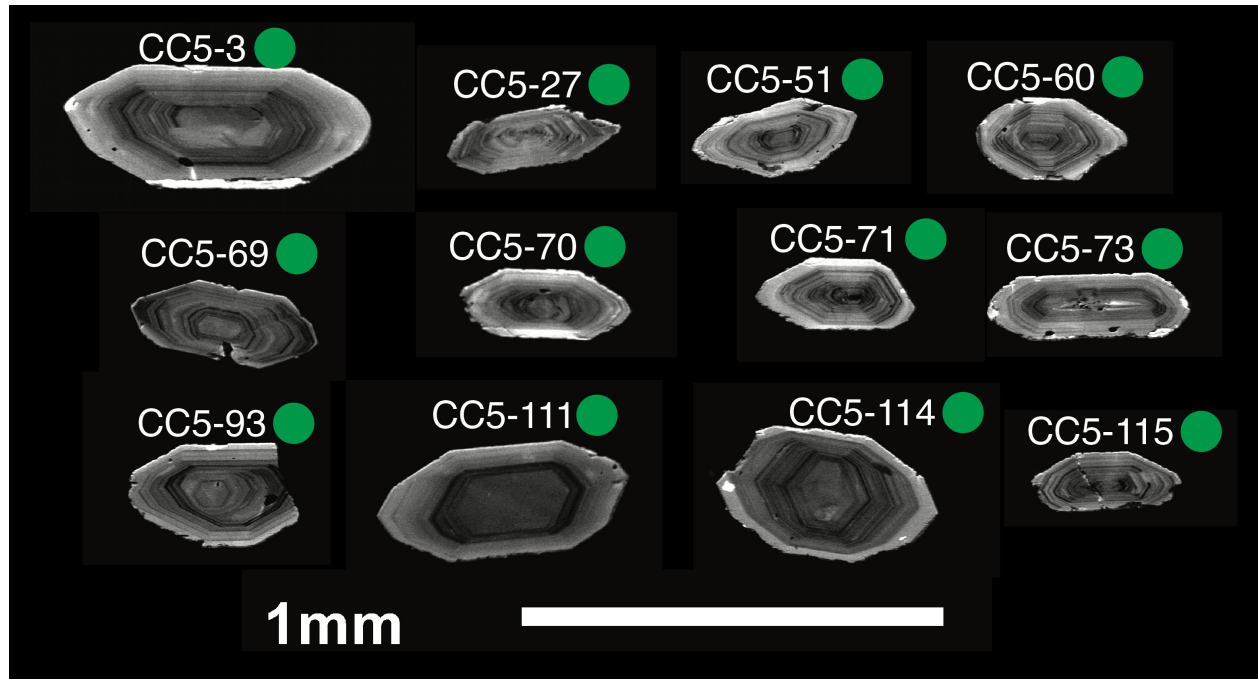
Sample CC4b



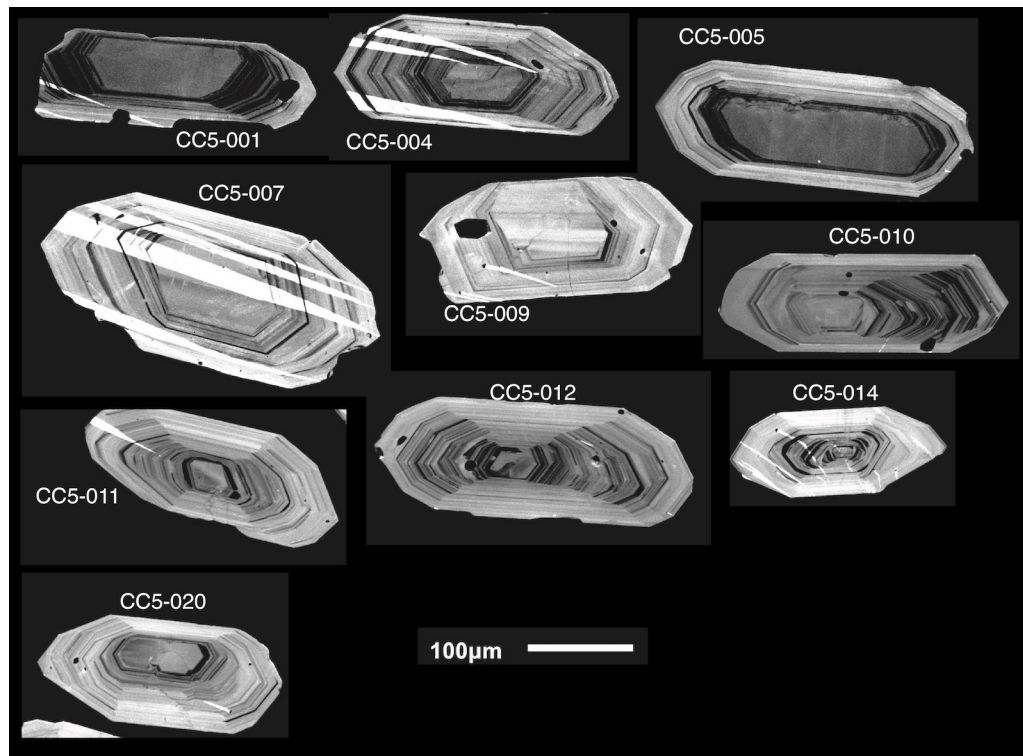
Sample CC4b (cont.)



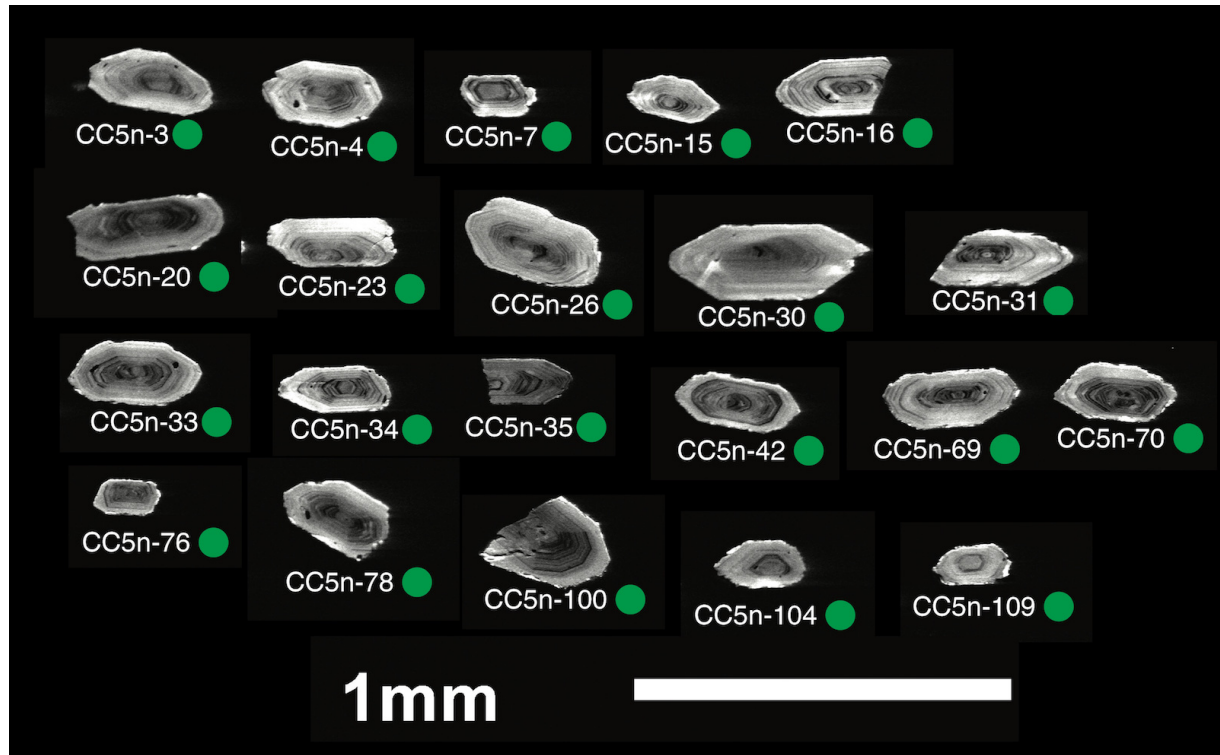
Sample CC5



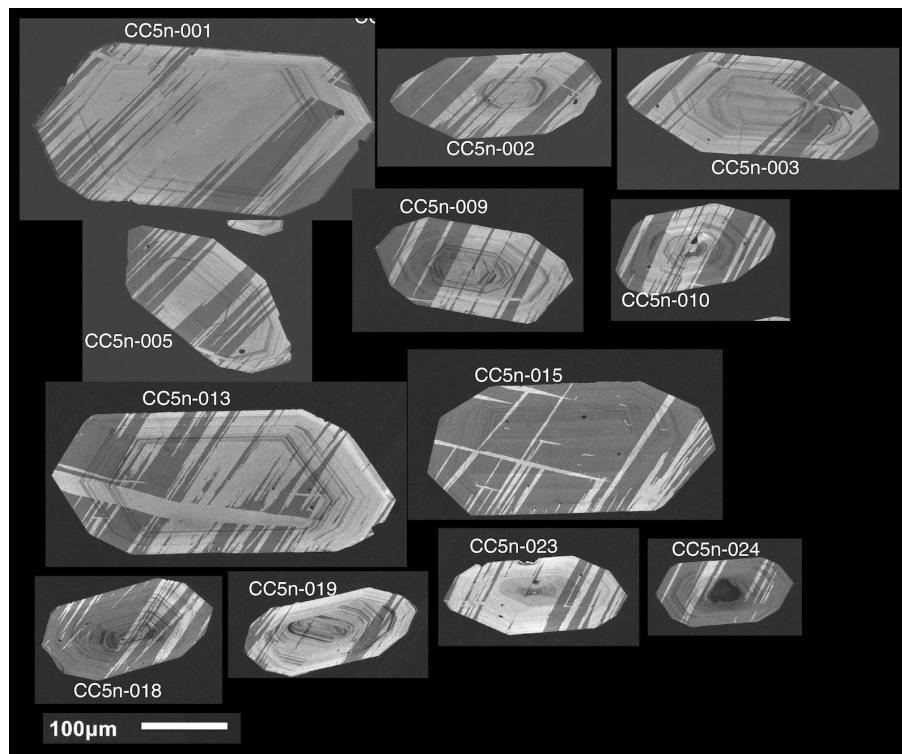
Sample CC5 (cont.)



