Characterization of magmas associated with porphyry deposits: Petrography and oxidation state of magmas associated with porphyry copper deposit at the Cerro Corona deposit, Peru.

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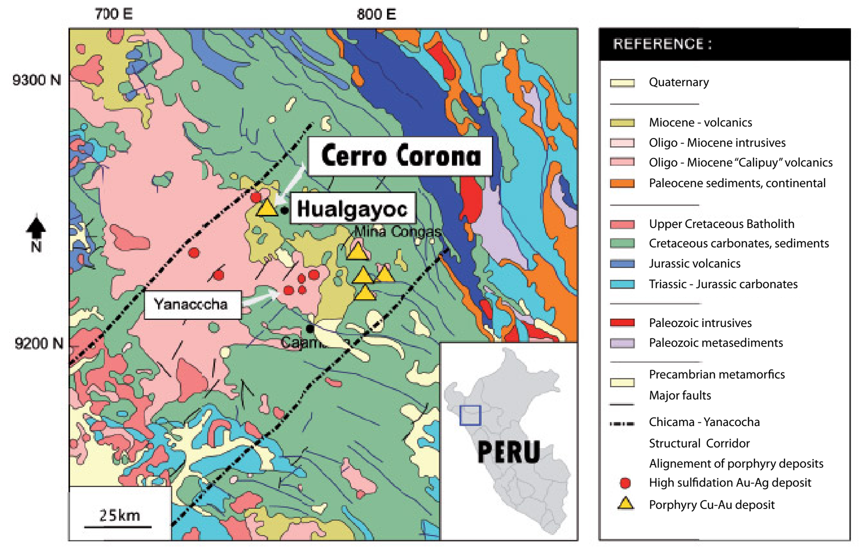
Introduction

Many Cu-Au porphyry deposits are associated with the intrusion of oxidized intermediate to felsic magmas in subduction zones.

A recent study (Shen et al., 2015) suggests a link between the degree of oxidation of magmas and the tonnage of Cu-Au deposits in the Central Asian Orogenic Belt.

Our project focuses on the evolution of the oxidation state of the granitic intrusions at the Cerro Corona porphyry Cu-Au deposit in the Northern Peruvian Cordillera.



Regional geology map, courtesy of Gold Fields La Cima S.A. Geology department

We examine the variation of the oxidation state of the magma within the Cerro Corona intrusion sequence using petrography and mineral chemistry, notably the trace elements in zircons.

Our objective is then to link these results with petrographic analysis, geochemistry and U-Pb age dating on zircon.

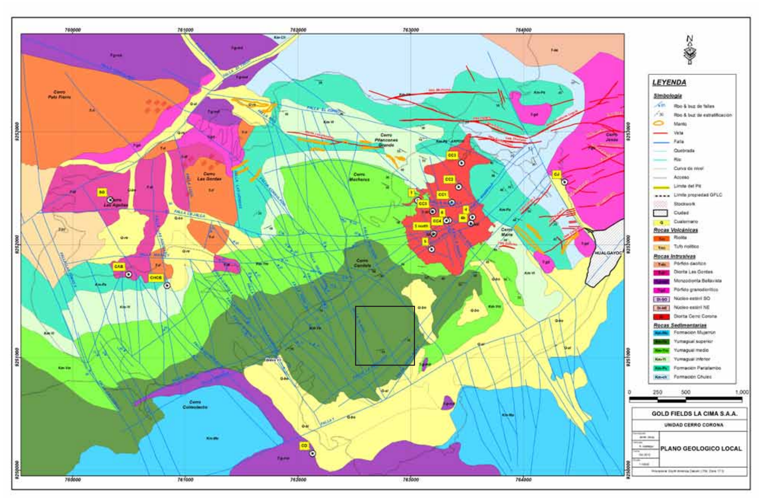
Geological Settings

The Cerro Corona Cu-Au deposit is situated in the Hualgayoc district in northern Peru. It is located 40km to the north of the very large high sulphidation epithermal Au-Ag Yanacocha deposit of 14.5 to 8.4 Ma (Longo et al., 2010).

