Magmas associated with Au-Cu deposits in the Hualgayoc Mining District, Northern Peru

M Viala[1], K Hattori[1], P Gomez[2], J Trujillo[3], K Heather[4]

[1]Department of Earth Sciences, University of Ottawa, Ontario, Canada; [2]Gold Fields La Cima, Lima, Peru; [3]Compania de Minas Buenaventura S.A.A., Lima, Peru; [4]Regulus Resources Inc., Lima, Peru

① Introduction

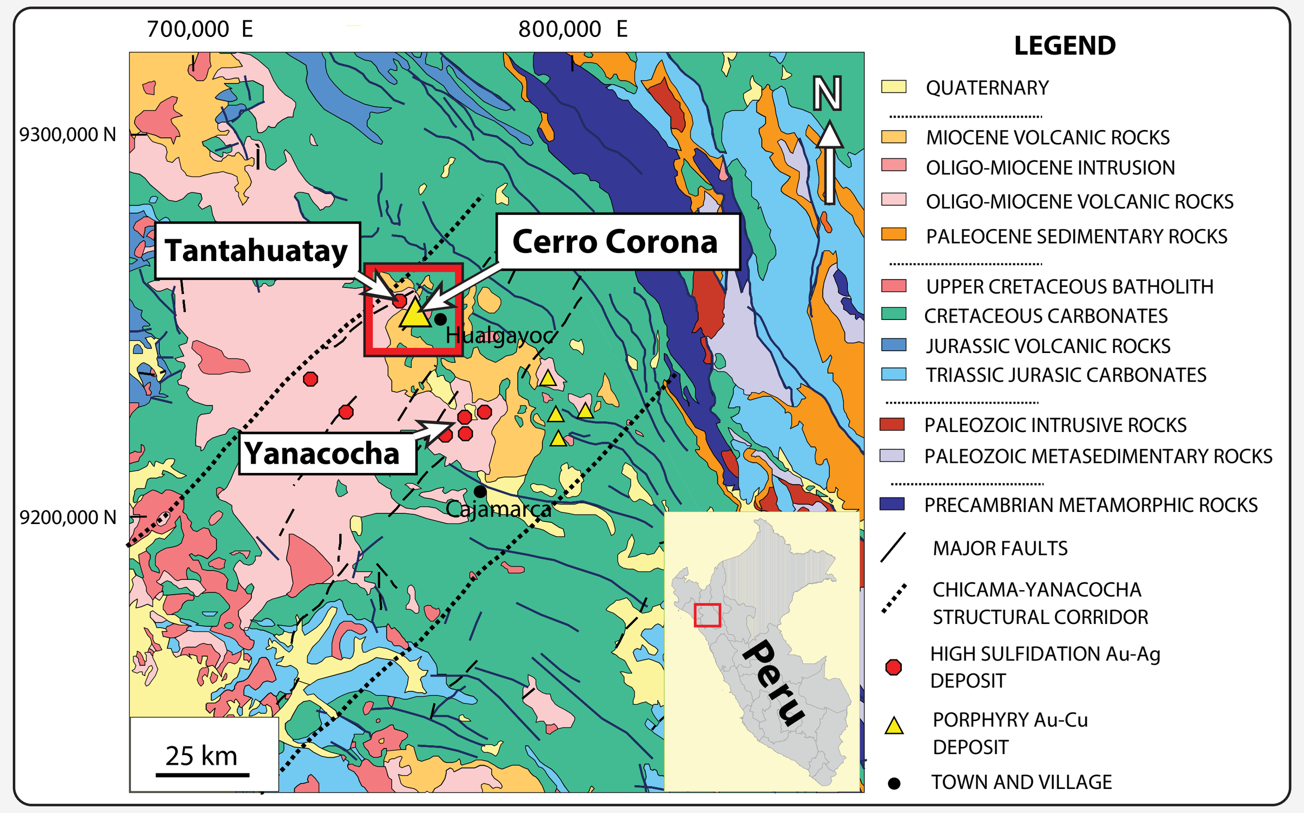


Fig. 1: Regional geological map of the Cajamarca province, from Cerro Corona technical report (2004).

The Hualgayoc mining district in the Peruvian Cordillera is located 30km north of the Yanacocha high-sulfidation Au deposits. The district hosts numerous Au-Cu deposits, including epithermal, skarn and porphyry. This study examine the igneous rocks associated with and without mineralization.