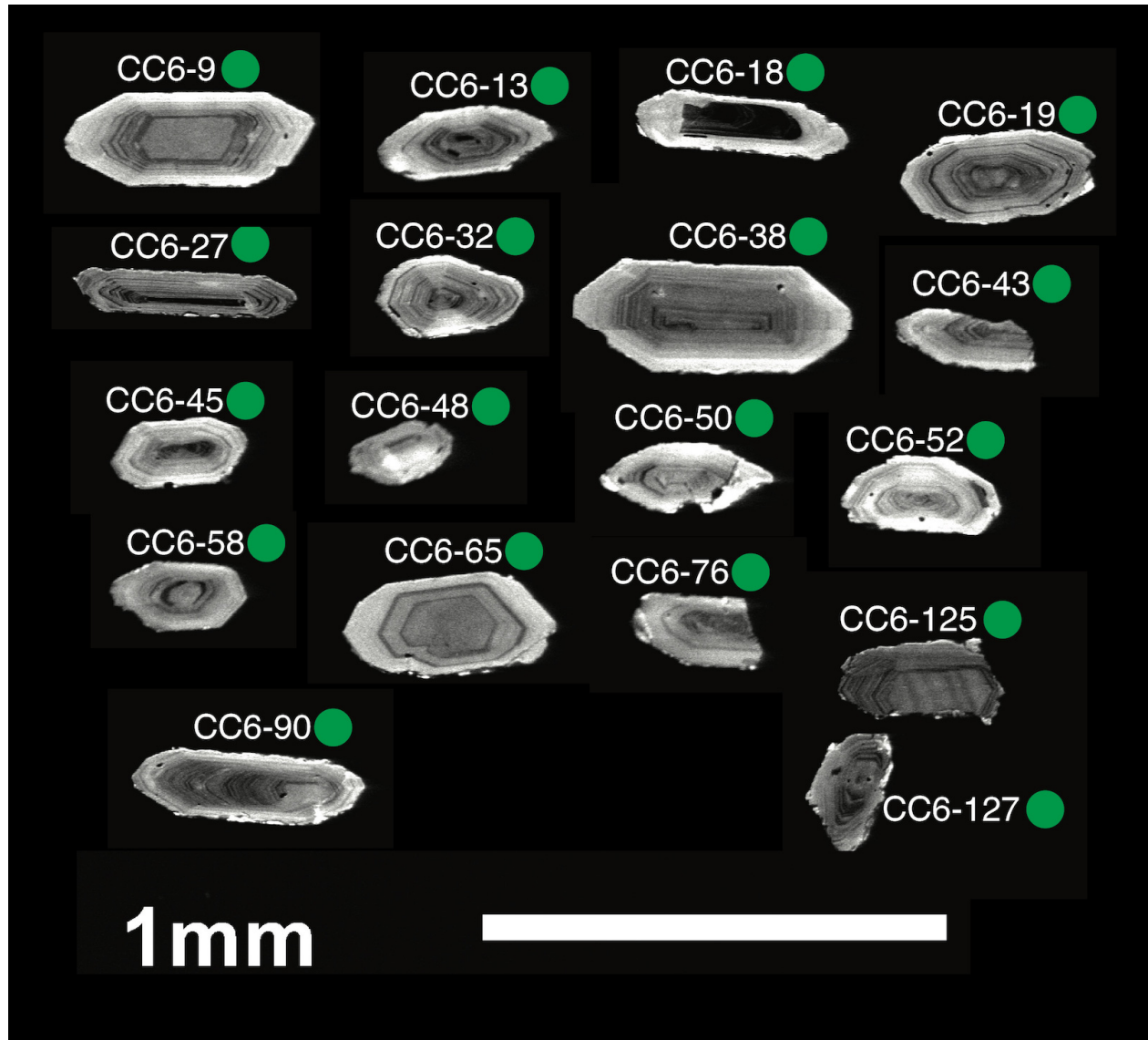
Sample CC5n



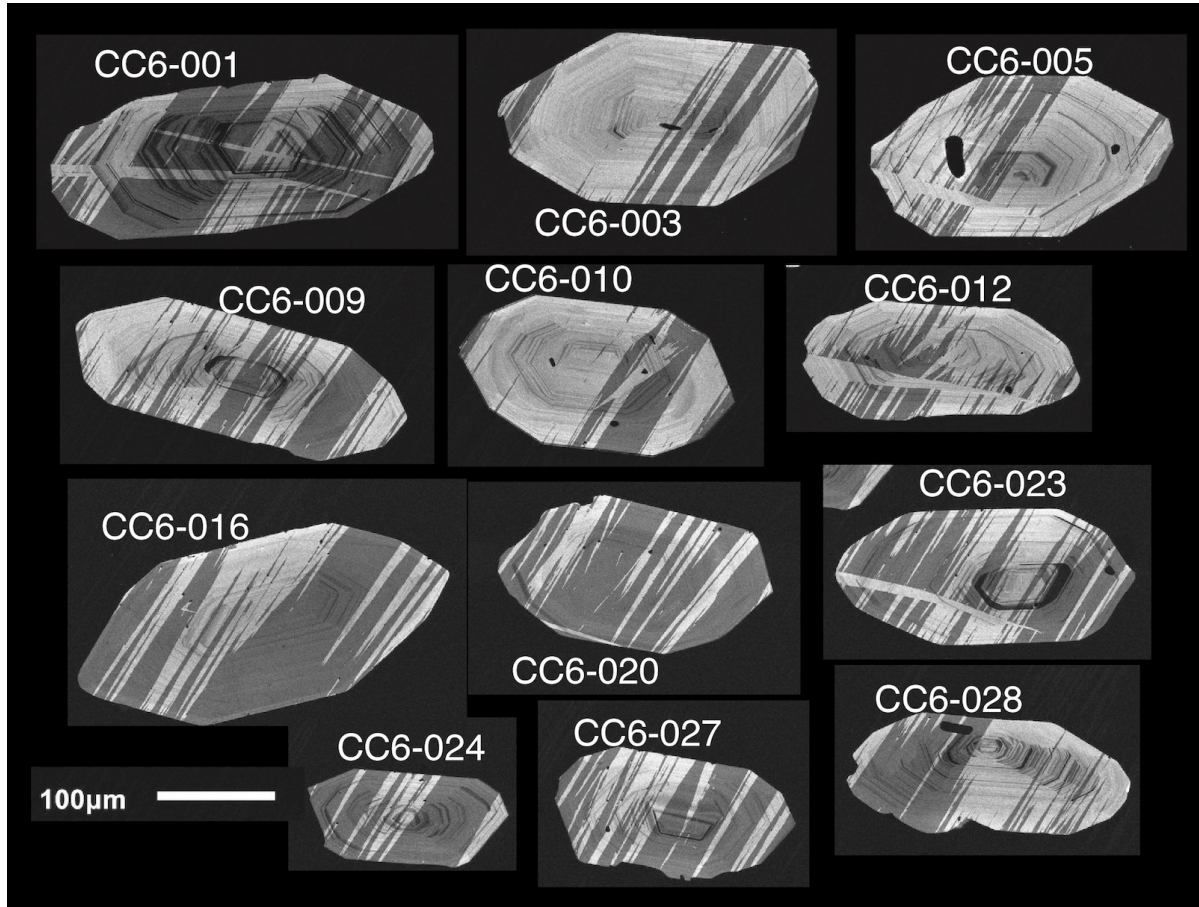
Sample CC5n (cont.)



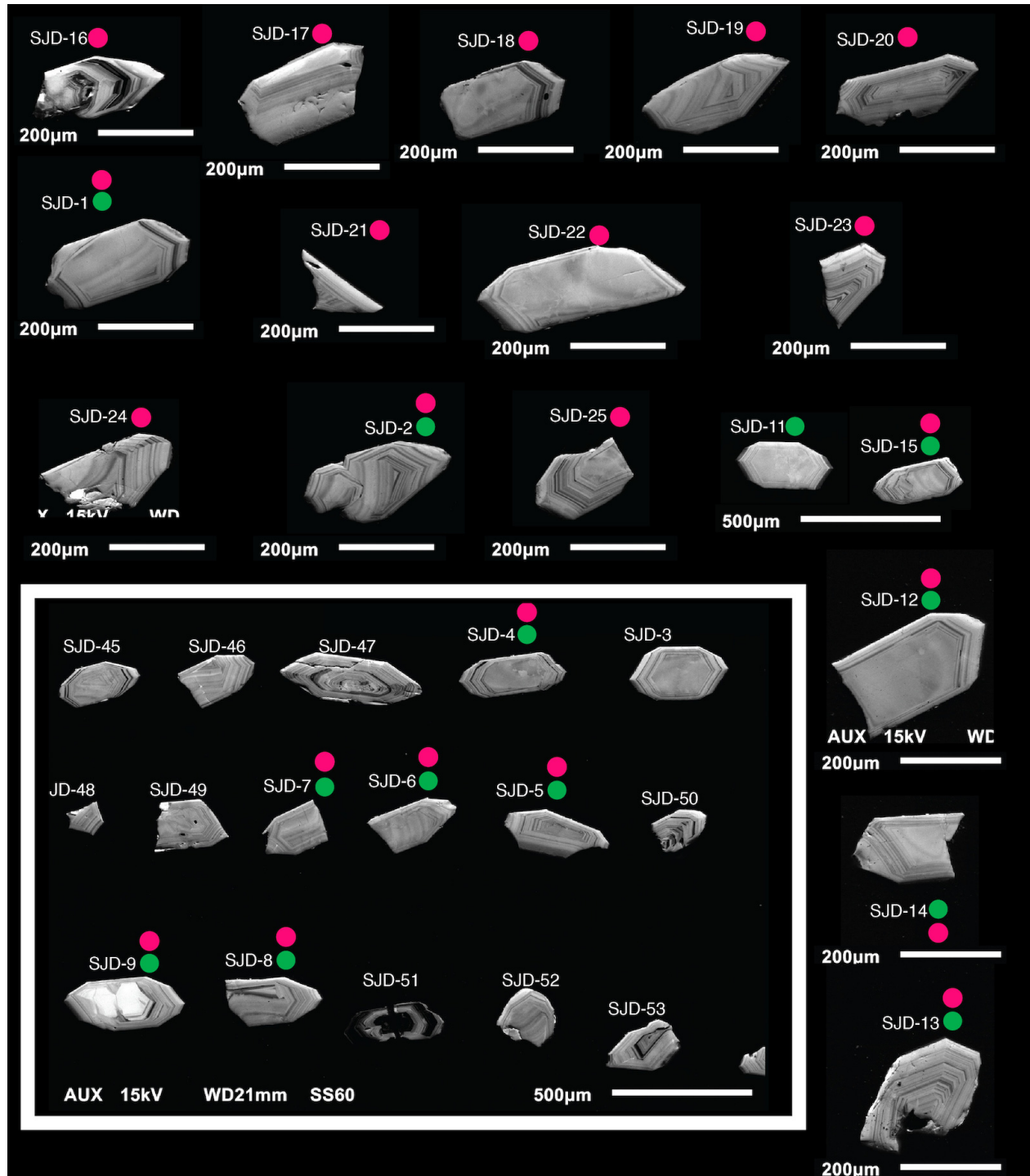
Sample CC6



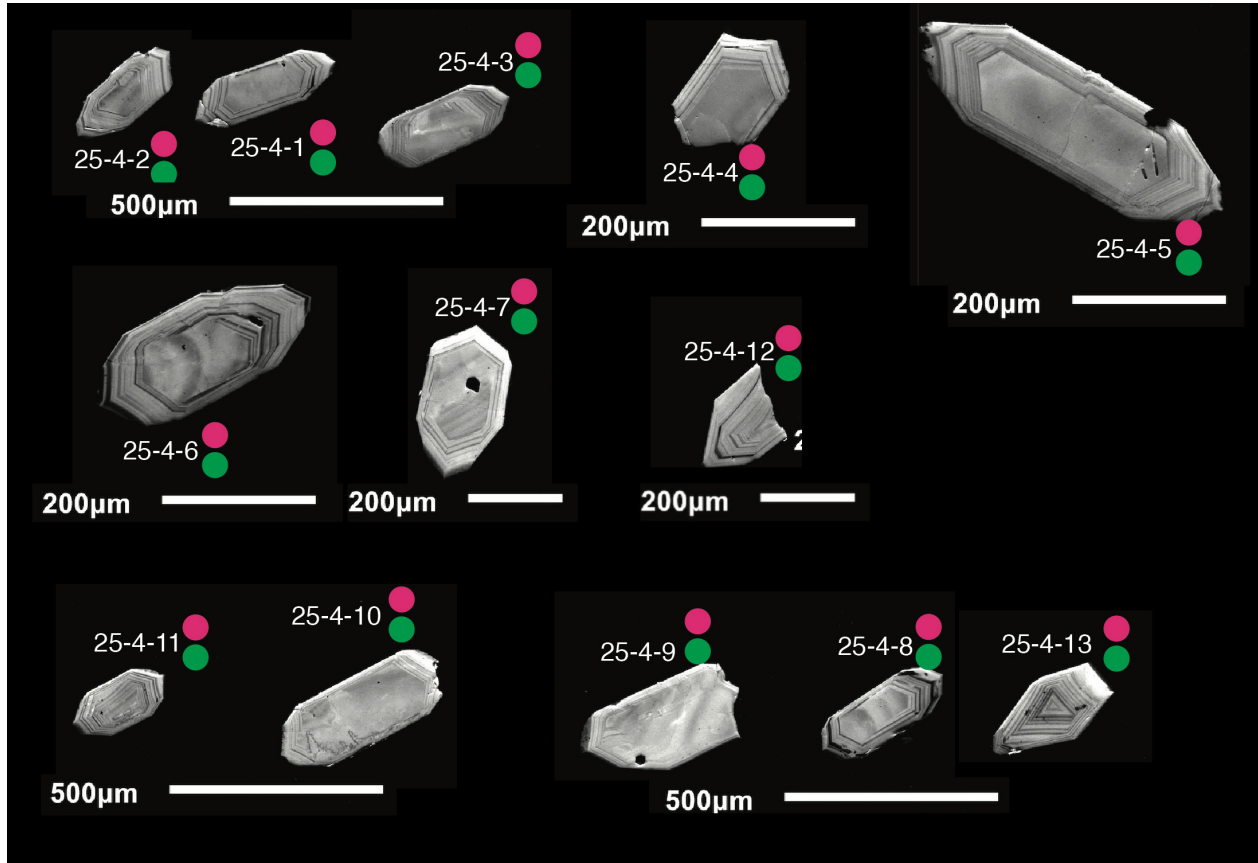
Sample CC6 (cont.)