The Cerro Corona deposit is hosted in a series of five main dioritic intrusions, only the earliest one being barren, the other pulses are mineralized. Similar to other deposits in the district, the intrusion occurs at the intersection of Andean-parallel and Andean-normal regional structures.

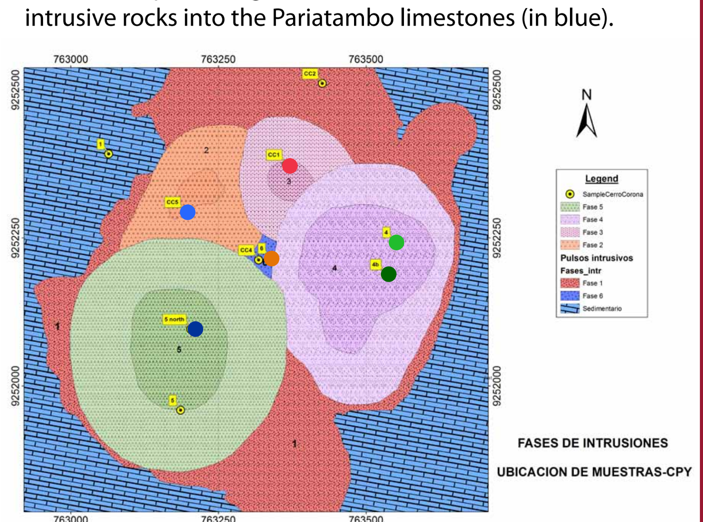
The magmas intruded into the late Cretaceous limestones of the Pariatambo Formation . U-Pb zircon ages indicate the diorite crystallization at 14.4 ±0.1 Ma (James, 1998).

For the present study, a total of 12 samples were examined; five main intrusive rocks and one post mineralization dioritic dyke from the mine property, and six from the area within ten kilometers from the mine.



Geological map of the Cerro Corona area showing the locations of samples.

Detailed map showing the distribution of the Cerra Corona intrusive rocks into the Pariatambo limestones (in blue).



Maps courtesy of the Gold Fields La Cima S.A. Geology department

Hand sample descriptions

Sample CC5n. Typical example of the unaltered dioritic plagioclase porphyry at the Cerro Corona. Note the presence of primary biotite phenocrysts.

Sample CC6. This sample represents a late dyke after the five main porphyric intrusions. The mineralogy and mineral textures are similar to those of the main phases of porphyry intrusives.

Sample CD (Cuadratura quarry porphyry) after K-staining, note the absence of K-feldspar and the euhedral biotite and hornblende phenocrysts.

Petrography

Porphyry intrusives at Cerro Corona have a typical magmatic assemblage composed of:

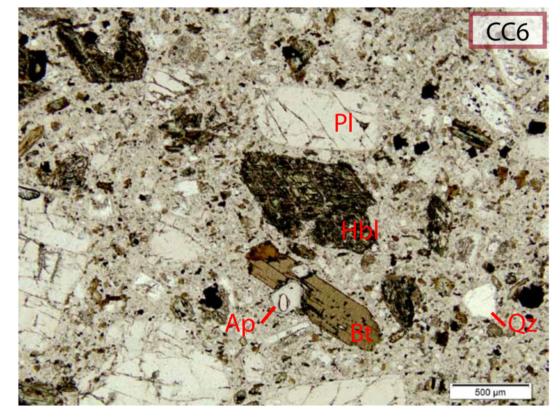
Plagioclase + quartz + biotite ± hornblende ± magnetite + zircon + apatite

Plagioclase, biotite and altered hornblende make up most of the phenocrysts, with minor quartz. The fine grained groundmass is composed of plagioclase, quartz and minor biotite.
Apatite, zircon and magnetite make up most of the magmatic accessory minerals.

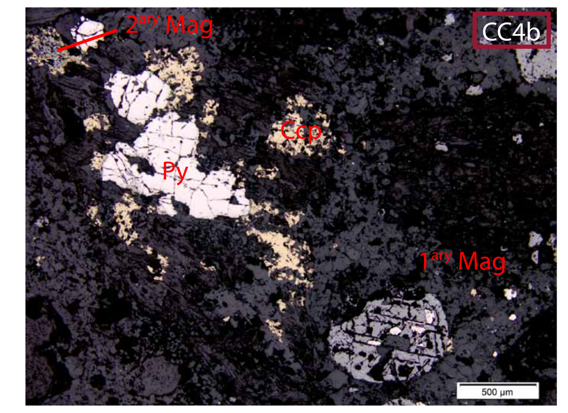
The alteration sequence comprises, in order:
1) Potassic alteration which transforms hornblende into biotite and plagioclase into fine-grained white micas.