② Geological setting

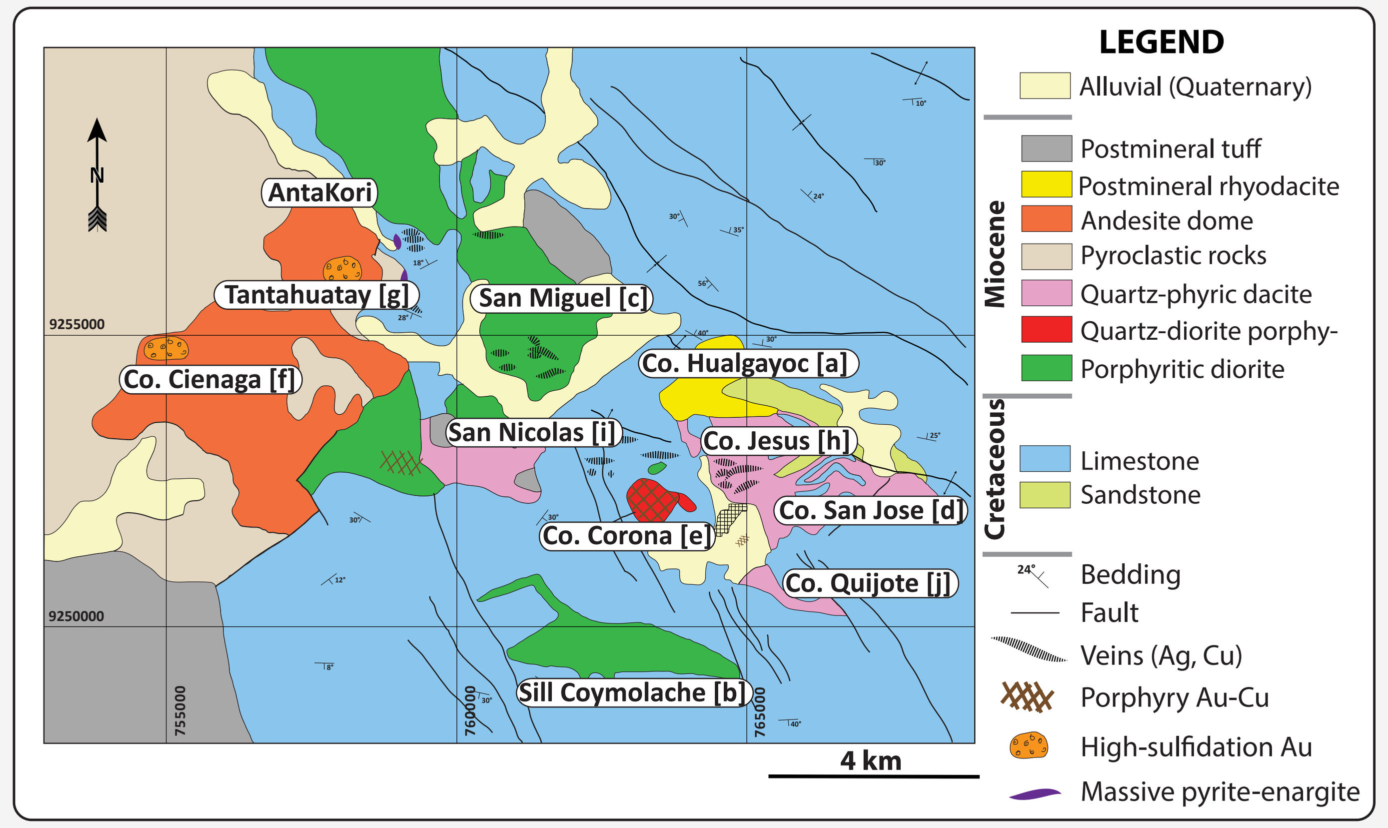


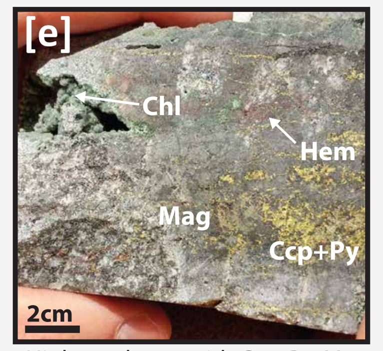
Fig. 2: Simplified geological map of the Hualgayoc district, modified after S. Canchaya, J. Paredes and R. Tosdal (1996), cited by Gustafson et al (2004). Letters in brackets correspond to panel #3.