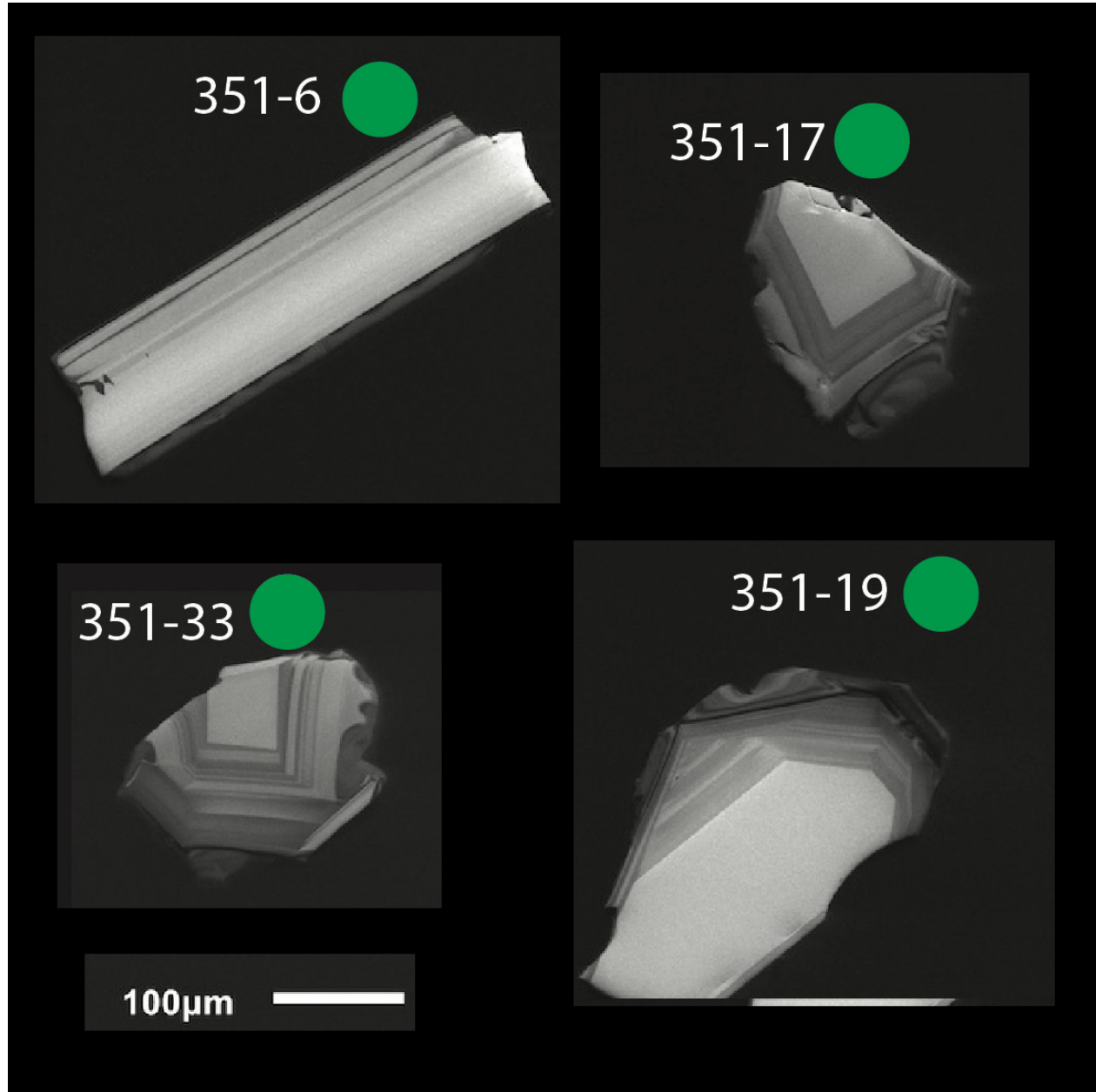
Sample SJD-02



Sample 25-4



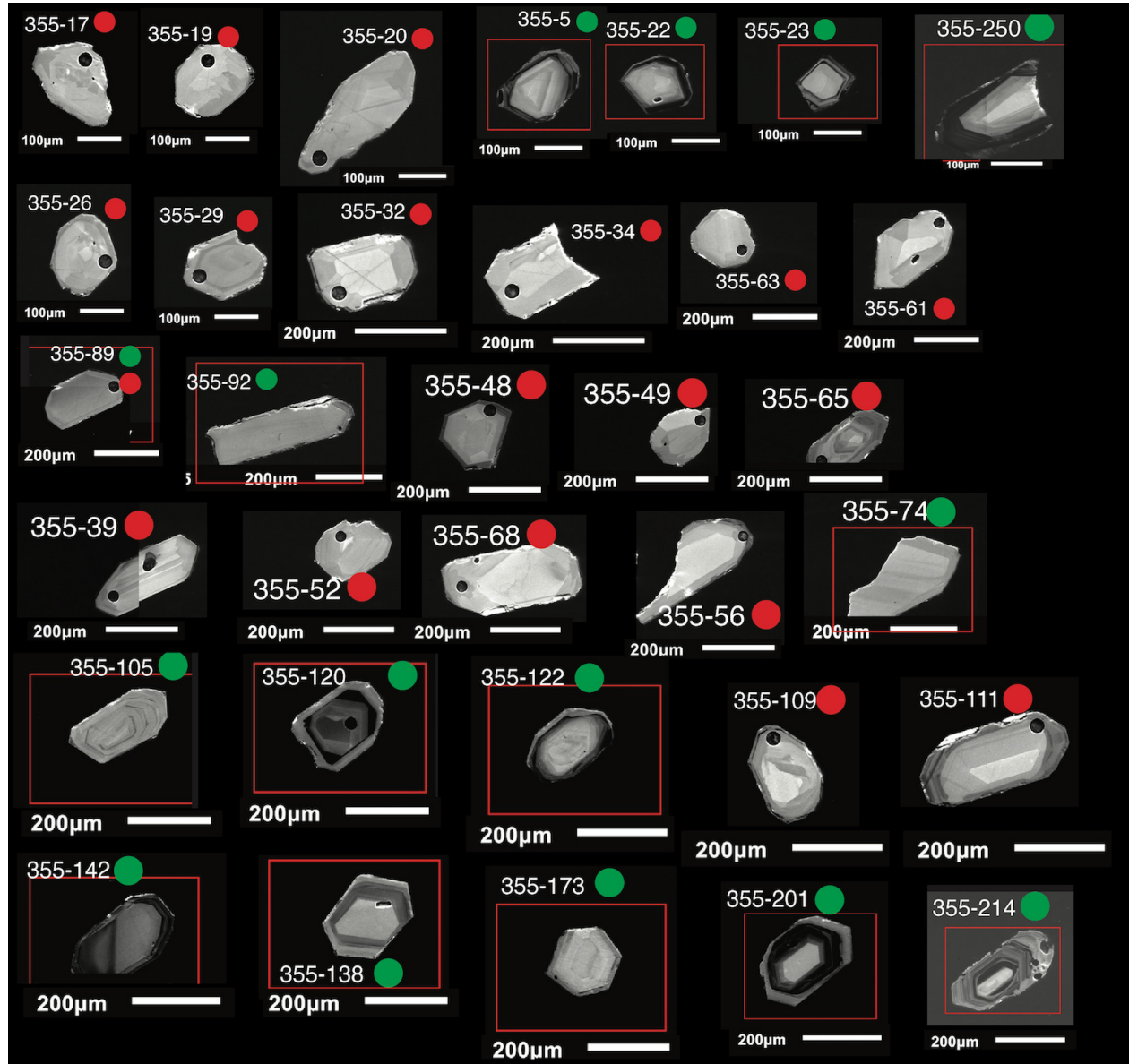
Sample T-351



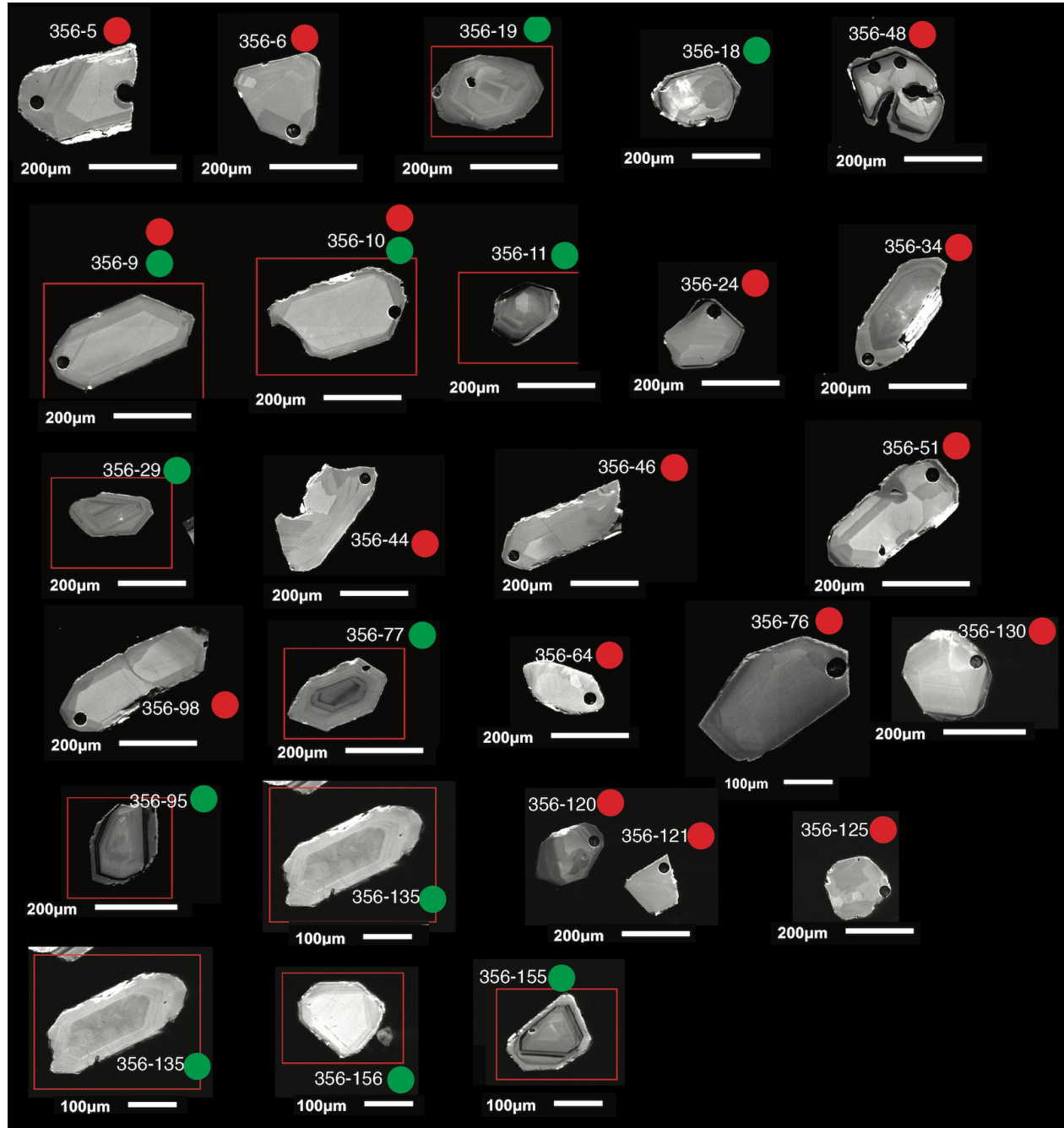
Sample T-352



