Gold-copper fertile intrusions in the Hualgayoc mining district, Peru

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① Introduction

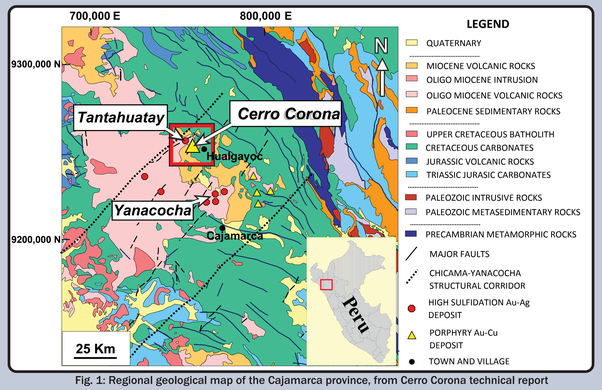


Fig. 1: Regional geological map of the Cajamarca province, from Cerro Corona technical report

The Hualgayoc mining district is located in the Andean Cordillera of northern Peru, 30km north of the Yanacocha high-sulphidation Au district. The district hosts numerous Au-Cu deposits, including the Cerro Corona Au-Cu porphyry, the Tantahuatay high sulfidation Au, and the AntaKori skarn/high sulphidation Au-Cu deposits.
In this study we characterize the igneous rocks in the Hualgayoc mining district and identify the features associated with Au-Cu fertile magmas.

② Geological setting

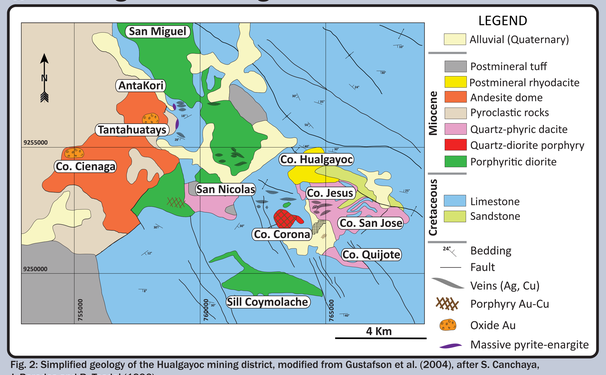
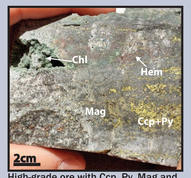


Fig. 2: Simplified geology of the Hualgayoc mining district, modified from Gustafson et al. (2004), after S. Canchaya, J. Paredes and R. Tosdal (1996)

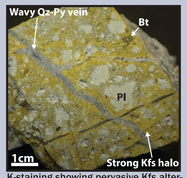
The Hualgayoc mining district consists of weakly deformed Cretaceous sedimentary rocks (mainly limestone, with minor sandstone and shale). These formations were intruded by several Miocene dioritic bodies including Cerro Corona, and overlaid by andesitic to rhyolitic flows, domes and tuffs. The AntaKori and Tantahuatay deposits are partially hosted in the Calipuy volcanic formation in the western part of the district, south-west of the San Miguel diorite. The Cerro Corona porphyry intruded Cretaceous limestones, west of Cerro Jesus and Cerro San Jose intrusions, which host historic mines of silver-rich intermediate sulfidation veins.

③ Lithology and alteration

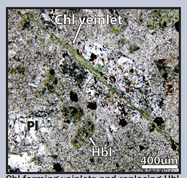
The dominant phase of intrusive rocks in the Hualgayoc mining district consist of hornblende±biotite-bearing porphyritic diorite with magnetite micro-phenocrysts, indicating relatively oxidized parental magma. This includes Cerro Corona, the Coymolache sill, the San Miguel diorite, and the San Nicolas, Cerro Jesus and Cerro San Jose intrusions.
Volcanic rocks include the Hualgayoc rhyodacite north of Cerro Corona, the San Miguel andesite which contains clinopyroxene with rare xenocrysts of blue sapphire, and the andesitic to rhyolitic Calipuy formation which partially hosts the Tantahuatay and AntaKori deposits.