Cretaceous sedimentary rocks were intruded by dioritic rocks, including the Cerro Corona porphyry, and overlain by andesitic to rhyolitic flows, domes and tuff. Mineral deposits include the Cerro Corona porphyry Cu-Au mine, Tantahuatay high-sulfidation Au mine, and the AntaKori Cu skarn deposit.

③ Lithology and alteration

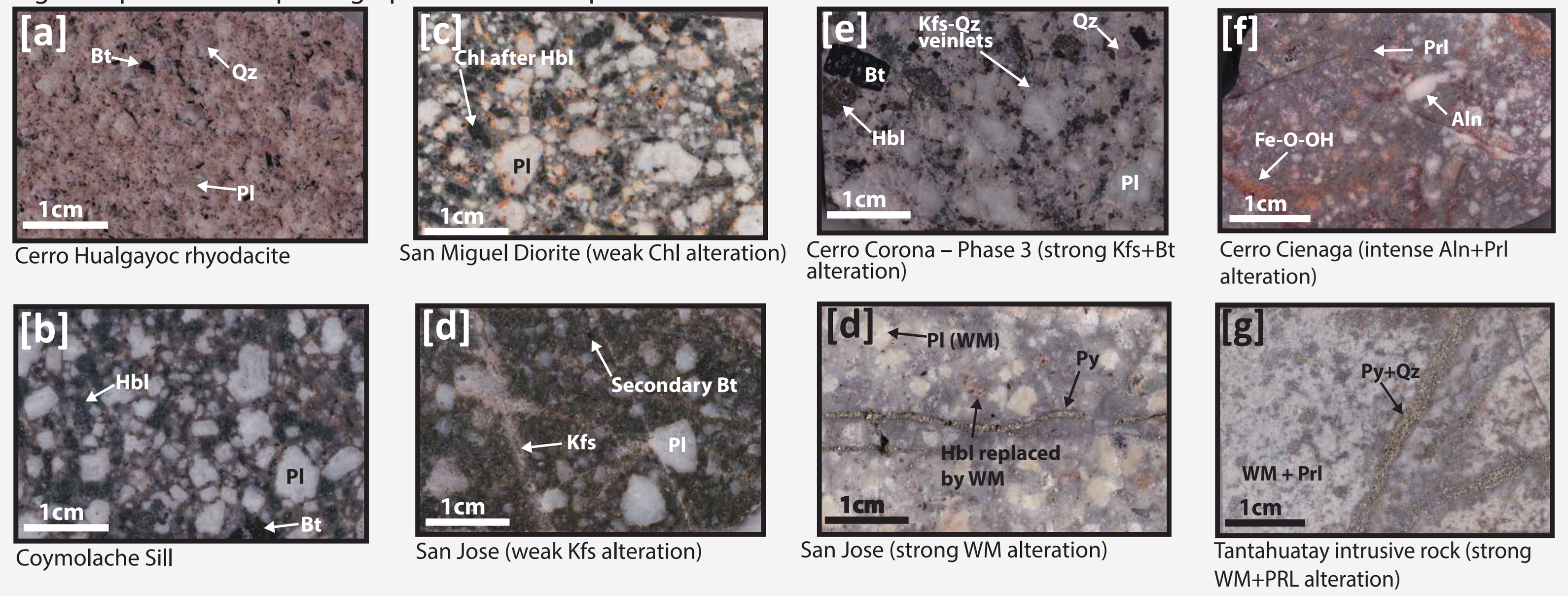
Dominant rocks are hornblende (Hbl) ± Biotite (Bt) porphyritic diorite with magnetite (Mag) micro-phenocrysts, suggesting relatively oxidized parental magmas. Volcanic rocks include rhyodacite domes north of Cerro Corona, and the andesitic to rhyolitic Calipuy formation which hosts part of the Tantahuatay and AntaKori deposits.