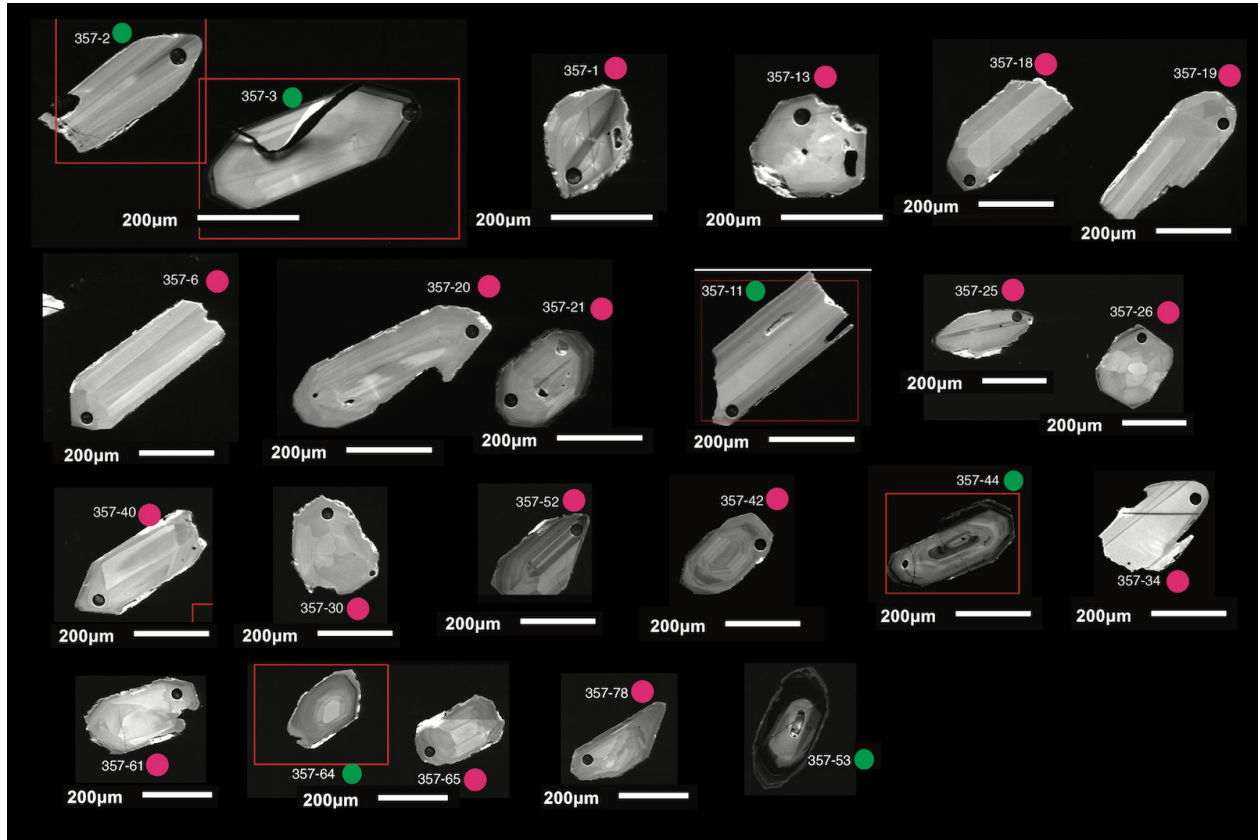
Sample T-355



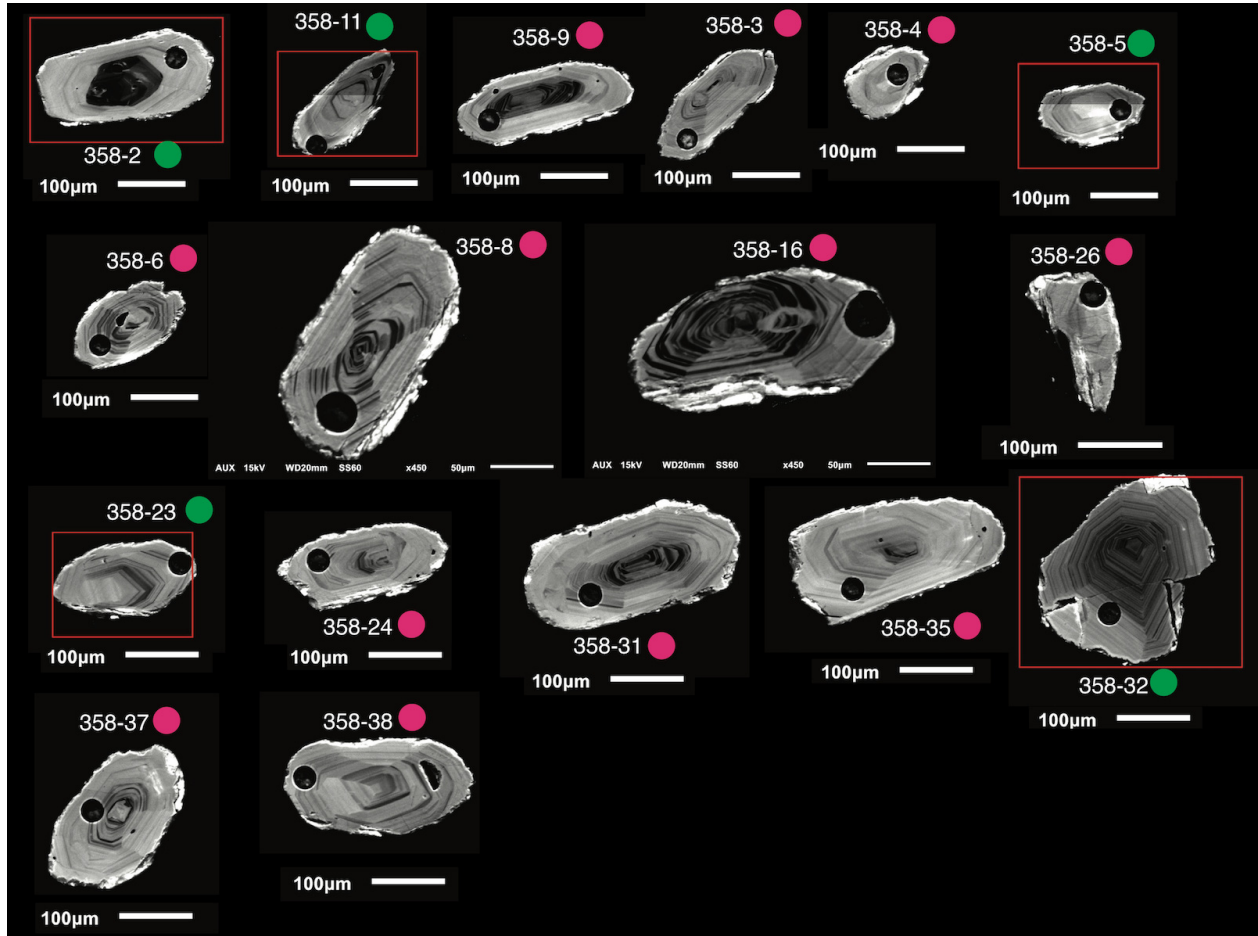
Sample T-356



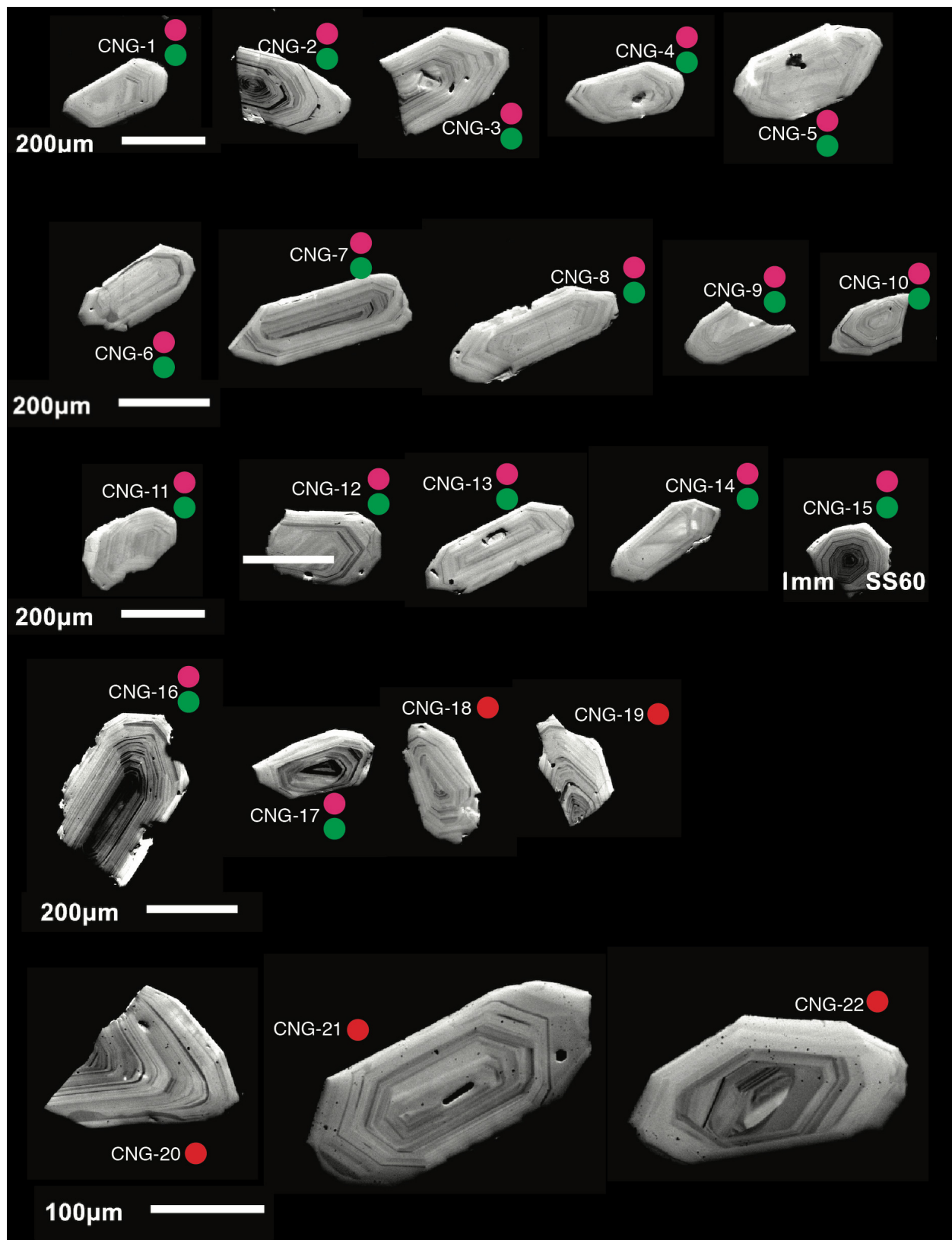
Sample T-357



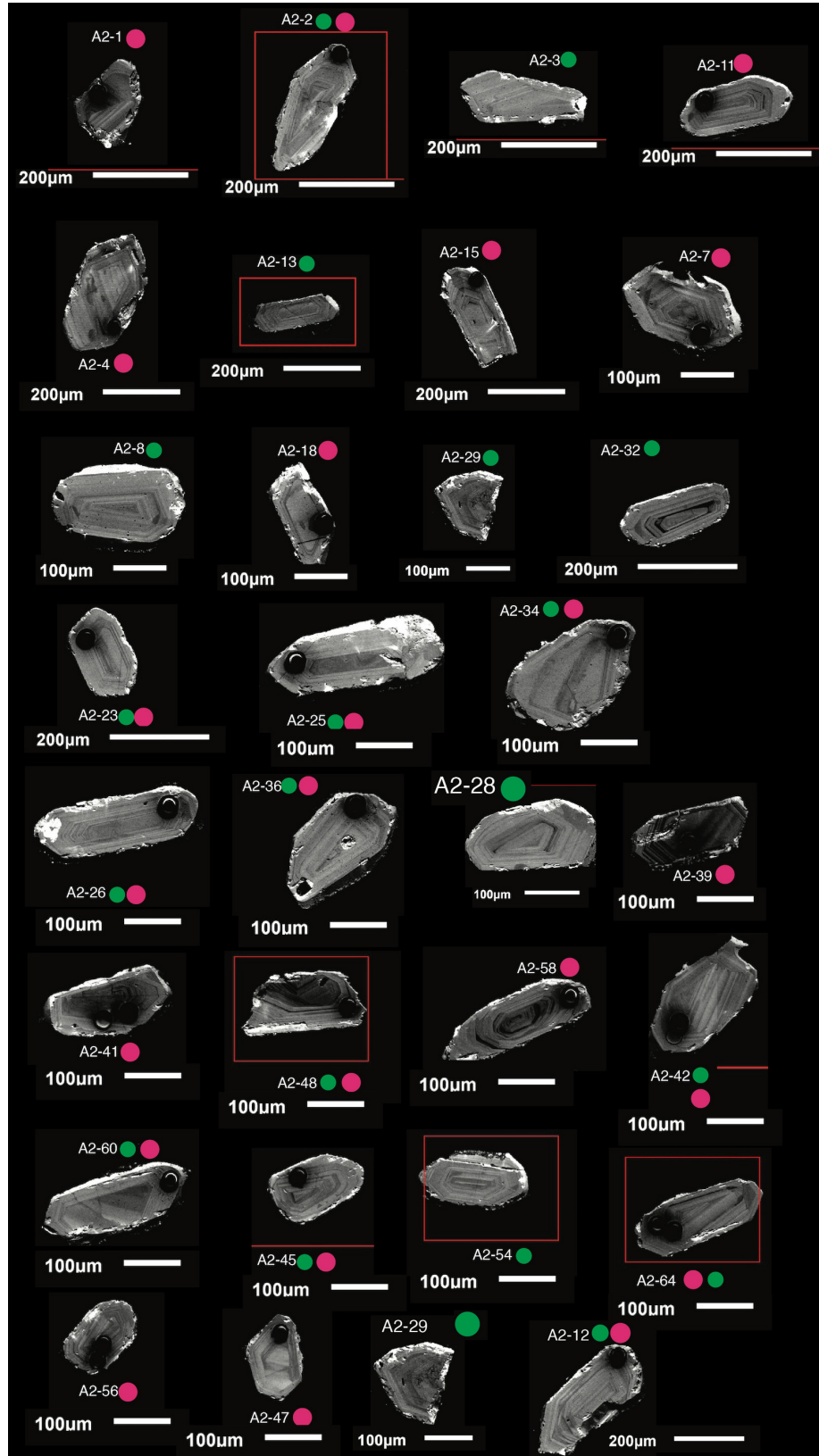
