6th International Symposium on Andean Geodynamics (ISAG 2005, Barcelona), Extended Abstracts: 738-741

Magnetic mineralogy in the Chuquicamata mine, Northern Chile: Application to paleomagnetic data for validation of structural interpretation in hydrothermal systems

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Introduction

Rock paleomagnetic properties are directly related to their ferromagnetic mineral contents and types upon acquired magnetization. Characteristic remanent magnetizations carried ferromagnetic minerals crystallized during a primary rock forming process are determined by a detailed study of paleomagnetic properties and easily interpreted assuming these minerals formed in a single event. In the case of hydrothermally altered rocks the situation is more complex as ferromagnetic minerals are susceptible to change, destruction or neo-crystallization. In porphyry copper systems the complexities associated with multistage events, both intrusive and hydrothermal, imply a need for detailed mineralogical studies to help understand the nature and paragenesis of ferromagnetic minerals with regard to primary magmatic and overprinted hydrothermal events. Results of a paleomagnetic – mineralogical study of the Chuquicamata porphyry copper deposit, northern Chile, are here presented. The objectives of this study are to relate paleomagnetic properties of hydrothermally altered rocks with both primary magmatic and hydrothermal mineralogy, and to determine the effects of different types of alteration on the original paleomagnetic properties, be it destructive or constructive.

Geological Setting

The Chuquicamata deposit is hosted within three porphyries which, from early intrusive phases to postdating supergene alteration, show evidence of spatial and genetic relationship with the evolution of the West Fault System. The oldest is the East porphyry (35-34 Ma), host rock to the largest proportion of copper mineralization. The West and Banco porphyries are younger (34-31 Ma) and show the largest proportion of alteration (Ballard, 2001). The early post-magmatic alteration is represented by selective potassic alteration, with partial K-feldspar and albite replacement of plagioclase and biotite replacement of hornblende. A propilitic association (chlorite-epidote) is superimposed on the biotitic alteration. A later fine-grained quarz-K-feldspar alteration obliterates biotite and is accompanied with cataclastic deformation. Quarz-molibdenite veins cut all previous alterations. The principal stage of hydrothermal alteration is related with phyllic alteration (quarz-sericite), overprinted on previous alteration associations, with evidence of partial remobilization of early mineralization. Late stages of hydrothermal alteration are represented by sulfide veins (enargite-pyrite). Copper mineralization in this deposit is mostly present within stockwork veining, related with repetitive fracturing along an active fault system, and disseminated (Ossandon et al., 2001). Later superimposed supergene alteration generated an important zone of secondary enrichment mineralization (chalcosite-covellite) and extensive surface zones of leaching. The Fortuna intrusive complex, located west of the West Fissure fault (Lindsay, 1997), is older than the previous (Ballard et al, 2001).