Alteration includes K feldspar (Kfs) + Bt + Mag at Cerro Corona (e in Fig. 2), and locally in the San Jose intrusion (d in Fig. 2), weak to moderate chlorite (Chl) ± epidote (Ep) alteration in San Miguel (c in Fig. 2) and Cerro Quijote intrusions (j in Fig. 2); intense WM alteration in the San Jose and Cerro Jesus intrusions (h in Fig. 2); and pyrophyllite (Prl) ± alunite (Aln) at Cerro Cienaga (f in Fig. 2) and Tantahuatay plus AntaKori (g in Fig. 2) deposits.



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

Fig. 3: Representative photographs of hand samples from several intrusions.



Cerro Hualgayoc rhyodacite; San Miguel Diorite (weak Chl alteration); Cerro Corona – Phase 3 (strong Kfs+Bt alteration); Cerro Cienaga (intense Aln+Prl alteration); Coymolache Sill; San Jose (weak Kfs alteration); San Jose (strong WM alteration); Tantahuatay intrusive rock (strong WM+PRL alteration)

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 – WM: white mica

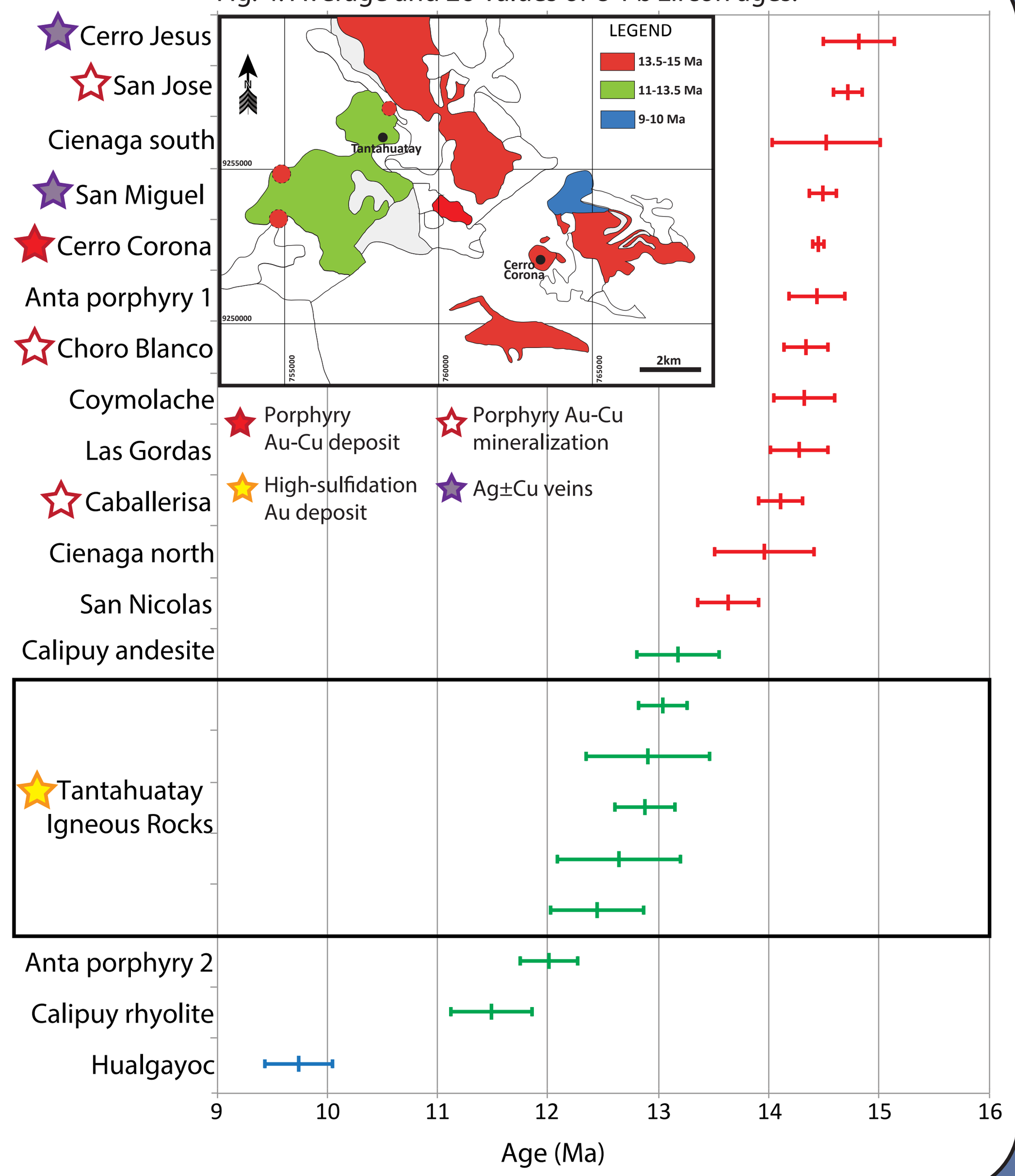
④ U-Pb zircon ages