Sample T-358



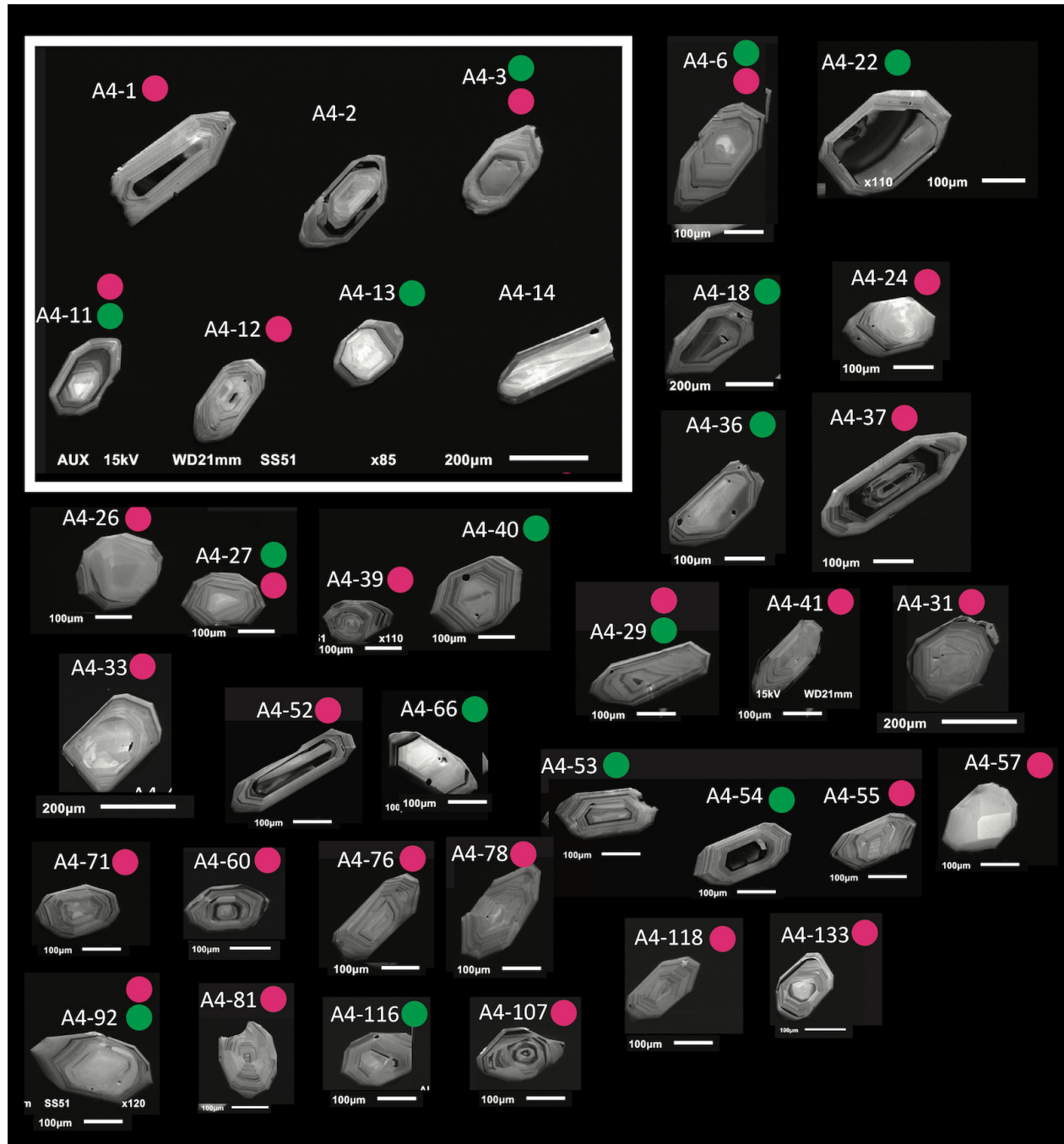
Sample CNG-1



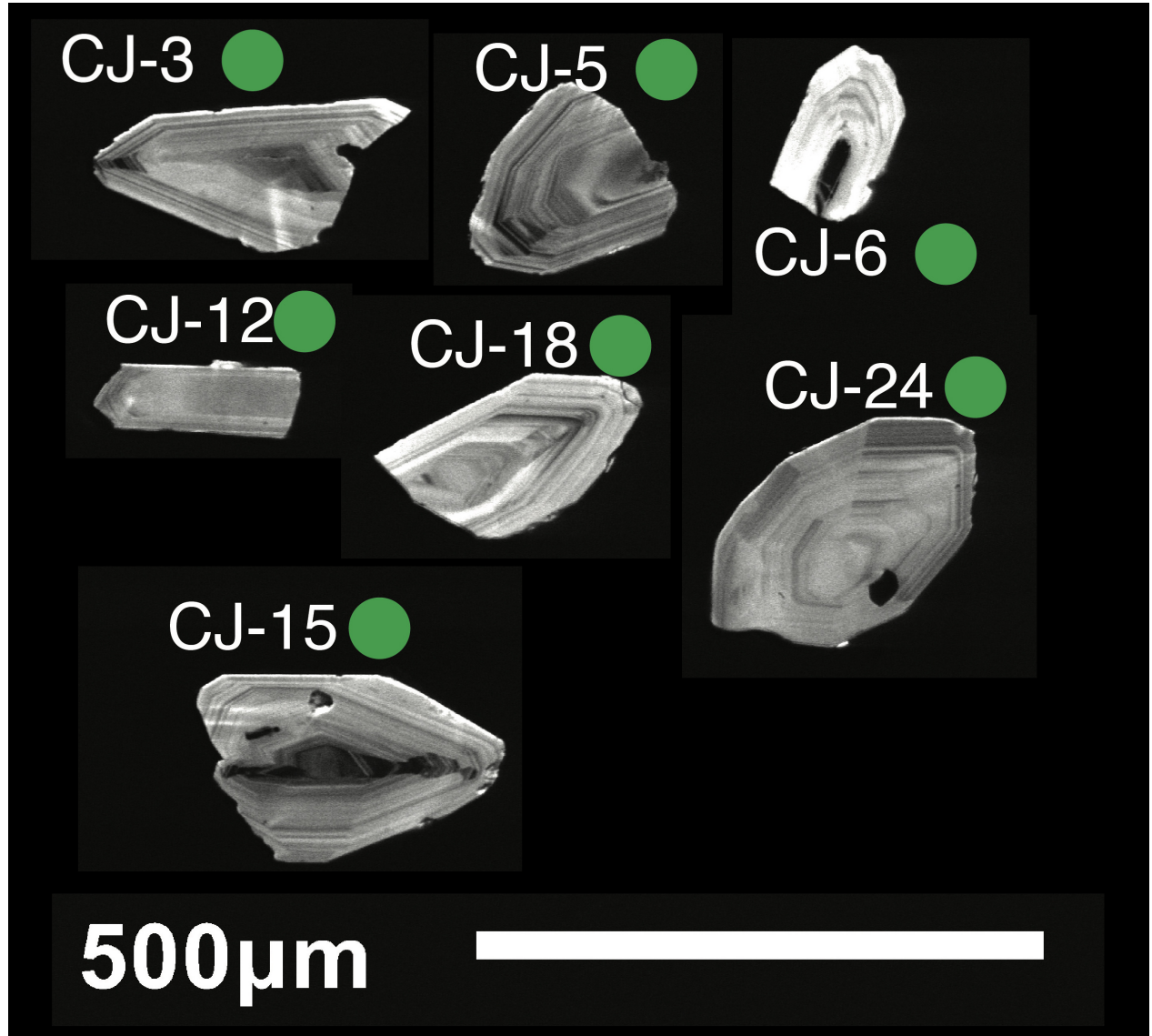
Sample Anta-PK



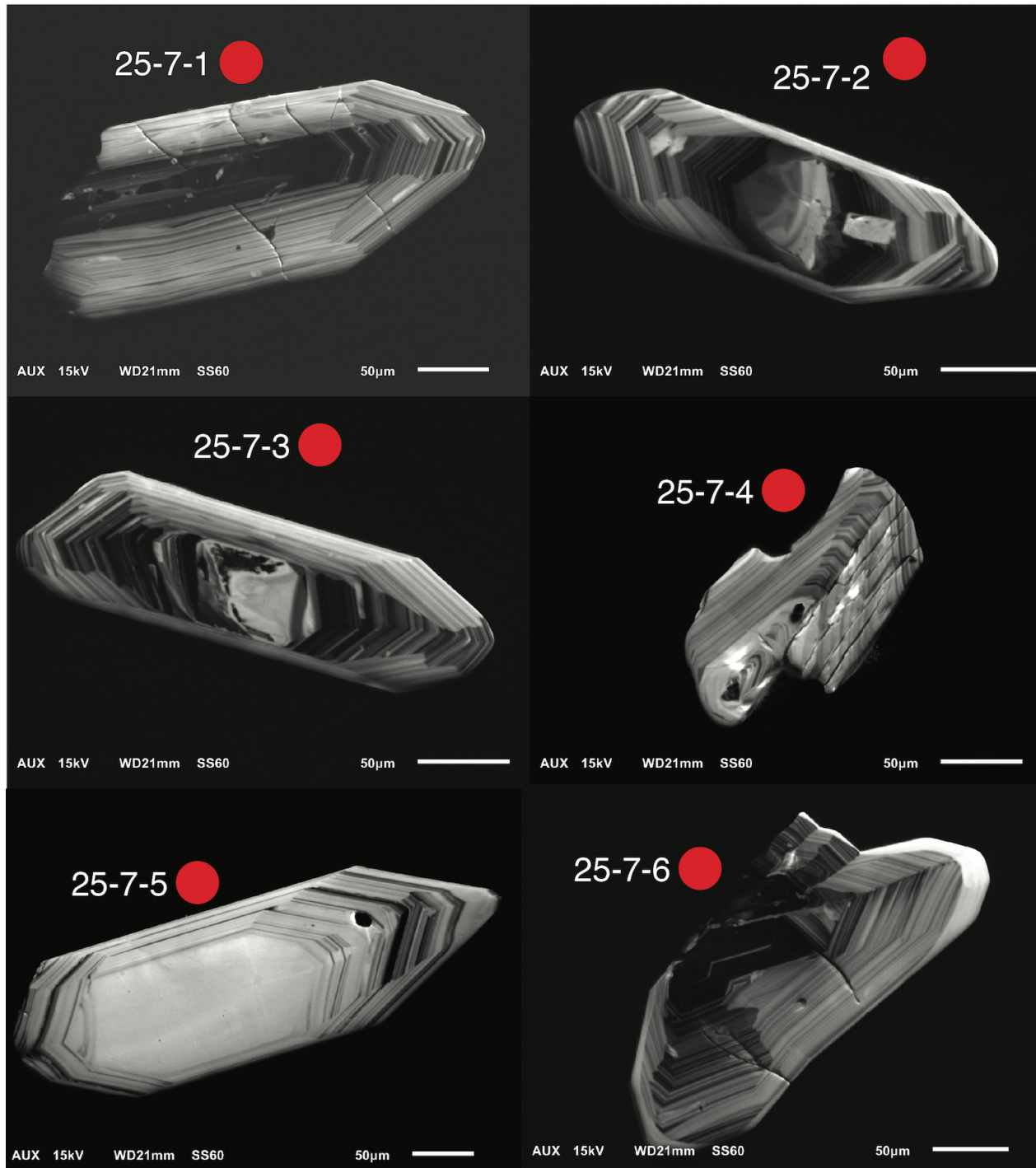
Sample Anta-PF