Magnetic techniques and mineralogical studies

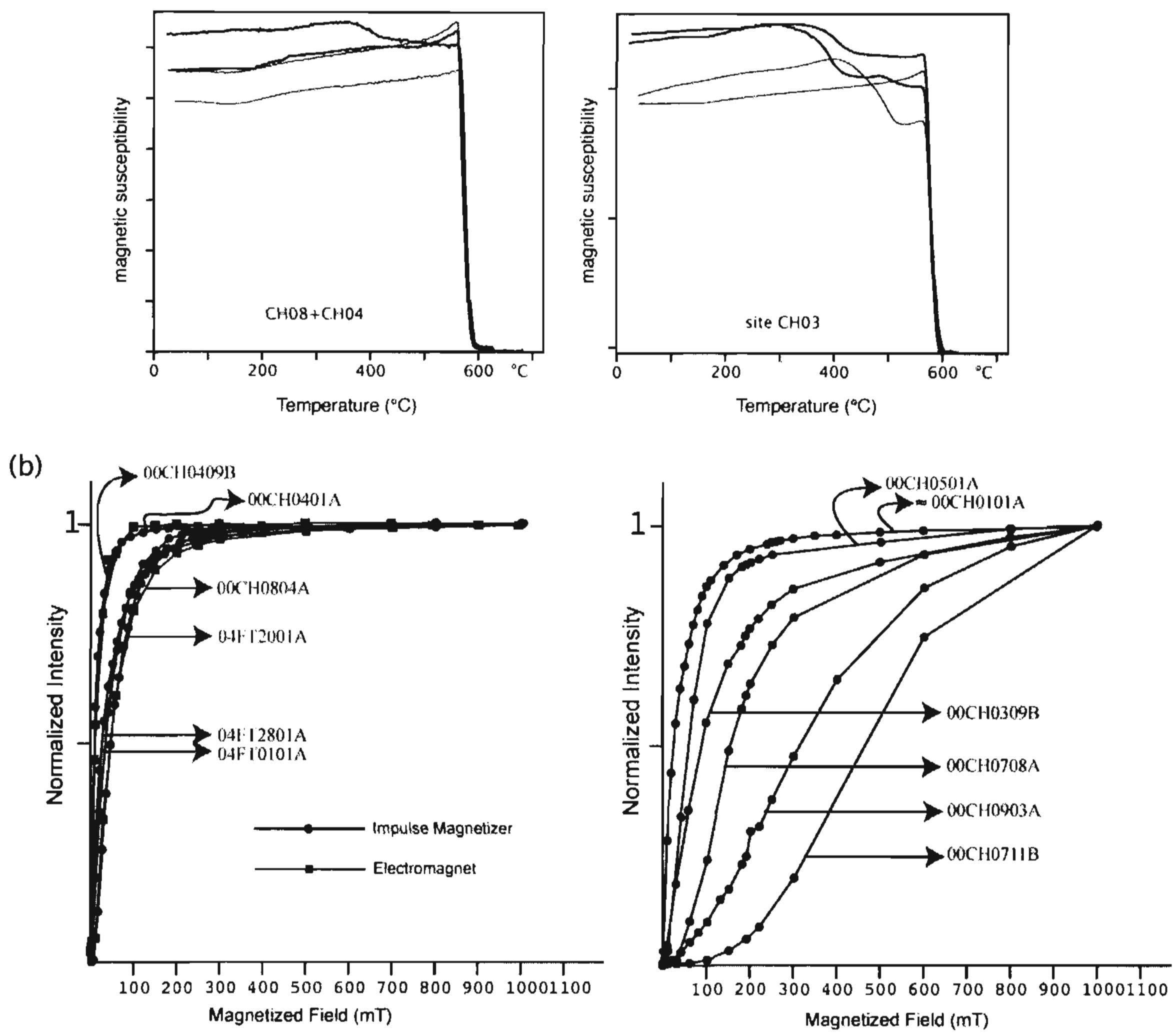

Figure 1: Selected magnetic results for the Fiesta granodiorite and East porphyry. (a) K-T curves. Pure magnetite with Curie temperatures near 580-585°C is the main ferromagnetic mineral (left, 2 samples from the Fiesta granodiorite; right, two samples from the east porphyry). A few samples show evidence for light maghemetization. (b) IRM curves: In the Fiesta granodiorite, very rapid saturation is especially observed at site CH04 indicating large multidomain grains as the main magnetic carriers. of titanohematite solid solution. For the East porphyry, saturation is not observed indicating a variable amount of hematite in samples.

Numerous paleomagnetic samples from multiple sites within the Chuquicamata mine and surroundings were taken for measurements of Natural Remanent Magnetization (NRM), Anisotropy of Magnetic Susceptibility (AMS), Anisotropy of Remanent Magnetization (ARM) and thermal and alternating field demagnetization tests (Astudillo et al., this meeting). Isothermal Remanent Magnetization (IRM) acquisition and susceptibility variation with temperature (K-T) were used to characterize ferromagnetic minerals. The effect of hydrothermal alteration upon these minerals was studied through detailed microscope observations of selected thin sections. In addition, high qualitative resolution (MEB, EPMA) and quantitative analysis (WDS) were carried out on selected samples, for an understanding of the cationic distribution in the ferromagnetic minerals and possible implications to paleomagnetic properties.

Results

Fiesta granodiorite

Four types of ferromagnetic mineralogy are recognized in this unit. The most important magnetic mineral is magnetite, with grain sizes in the range 2 - <0, 01mm. The largest magnetites are associated with ferromagnesian minerals (hornblende and biotite), related mostly with alteration biotite, but in several cases with biotite of primary magmatic origin. The second group, of intermediate and smallest sizes, appear associated with alteration of primary magmatic titanomagnetite, related as well with alteration biotite. In these rocks, exsolution processes and metasomatism strongly affect the original titanomagnetites. Two extended exsolution series are observed for these minerals. The first "composite type" is associated with the exsolution of Ti poor titanomagnetite and ilmenite (C2-C3 stage of oxidation). The second corresponds to gross exsolution of hemoilmenite and ilmenohematite (C4-C5 stage of oxidation). The hemoilmenites evidence Ca metasomatism, related with crystallization of sphene – rutile - hematite and, in several cases, maghemite (C6-C7 stages of oxidation; Haggerty, 1976 and Buddinton and Linsdley, 1964). Inclusions of chlorapatite are observed in these minerals, bearing implications in terms of a hydrothermal origin. A third group of magnetite occurs within the ground mass of porphyry rocks, likely associated to primary magmatic genesis. These magnetite crystals present oxidation to hematite in edges and fractures.