2) During subsequent propylitic alteration, hornblende and biotite are replaced by chlorite and magnetite. Epidote is associated with this episode in only one of the samples.

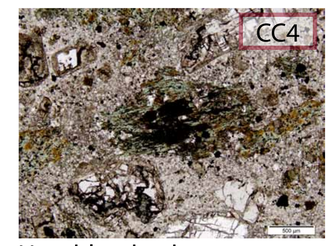
3) Late stage alteration includes quartz vein (with associated magnetite). Minor carbonate and clay replace feldspars.



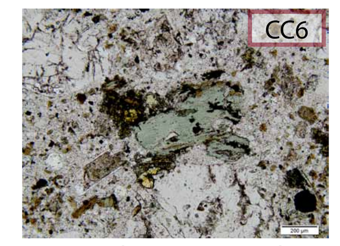
Typical magmatic phenocryst assemblage.



Primary magnetite along with secondary magnatite in an alteration assemblage with pyrite and chalcopyrite.



Hornblende phenocrysts replaced by biotite which is in turn replaced by chlorite and magnetite.



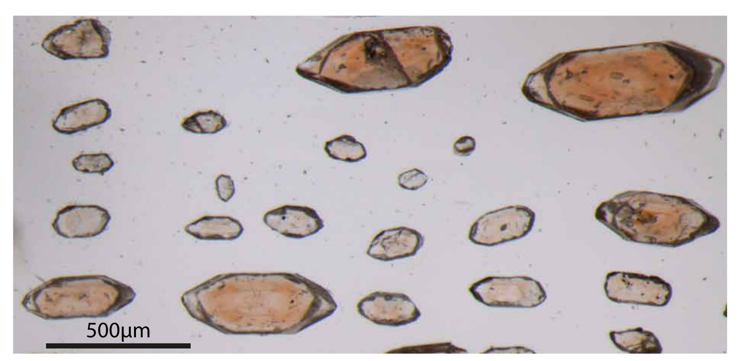
Rare epidote associated with chlorite replacing biotite.

Quartz veinlets crosscutting a large biotite phenocryst. Secondary magnetite is associated with the veins.

Zircon petrography

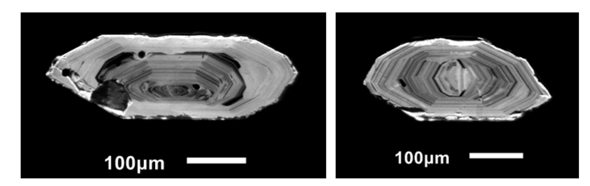
Zircons in Cerro Corona samples are euhedral; show typical magmatic oscillatory zoning and inherited cores are rare.
Zircons commonly show sector zoning and often contain apatite inclusions. The presence of a U-rich irregularly-shaped domain in the zircon may suggest short-lived perturbation of the zircon crystallization for which we have no interpretation yet.

Estimation of the oxidation state of the magma is primarily based on the trace element composition of zircon. A lot of care was given to selecting zircon grains suitable for the study. Avoiding grains with many inclusions, inherited cores and sector zoning were the main factors in selecting zircons.

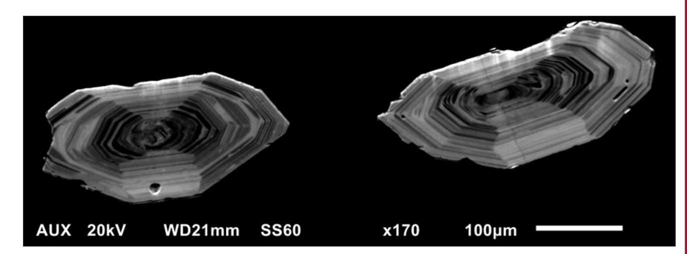


Binocular microscope image of typical zircons from sample CC4.