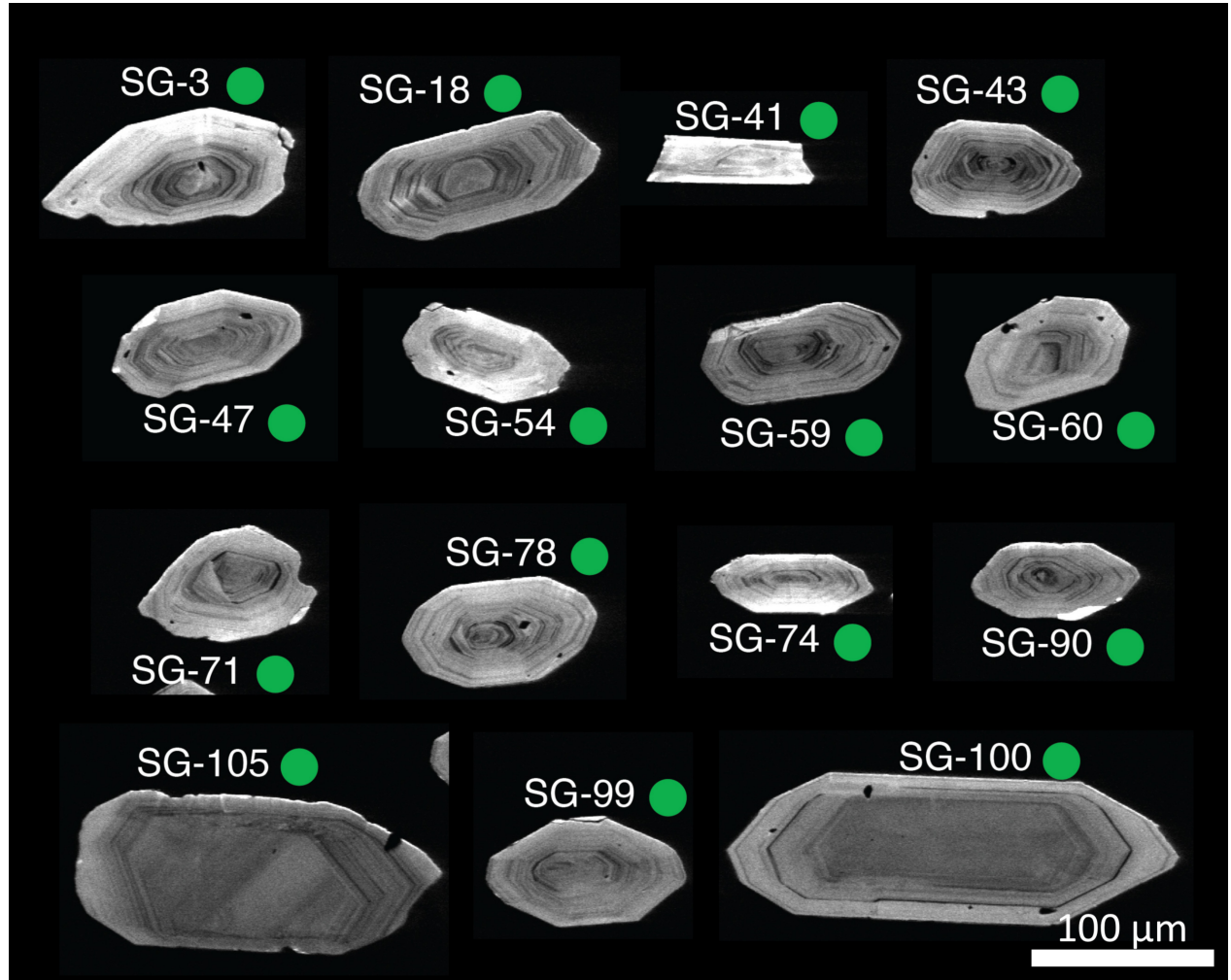
Sample CJ



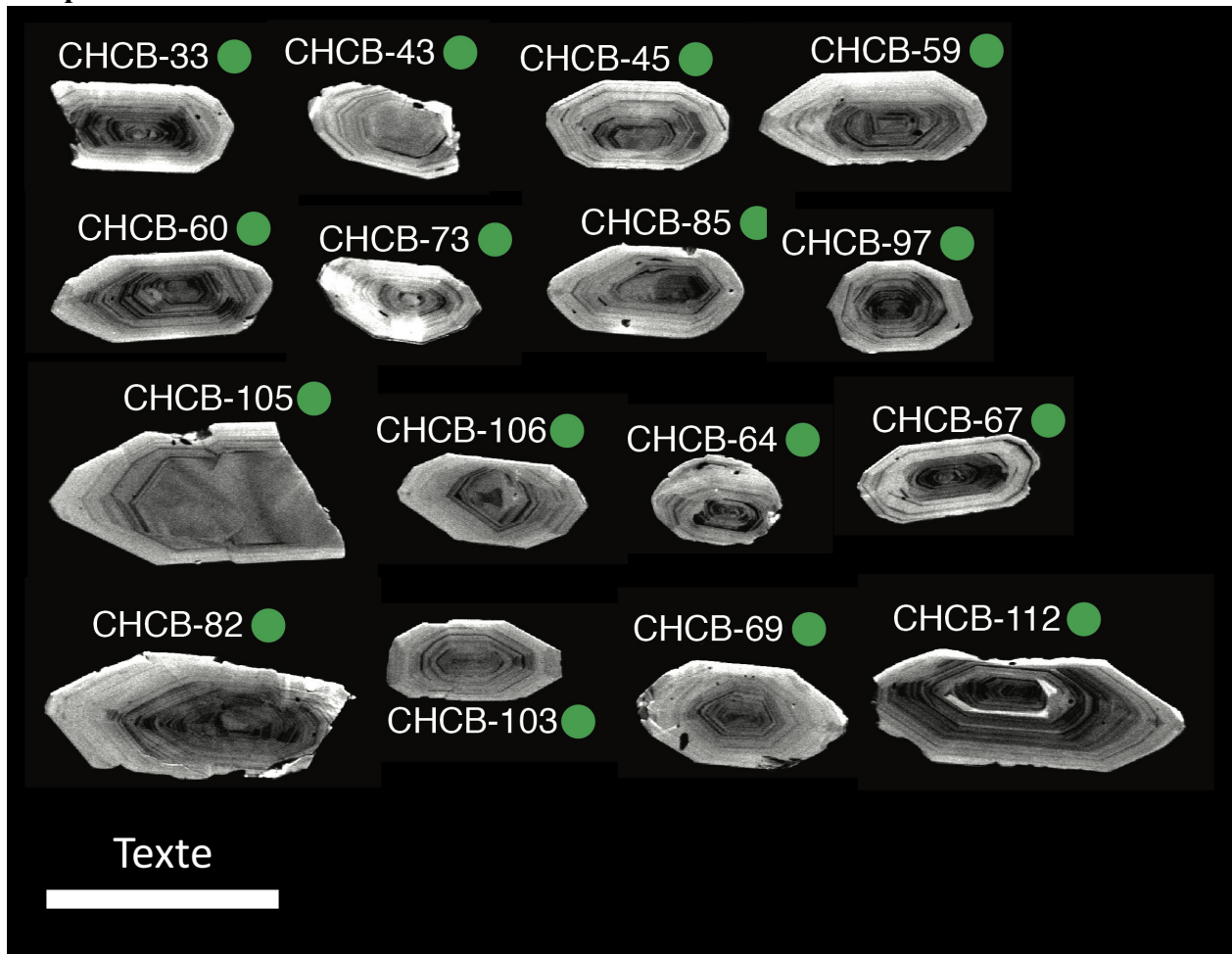
Sample 25-7



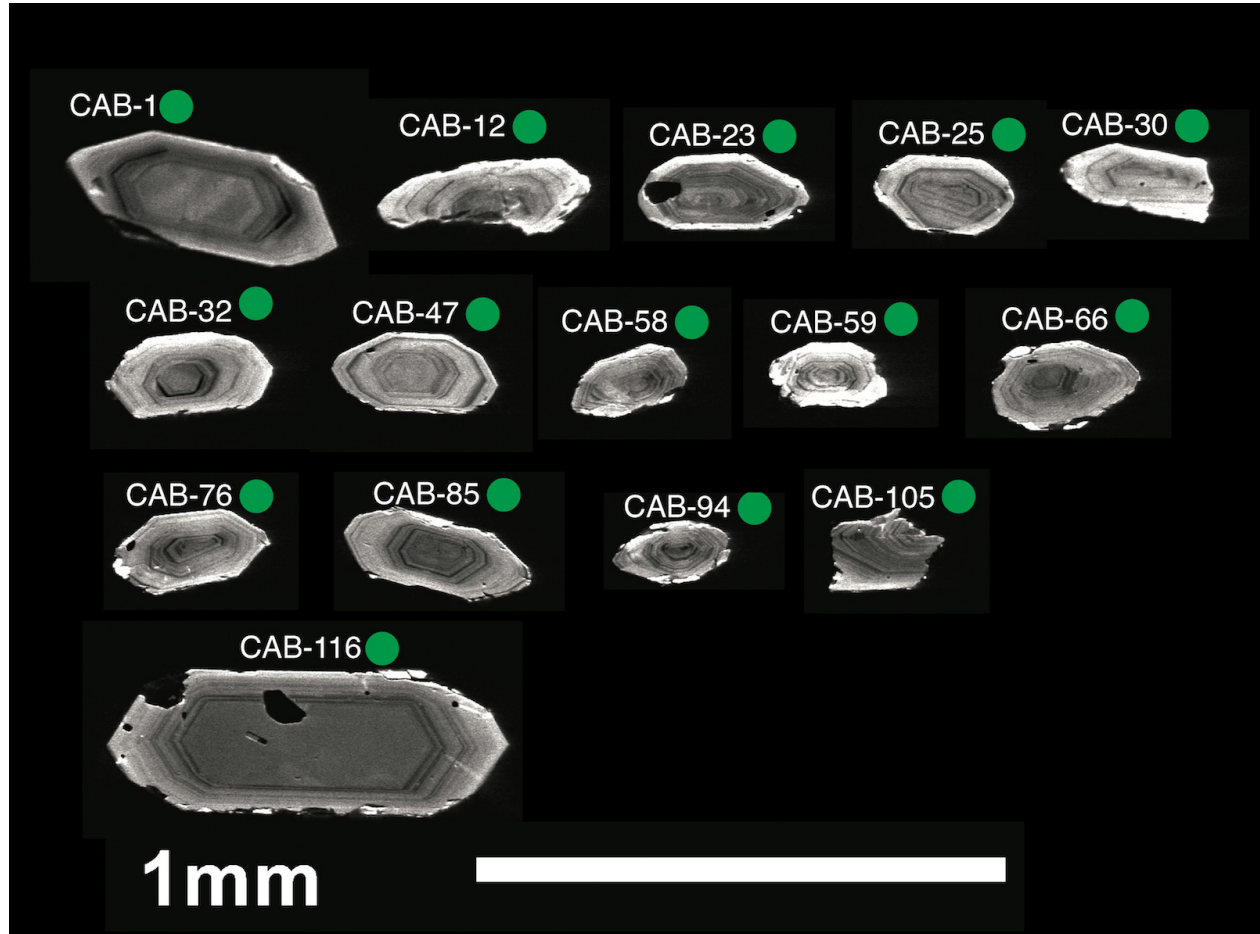
Sample LG



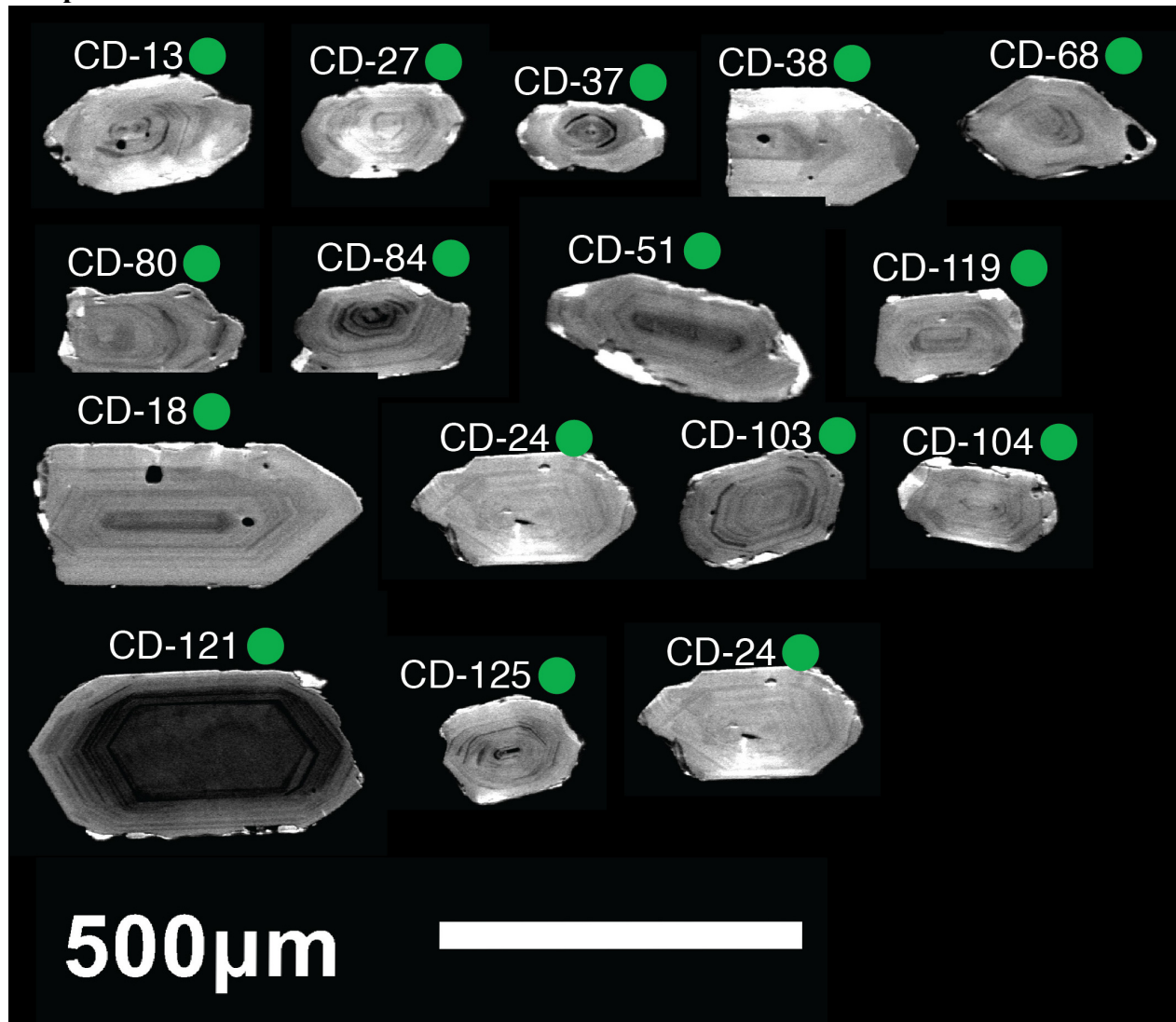