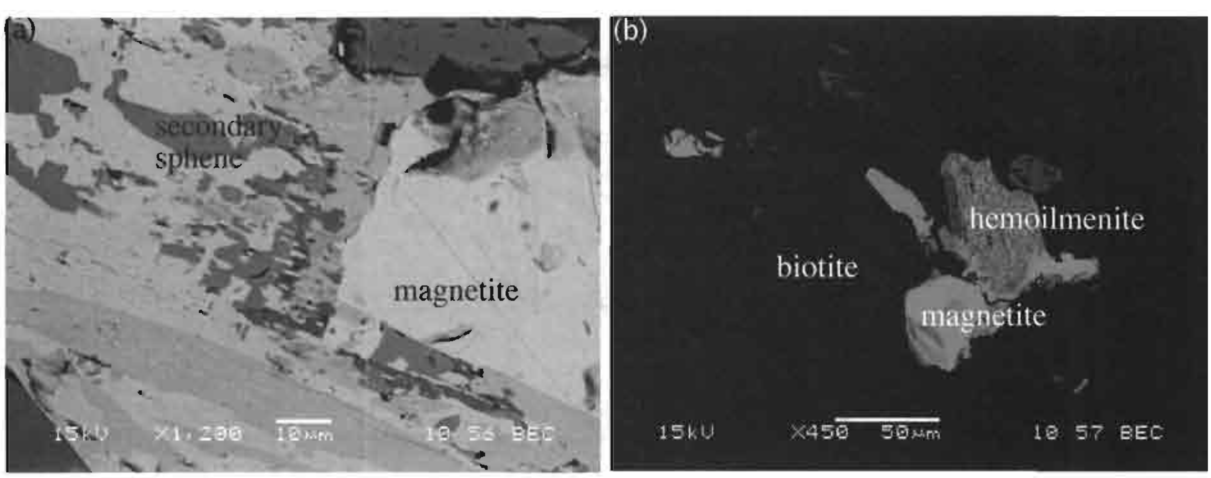

Figure 2: Exsolution and metasomatism of ferromagnetic minerals in the Fiesta granodiorite. (a) Complex pattern of hemoilmenite-ilmenohematite and rutile-hematite exsolution, originating from prior composite exsolution. (b) Magnetite – biotite association. The minerals are magnetite, ilmenite with exsolution of hematite, hemoilmenite with exsolution of hematite and rutile (mottled texture).

Antenna granodiorite

The principal magnetic mineral is magnetite, with two grain size distributions. The largest, between 1 - 0.5 mm are related with ferromagnesian minerals and present evidence of martitization, presence of hematite parallel to (111) planes. Small grain magnetites are generally euhedral and occur within the rock ground mass and silicate inclusions. Distribution and abundance of these two types of magnetites are heterogeneous.

East Porphyry

In this unit the magnetic mineralogy is clearly related with potassic alteration. In sites with selective potassic – chlorite alteration, the predominant magnetic minerals are large grained anhedral magnetites (up to 3 mm). These occur with biotite, as primary minerals and, at times, as product of biotitization of igneous biotite (cleavages and edges), showing weak to moderate cataclasis. Hematite and occasional maghemite are observed on edges of magnetite, without a defined pattern, likely associated with biotite-chlorite. In the case of pervasive potassic alteration which occurs under higher fO_2 and fS (Wood, 1998), magnetite content is lower, associated with Fe-Cu sulfides. In areas of rich mineralization, the predominant magnetic mineral is hematite, scarce and generally relict of previous magnetite. Finally, in the sites affected by strong supergene alteration, the dominant magnetic mineral is hematite, but with marked differences respect to hypogene hematite (crystalline). Other magnetic minerals observed such as goethite-jarosite, have a minor contribution in the magnetic analyses. In several cases a mix of the three magnetic minerals are observed, evidence of superimposed events.

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