Most zircons have euhedral shapes. Their color is clear to pinkish-orange. Note that many zircons have inclusions. Most clear inclusions are euhedral apatite and irregularly shaped feldspars. Opaque inclusions are magnetite and minor ilmenite.



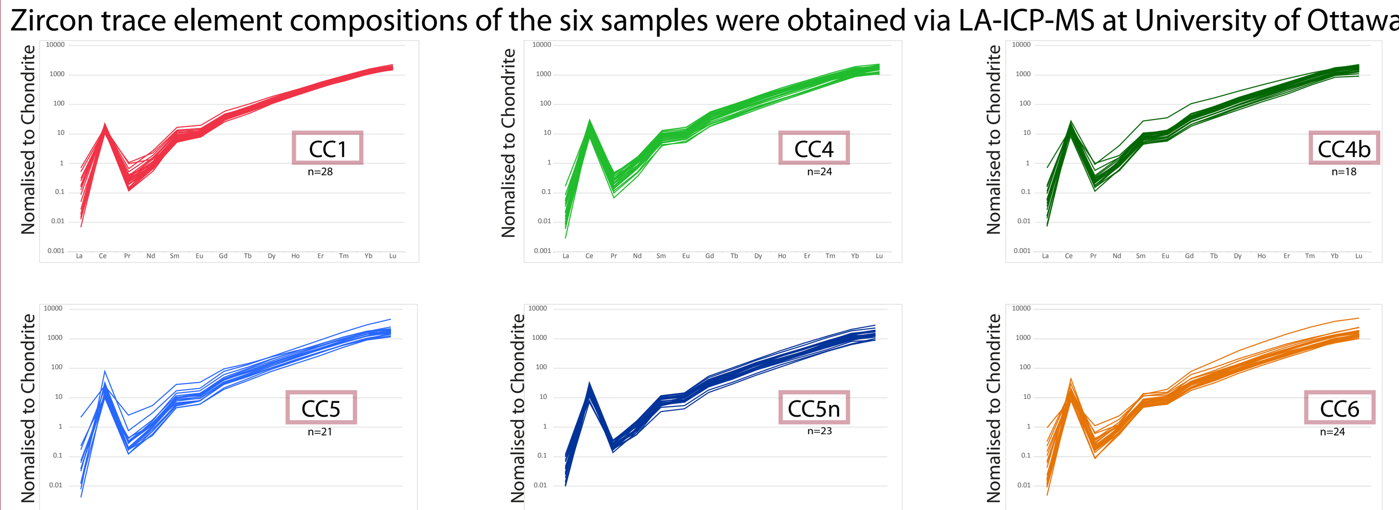
Example of dark CL domains (Sample CC1).
Many zircons show a dark domain in CL images. These darker domains are typically discontinuous and have rounded edges. The zircon zoning pattern does not differ significantly on either side of the dark domains, suggesting a minor episode of dissolution within the main crystallization sequence.

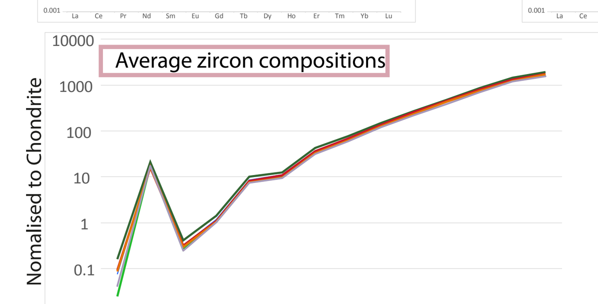


Example of sector zoning (Sample CC5).
Such zircons are not suitable for estimating the oxidation conditions of magma.

Zircon trace elements

Zircon trace element compositions of the six samples were obtained via LA-ICP-MS at University of Ottawa.