Sample CHCB



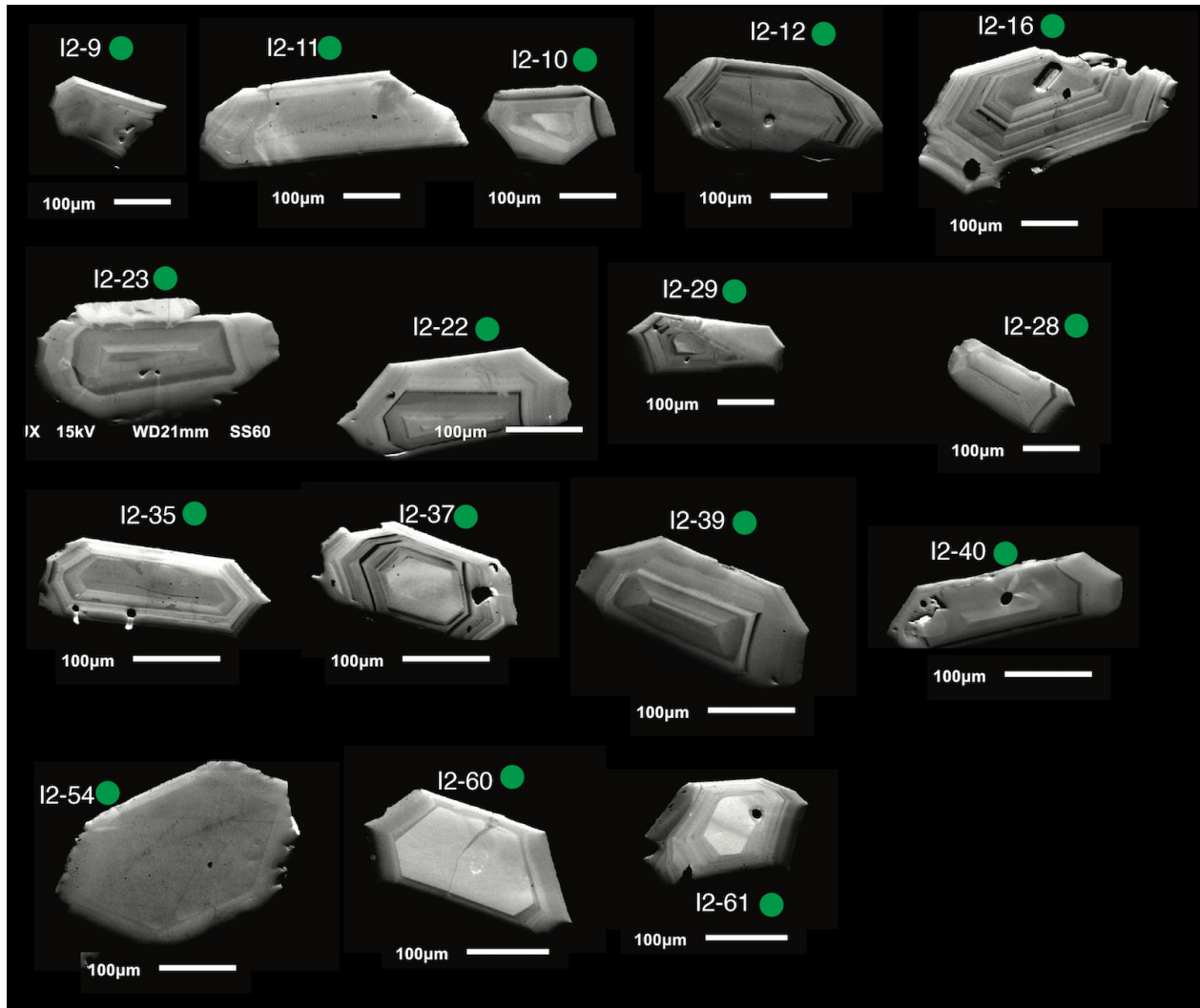
Sample CAB



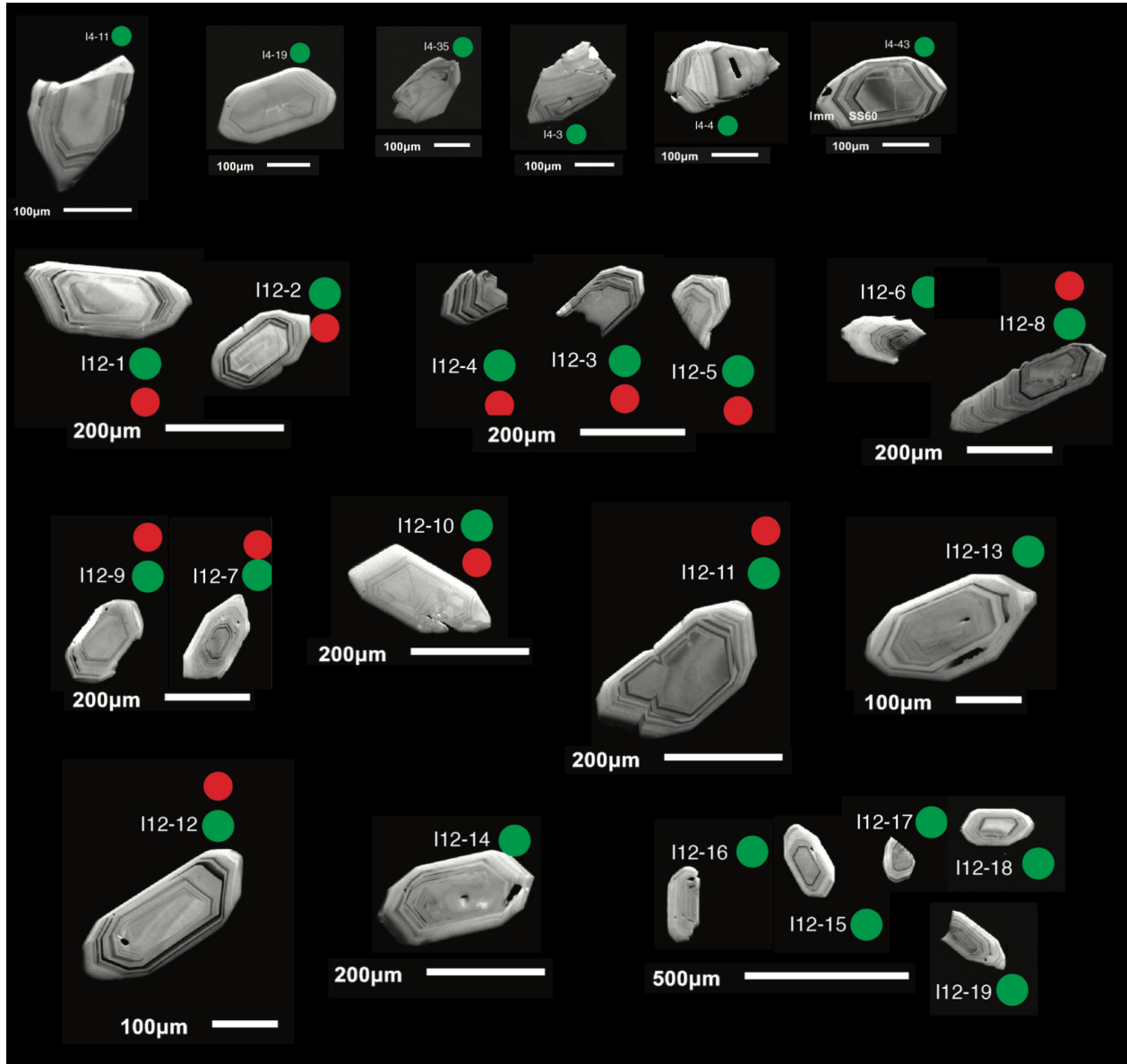
Sample CD



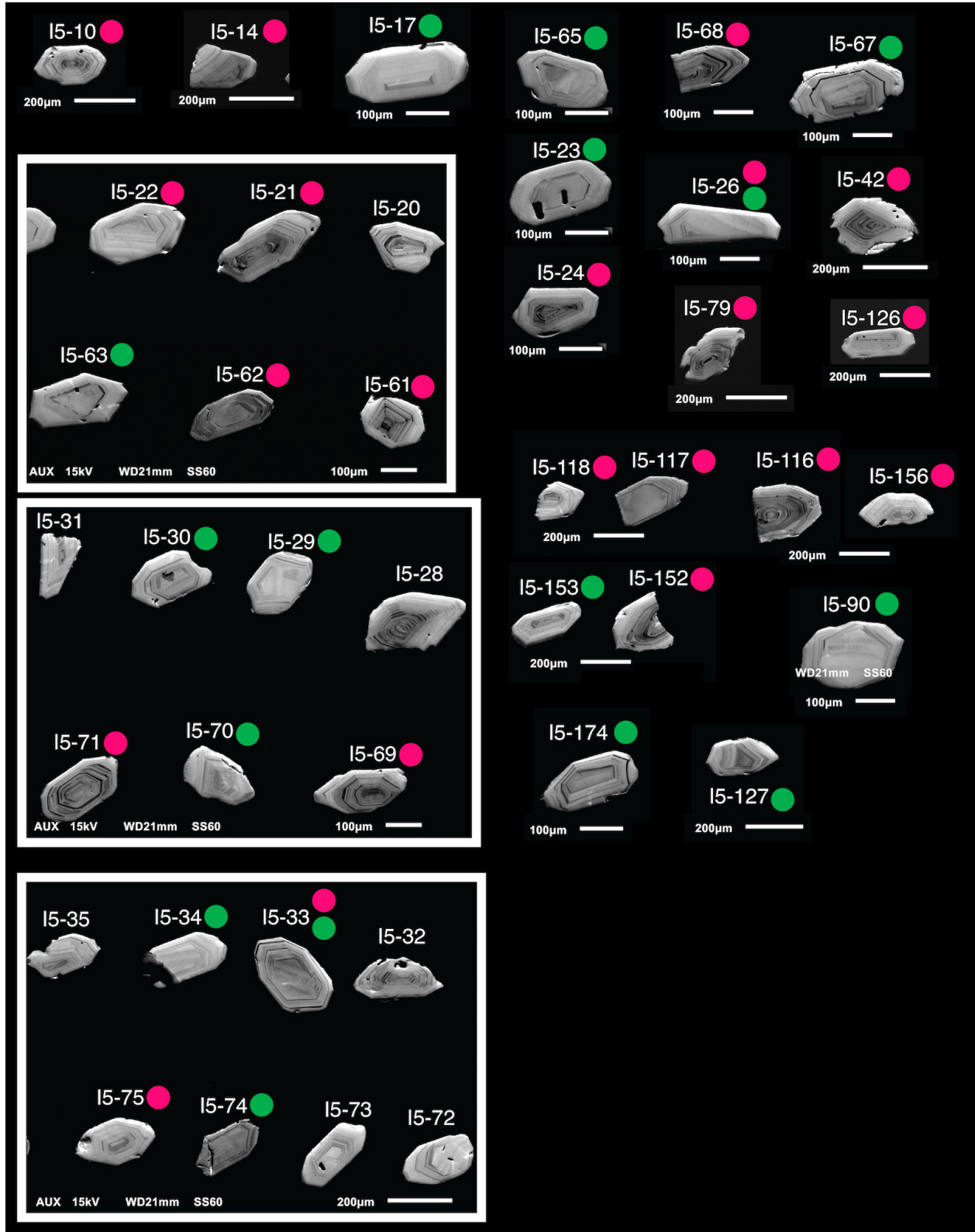
Sample 25-5