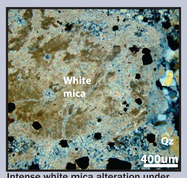
High-grade ore with Ccp, Py, Mag and Hem – Cerro Corona.



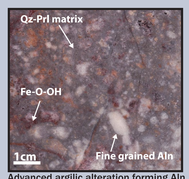
K-staining showing pervasive Kfs alteration (yellow color) – Cerro Corona.



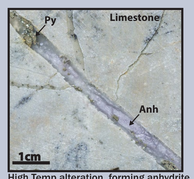
Chl forming veinlets and replacing Hbl and Bt – San Miguel Diorite.



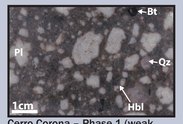
Intense white mica alteration under crossed polars – AntaKori



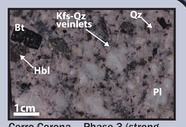
Advanced argilic alteration forming Aln and Prl – Cerro Cienaga.



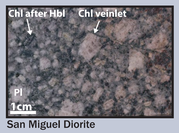
High Temp alteration forming anhydrite veins – AntaKori.



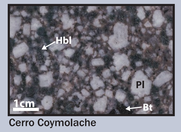
Cerro Corona – Phase 1 (weak potassic alteration)



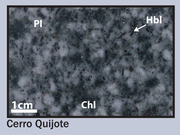
Cerro Corona – Phase 3 (strong potassic alteration)



San Miguel Diorite

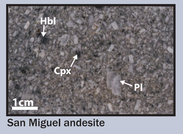


Cerro Coymolache

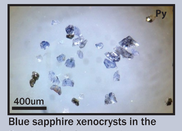


Cerro Quijote

Cerro Hualgayoc rhyodacite



San Miguel andesite



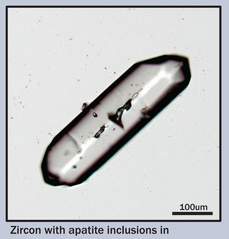
Blue sapphire xenocrysts in the San Miguel volcanic rocks

Alteration is prevalent in all intrusions except the Coyomolache sill, the San Nicolas intrusion and the Hualgayoc rhyodacite. Weak to medium chlorite±epidote alteration affects the San Miguel diorite and Cerro Quijote intrusions. Strong white mica alteration occurs at San Jose, Cerro Jesus, Tantahuatay and AntaKori. Acidic alteration of pyrophylite±alunite is present in Cerro Cienaga, Cerro Tantahuatay and AntaKori. Potassic alteration of K-feldspar+biotite+magnetite occurs at Cerro Corona, and locally in the San Jose intrusion.

Abbreviations: Bt: biotite – Hbl: hornblende – Pl: plagioclase – Qz: quartz
Chl: chlorite – Kfs: potassic feldspar – Cpx: clinopyroxene – Anh: anhydrite
Aln: alunite – Prl: pyrophyllite – Py: pyrite – Ccp: chalcopyrite – Mag: magnetite
Hem: hematite

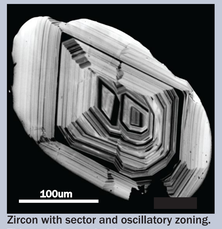
④ Zircon textures

Pinkish euhedral zircons with pyrite after heavy liquid separation.

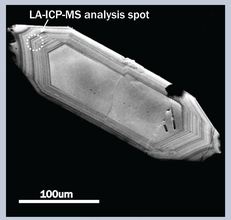


Zircon with apatite inclusions in transmitted light.