Igneous activity in the district was previously considered to have started in the Paleocene. Our U-Pb zircon ages indicate nearly continuous magmatism from 14.8 to 9.7 Ma with a hiatus between 11 and 10 Ma.

Intrusions in the eastern and northern part of the district formed between 15 and 13.5 Ma. Some are associated with mineralization (e.g., Cerro Corona, e in Fig. 2) whereas others appear to be barren (e.g., Coymolache, b in Fig. 2).

Magmatism from 13.5 to 11 Ma was focused in the Tantahuatay and AntaKori areas, consisting of porphyritic intrusions and volcanic rocks (largely Calipuy Formation). The Cerro Hualgayoc rhyodacite dome (Fig. 2, a) at 9.7 Ma appears to represent the final magmatic activity in the area.

Fig. 4: Average and 2σ values of U-Pb zircon ages.



⑤ Magmas source and evolution

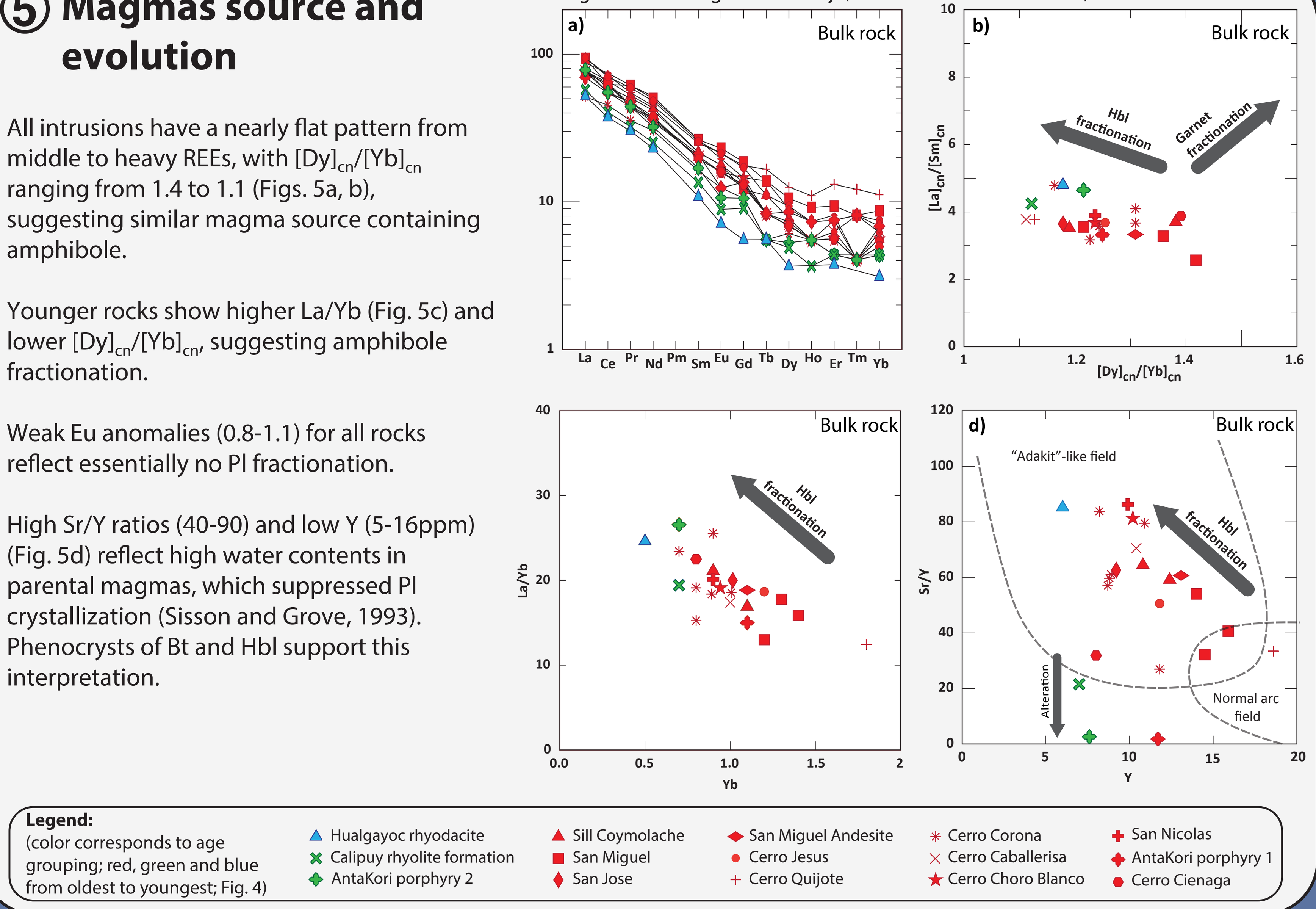
All intrusions have a nearly flat pattern from middle to heavy REEs, with $[Dy]_{cn}/[Yb]_{cn}$ ranging from 1.4 to 1.1 (Figs. 5a, b), suggesting similar magma source containing amphibole.