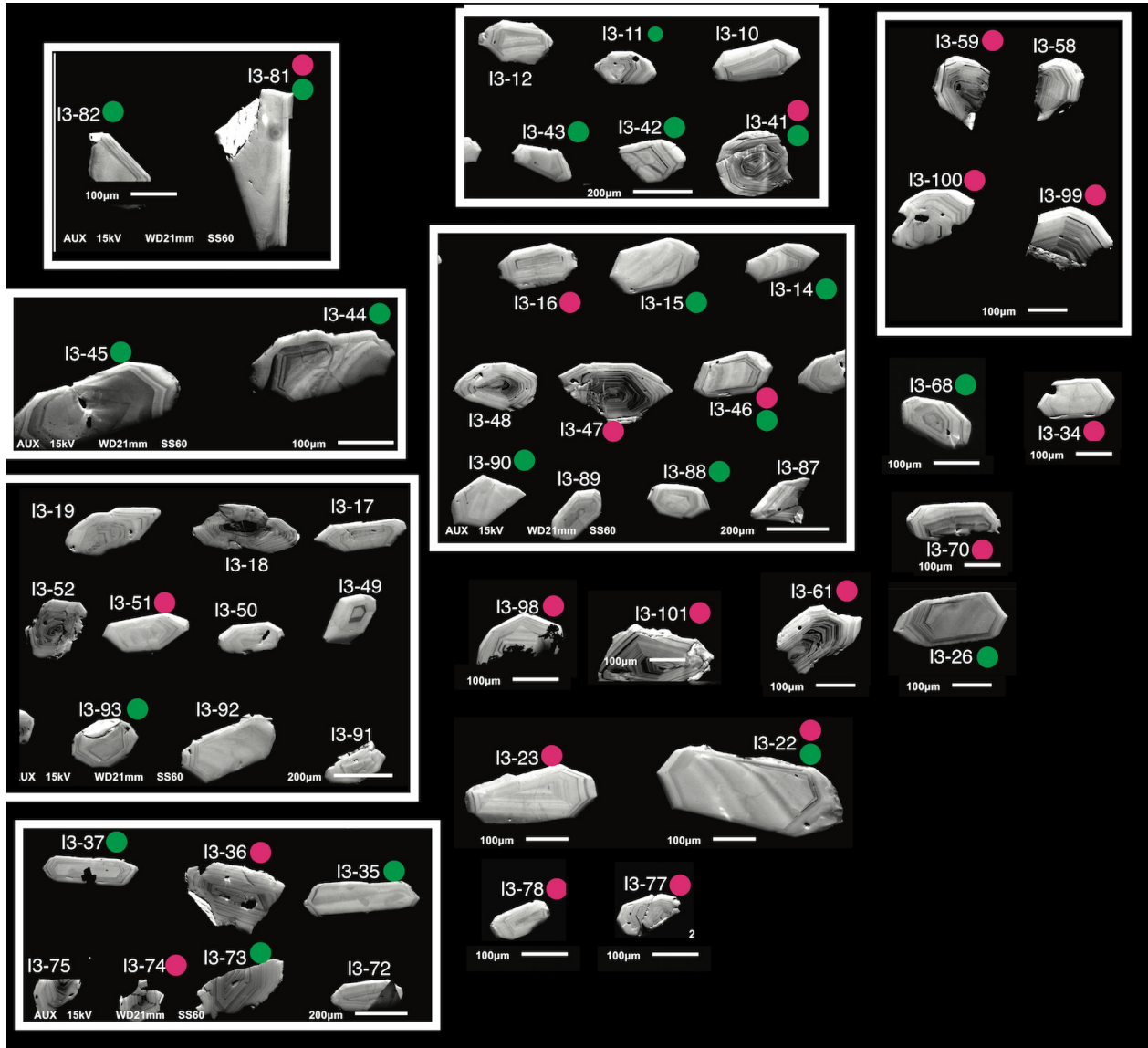
Sample SCO-1



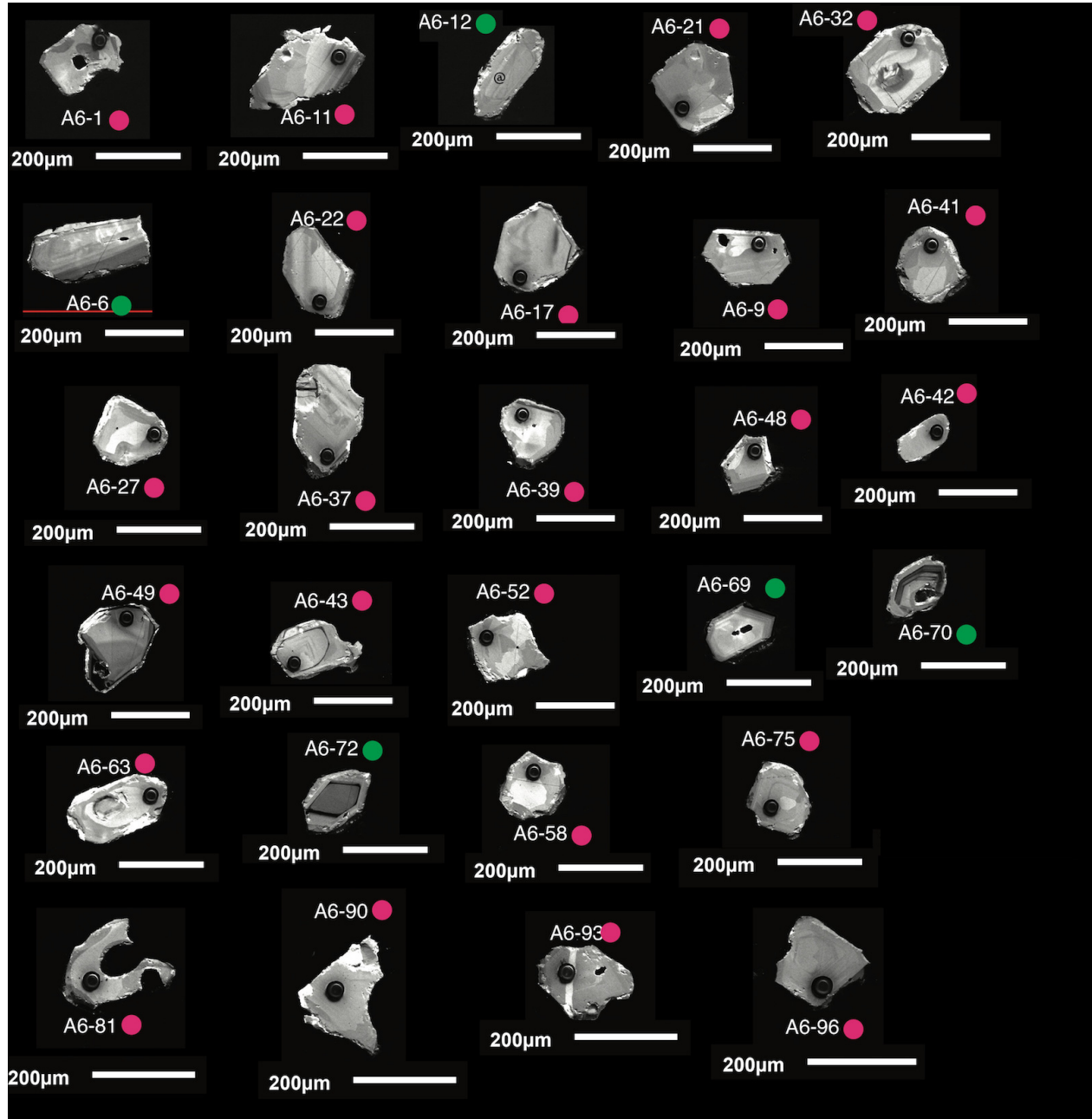
Sample SCO-2



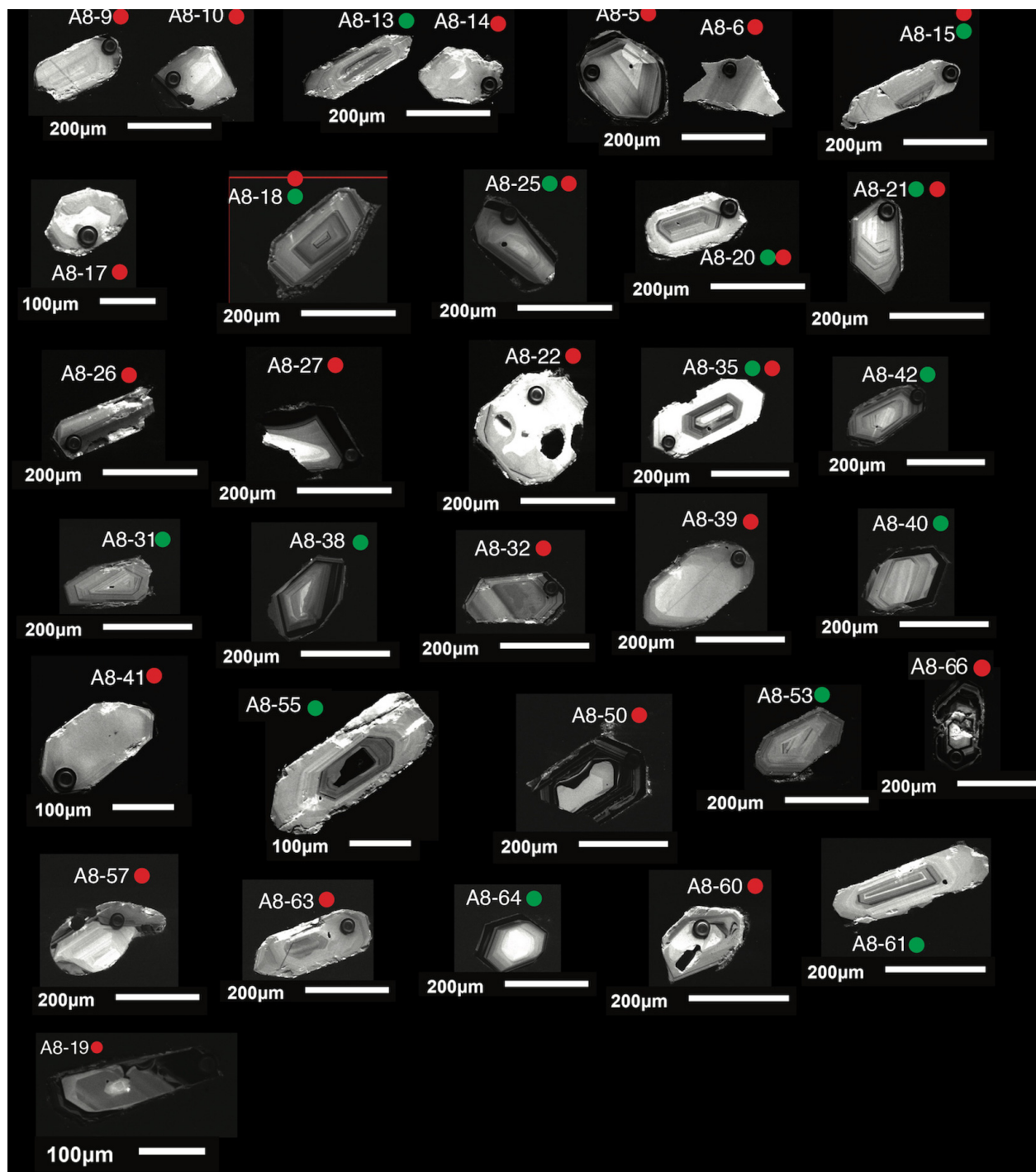
Sample SCO-3



Sample Anta-6



Sample Anta-8



Sample 25-6