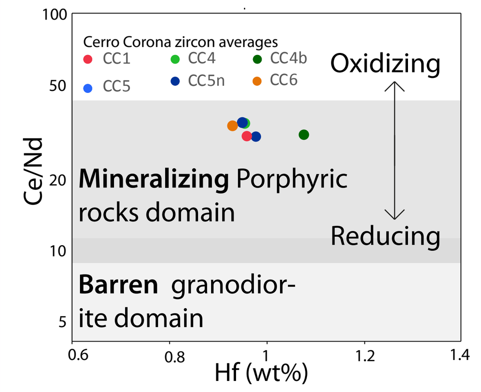
Samples	Eu anomaly	Ce/Nd
CC1	0.612	22.3
CC4	0.62	19.3
CC4b	0.603	19.7
CC5	0.619	19.4
CC5n	0.612	21.7
CC6	0.612	22.5

All zircons from Cerro Corona have typical REE patterns, preferentially enriched in HREE. Among the selected zircons, only one population is observed and shows a homogeneous composition.

There are no major differences in zircon REE patterns among the six samples.

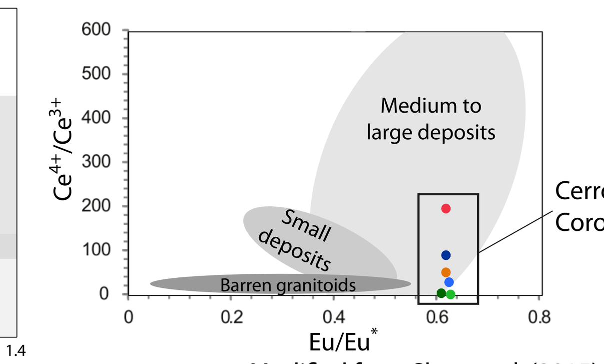
Preliminary results for determining oxidation state of magma from zircon

Zircon can accomodate Ce and Eu which both can have two valences. Using Ce and Eu anomalies in zircon it is possible to estimate the oxidation state of the magma at the time of crystallization (Shen et al., 2015). We used the method of Ballard et al. (2002) to overcome the low concentration of La in zircon to estimate the Ce anomaly which is a proxy for Ce^{4+}/Ce^{3+}.



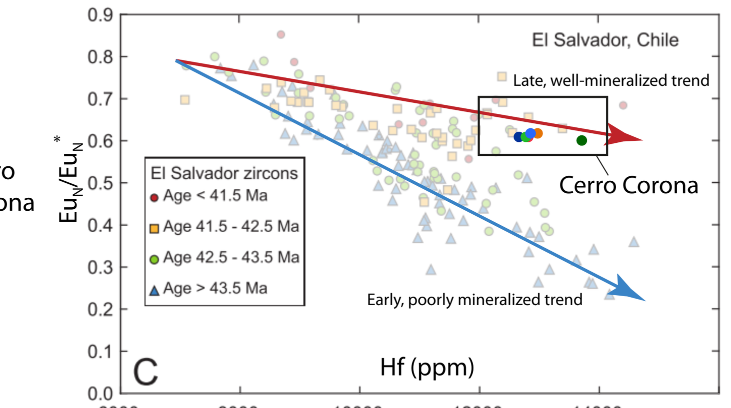
Fields from Chelle-Michou et al. (2014)

Zircon Ce/Nd ratios can be used as a proxy for the oxidation state. At Cerro Corona, the average values per sample vary from 19.3 to 22.5, which is within the range found by Chelle-Michou et al. (2014) in the Coroccohuayco Deposit (Peru) mineralizing porphyry intrusions.



Modified from Shen et al. (2015)

Based on samples from the Central Asian Orogenic Belt, the study indicates that high Ce^{4+}/Ce^{3+} are associated with the larger Cu tonnage deposits while barren granitoids have lower Ce^{4+}/Ce^{3+}. Peruvian Cordillera samples from Cerro Corona plot in the range of intermediate-sized deposits.



Modified from Dilles et al. (2015)

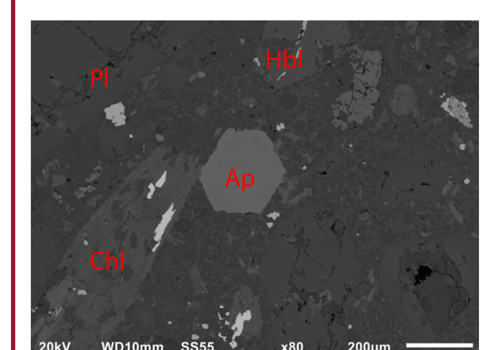
Dilles et al. (2015) uses the Eu anomaly as a proxy for the oxidation state of the magma. The Cerro Corona samples have a similar trend compared to the "well-mineralised" trend of samples from El Salvador, Chile.