Younger rocks show higher La/Yb (Fig. 5c) and lower $[Dy]_{cn}/[Yb]_{cn}$, suggesting amphibole fractionation.

Weak Eu anomalies (0.8-1.1) for all rocks reflect essentially no Pl fractionation.

High Sr/Y ratios (40-90) and low Y (5-16ppm) (Fig. 5d) reflect high water contents in parental magmas, which suppressed Pl crystallization (Sisson and Grove, 1993). Phenocrysts of Bt and Hbl support this interpretation.

Fig. 5: Bulk rock geochemistry (cn: chondrite-normalized).



⑥ Zircon as records of magmatic processes

A similar REE pattern for zircon reflects a similar parental magma composition.

In 13.5-11 Ma magmas, Hbl and Mag crystallized with zircon (Fig. 6c, d), whereas Hbl and Mag crystallized before zircon in 15-13.5 Ma magmas.

Most zircons compositions indicate weak negative Eu anomalies (Eu/Eu*=0.4-0.8) and moderate to very high Ce anomalies (Ce/Ce*=50-600), reflecting oxidized parental magmas (Fig. 6e).

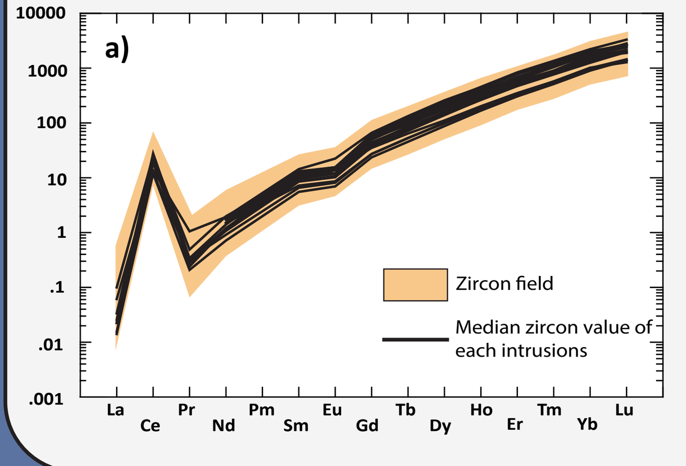
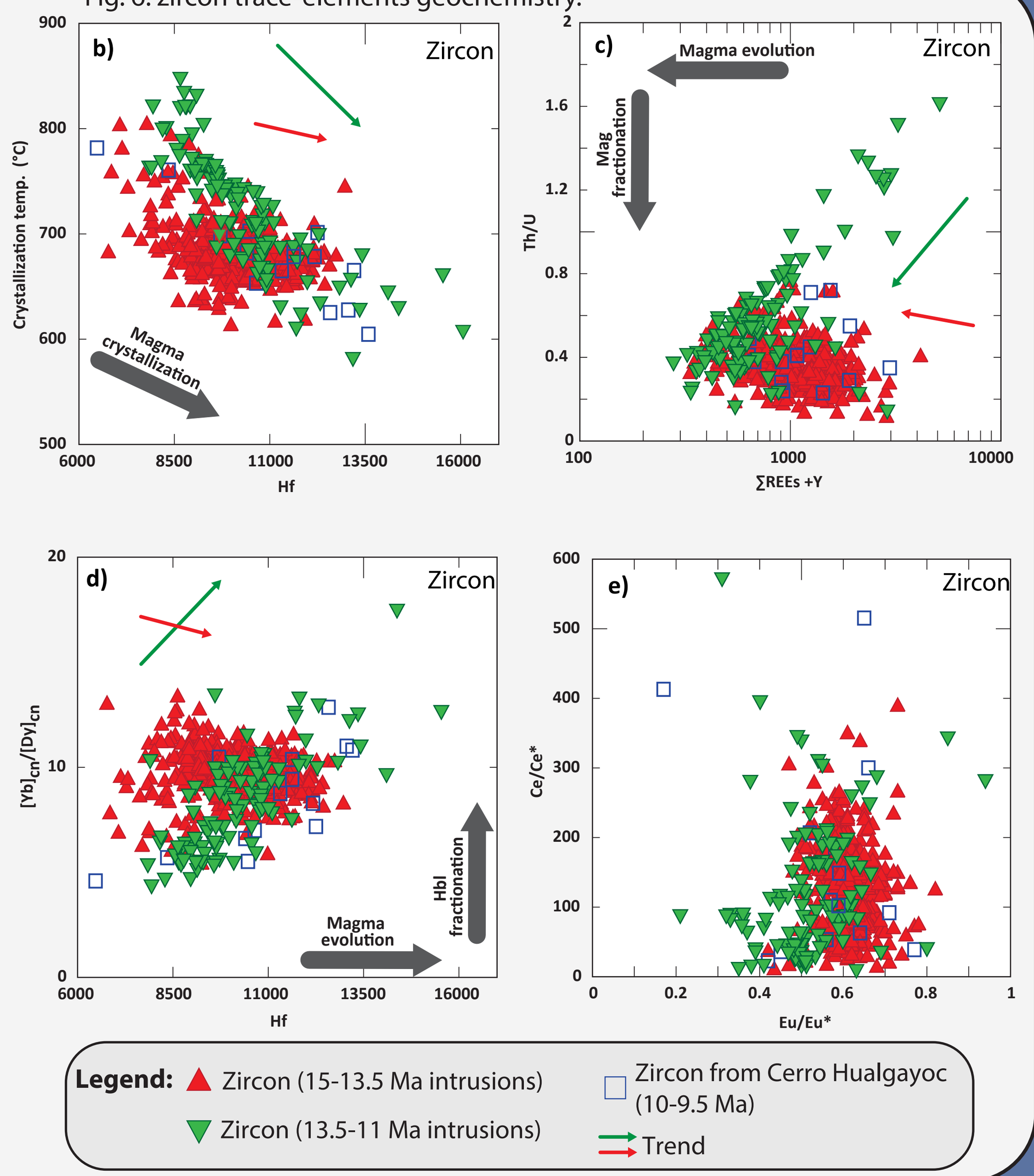


Fig. 6: zircon trace-elements geochemistry.



⑦ Magmatic oxygen fugacity calculated from amphibole composition

The oxygen fugacity of barren Coymolache sill and barren San Nicolas intrusion were calculated following the method of Ridolfi et al. (2010). The results indicate oxidized values (FMQ +1.6 to +2.9) (Fig. 8). These values are similar of those from Yanacocha, calculated using the amphibole compositions presented by Longo