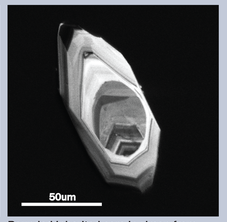
Zircon is a common accessory mineral in most intrusions. The grains are euhedral with a pinkish color. Most grains range from 50um to 300um and commonly contain apatite and feldspar inclusions.
All zircons show typical magmatic oscillatory zoning, and common sector zoning.
Inherited cores are present but rare, and are only found so far in zircons from Cerro Corona and Cerro Hualgayoc.



Zircon with sector and oscillatory zoning. This grain is unsuitable for trace elements analysis.

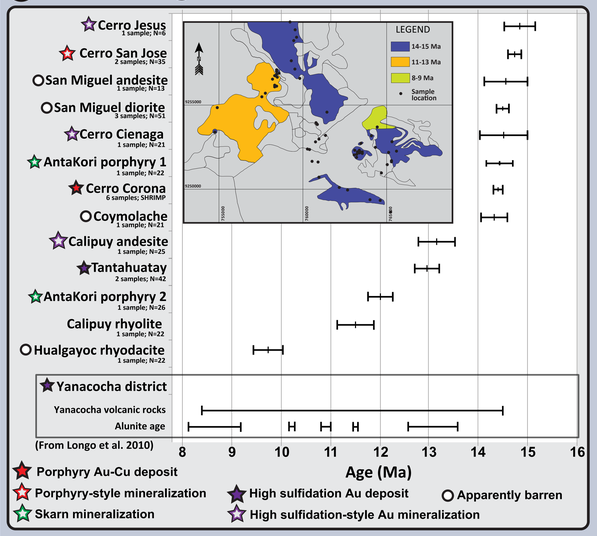


Zircon with oscillatory zoning.



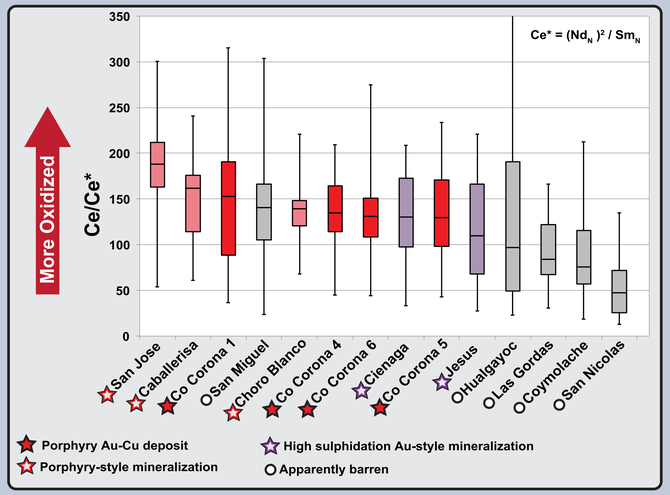
Rounded inherited core in zircon from Cerro Hualgayoc.

⑤ $^{238}U/^{206}Pb$ ages of intrusions from zircons



The magmatic activity in the Huagayoc mining district was previously thought to range from Paleocene to Miocene in age. New U-Pb zircon ages indicate that magmatic activity ranged from 14.8Ma to 9.7Ma, similar to the ages of igneous and hydrothermal activity of the Yanacocha high-sulfidation Au district. Most intrusions formed in a 1 m.y. period between 14-15Ma. Some are associated with mineralization (Cerro Corona) while others appear to be barren (Coymolache). Late magmatism at 9-10Ma consists of barren rhyodacite-rhyolite domes.