Apatite composition

Apatite is a minor but ubiquitous component of the Cerro Corona mineral assemblages. Apatite can accommodate some sulfur in its structure via a small number of different substitutions (Streck and Dilles, 1998). Since sulfur can have various valences (S^{2-} or S^{6+} in $SO4^{2-}$), it can be used as a tracer for the evolution of the magmatic oxidation stage.

Cerro Corona samples contain both magmatic and secondary apatite. Most apatites observed are secondary based on the fact that they are often associated with chlorite in the assemblage replacing primary biotite. Those apatite are not considered for this study since they do not reflect the magmatic stage.

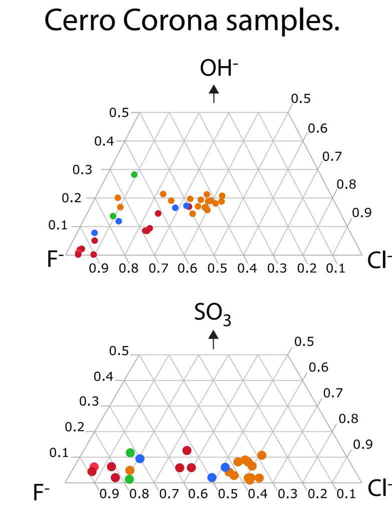
Primary apatites were selected based on textural evidences (i.e. euhedral, lack of intergrowth).

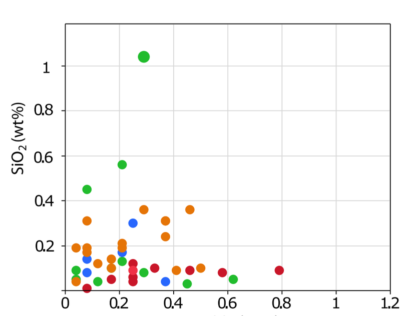


Magmatic apatite in sample CC6.

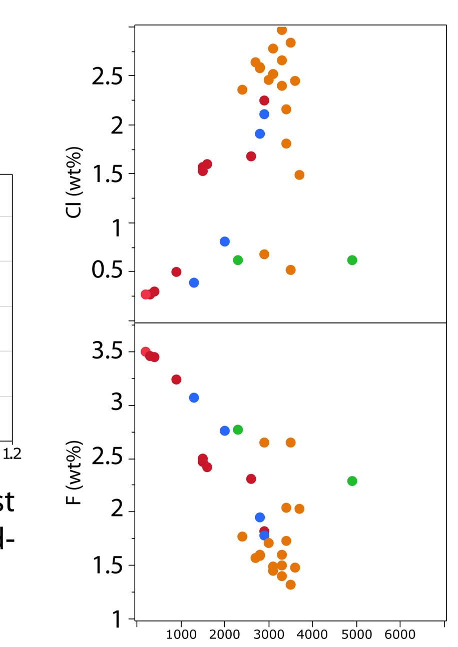
Sample
CC1 CC4
CC5 CC6

Apatite classification in the Cerro Corona samples.





Sulfate is present in most apatites that are considered magmatic.



Summary and future work

- Cerro Corona provides a good example of an intermediate to large sized Cu-Au porphyry deposit where petrology and age can be linked to the evolution of the oxidation state.
- Preliminary results of trace element compositions of zircon at Cerro Corona are comparable to those for intermediate-sized porphyry deposit in the Central Asian Orogenic belt and other proxies that have been recently developed.
- More detailed analysis of zircon and apatite preliminary results should help evaluating if there is variation of the oxidation state of magma within the Cerro Corona intrusion sequence.

Future analytical work on Cerro Corona Samples:
- SHRIMP U-Pb ages in zircons will provide a time-frame for the evolution of the oxidation state.
- Analysis of zircon and apatite from samples outside of the mine property will provide background values for comparison.

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