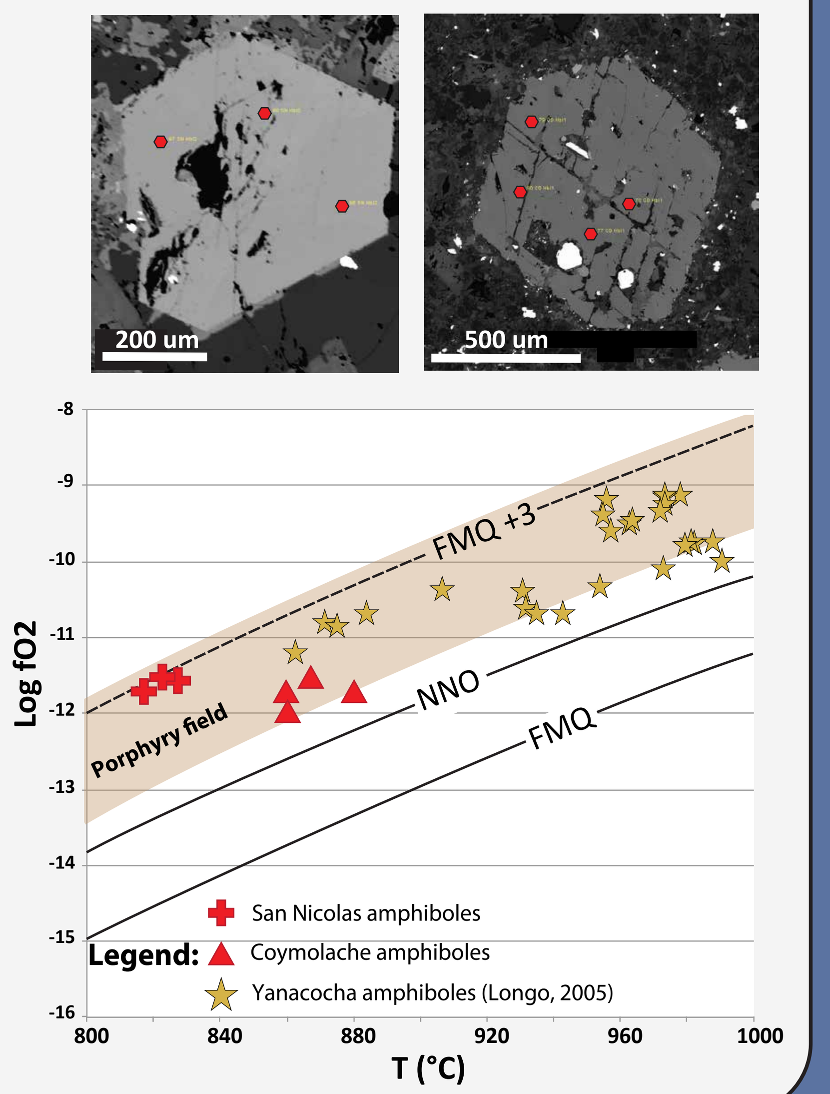


Fig. 8: [Top] Unaltered amphibole from the San Nicolas (left) and Coymolache (right) intrusions. Red circles are areas for the analylsis. [Bottom] Calculated crystallization temperature (°C) vs. magmatic oxygen fugacity.

⑧ Summary

- **Parental magmas in the district were hydrous, moderately to highly oxidized and originated from garnet-free, amphibole-bearing subcontinental lithospheric mantle or lower crust. Amphibole fractionation was the major cause for the compositional variation.**
- **Mineralized and barren intrusions are similar in composition and contemporaneous, suggesting similar magma sources and evolution.**
- **The mineralization requires other factors, including geometry of the intrusion and the depth of emplacement.**

References

•Gustafson, L. B., Vidal, C. E., Pinto, R., & Noble, D. C. (2004). Porphyry-epithermal transition, Cajamarca region, northern Peru. Society of Economic Geologists, 11, 279-299.

•Longo, A. A. (2005). Evolution of volcanism and hydrothermal activity in the Yanacocha mining district, northern Peru. Unpublished PhD. Thesis at the Oregon State University.

•Ridolfi, F., Renzulli, A., & Puerini, M. (2010). Stability and chemical equilibrium of amphibole in calc-alkaline magmas: an overview, new thermobarometric formulations and application to subduction-related volcanoes. Contributions to Mineralogy and Petrology, 160(1), 45-66.

•Sisson, T. W., & Grove, T. L. (1993). Experimental investigations of the role of H_2O in calc-alkaline differentiation and subduction zone magmatism. Contributions to Mineralogy and Petrology, 113(2), 143-166.

Aknowledgements

We thank Gold Fields Cerro Corona mine staff for their logistic support during our field work; Buenaventura and Regulus Resources Inc. for their help with sampling; Samuel Morfin, Glenn Poirier and Alain Mauviel for their analytical assistance; and Jeffrey Hedenquist for his advice on the project. The project was supported by a Natural Science and Engineering Council of Canada Discovery Grant to K.H.