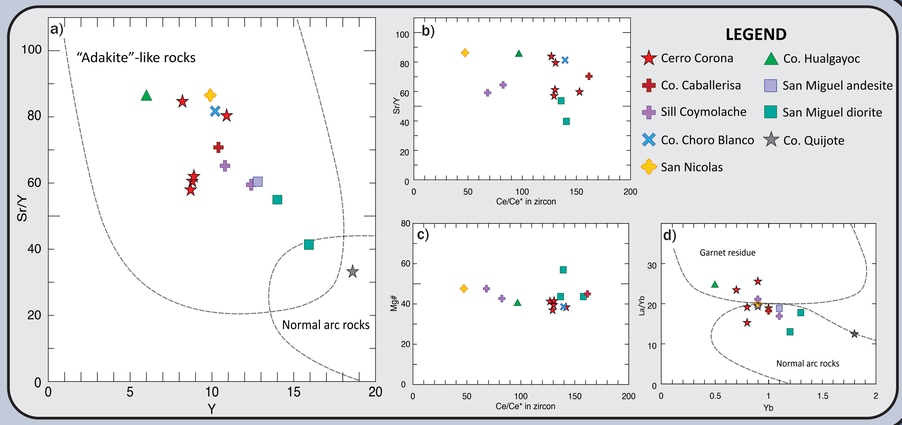
⑥ Cerium anomaly in zircon: indication of magma oxidation state



Unlike the other Rare Earth Elements, which only exist at the 3+ state, cerium (Ce) can also exist in the 4+ state. In zircon, Ce^{4+} readily substitutes for Zr^{4+} while Ce^{3+} is strongly excluded. Therefore, the Ce anomaly in zircon can be used as a tracer of magmatic redox state (Ballard et al, 2002).
We observe that all intrusions associated with mineralization have a median Ce/Ce* value between 100-170. In contrast, most apparently barren intrusions have a lower median Ce/Ce* value between 50-100. The data suggest that mineralized intrusions are characterized by intrinsically oxidized parental magma, which may be an factor for the Au-Cu mineralization.

⑦ Bulk rock composition

All intrusions except Cerro Quijote show an "adakitic"-like signature with high Sr/Y ratios (40-90) and low Y (5-16ppm) (Fig. a). This can be explained by high water contents in parental magmas (>4wt% H_2O) that suppress plagioclase crystallization (Sisson and Grove, 1993). This is consistent with the presence of biotite and hornblende phenocrysts in most intrusions.
Samples from Cerro Corona, which host the Au-Cu deposit, are among the highest Sr/Y and Ce/Ce* in zircon, along with Cerro Choro Blanco and Cerro Caballerisa (Fig. b).
Oxidation condition does not seem to correlate with magma evolution, suggesting that the magmas were intrinsically oxidized (Fig. c).
Low La/Yb ratio (<20) of most intrusion indicate that these rocks are not adakites, partial melt of the subducting slab with a garnet residue (Fig. d).



⑧ Implications for exploration

The age range of intrusions in the district was previously uncertain, with some suggestion of at least Eocene to Miocene ages. This study showed that the dated samples range from ~15 to 9Ma; the Cerro Corona porphyry that hosts the Au-Cu deposit is amongst the oldest intrusions. Also, zircon grains from mineralized intrusions have higher Ce/Ce* ratio than most zircon grains from barren intrusions. This suggests that the cerium anomaly in zircon can be used to identify more oxidized intrusions that may potentially be Au-Cu fertile.

⑨ Summary and on-going work

The Hualgayoc mining district has been affected by Miocene magmatism, from 14.8Ma to 9.7Ma. Most intrusions formed early, in a ~1 m.y. period, and have a variable bulk-rock composition and degree of magma oxidation state. This suggests they could have been formed from different batches of parental magma, which could explain contemporanuous barren and mineralized intrusions. The younger intrusions and volcanic rocks from Tantahuatay and AntaKori plus the Hualgayoc rhyodacite coincide with ages of volcanism and hydrothermal activity associated with the nearby Yanacocha high-sulfidation Au district. This suggests that the similar aged igneous rocks of both districts may originate from the same regional magmatic event.
On-going work includes: more zircon dating to better understand the chronological relationship between the intrusions; hornblende geothermobarometry to define the depth of emplacement and temperature of crystallization; Sr and Nd isotopes to characterize the magmatic signatures and contamination from country rocks.

References

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Aknowledgement

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