

MAGNETITE-APATITE ORES IN THE ATACAMA FAULT ZONE, EL SALVADOR REGION, NORTHERN CHILE.

Peter J. TRELOAR⁽¹⁾, and Howard COLLEY⁽²⁾

⁽¹⁾ School of Geological Sciences, Kingston University, Penrhyn Road, Kingston-upon-Thames, KT1 2EE, UK.

⁽²⁾ School of Construction and Earth Sciences, Oxford Brookes University, Gypsy Lane, Oxford, OX3 0BP, UK.

RESUME. Les gisements de magnetite-apatite de la faille d'Atacama sont situes dans des fentes au domino. Les apatites y presentent de fortes zonations en F, Cl et OH. Les variations des fugacities en F, Cl et OH refletent les changements de fugacite des halogenes au cours de l'evolution des magmas qui sont a l'origine des fluids hydrothermaux de la mineralisation.

KEY WORDS: Apatite, Halogens, Atacama Fault, Chile.

INTRODUCTION.

Iron ore deposits, with or without apatite, are characteristic of the westernmost part of the Chilean ore province (Sillitoe 1976; Brookstrom 1977). However, magnetite-apatite deposits are globally unusual and poorly understood. Once considered to represent ore deposits directly crystallised from a magma, a hydrothermal origin is now more generally accepted. However, questions about the origin of such deposits still remain, especially: how far removed are they from the magmatic/hydrothermal interface?; do they reflect a particularly high halogen concentration or oxygen fugacity within the parent magma from which the hydrothermal fluids are derived?; and why are they not widespread? Some small, well exposed, magnetite-apatite deposits within the Atacama Fault Zone of northern Chile present the opportunity to answer some of these questions.

GEOLOGICAL SETTING.

The Atacama Fault Zone is a trench parallel strike slip fault zone (Brown et al. in press) that runs N-S through northern Chile for over 1000km. Although displacement is dominantly left lateral, the fault zone has a complicated movement history. Within the El Salado sector, between 26 and 27°S, two distinct displacement trajectories are determined. An early phase of ductile dip slip movement with E-side down (Colley et al. 1989), was succeeded by a phase of sinistral strike slip movement which commenced within the ductile field but continued throughout a falling temperature regime into the brittle field (Brown et al. in press). Faulting, especially the more ductile faulting, was synchronous with granite emplacement (Grocott et al. 1993). The deformation history, kinematics and chronology of granite emplacement are all consistent with granite emplacement into a transtensional left lateral fault system,

ductility contrasts being driven by the thermal effects of granite emplacement.

The later, brittle, stages of this movement were accompanied by widespread iron mineralisation. Brittle faults are all coated with a magnetite ore, large areas of weakly fractured basic volcanics are iron stained on surface, and large, barely to viably economic, Fe deposits located within dilational fault jogs, are currently being evaluated and/or exploited. The strong structural control localising iron mineralisation into fault planes, together with extensive propylitic alteration suggest a fault controlled hydrothermal origin for the iron. In a small number of deposits magnetite, which is the dominant mineral within this part of the fault system, occurs in association with apatite and actinolite.

MAGNETITE-APATITE DEPOSITS.

The Fresia deposit is one of three magnetite-apatite deposits located within the Atacama fault system, north of El Salado. This deposit has a sinuous shape which is controlled by two sets of faults trending at 080° and 065°. Slickensides on both fault sets are shallow plunging, indicating localised dilation within the overall N-S trending Atacama fault system.

Carmen Mine lies 20km E of the Atacama fault system. This large open pit is located in Cretaceous volcanics of the La Cerro Florida formation. The deposit is marked by the intersection of two fault systems: an E-W trending set of steep faults with subhorizontal slickensides, and a N-trending array of conjugate dip-slip faults, a geometry also consistent with localised dilation.

TEXTURES.

All the deposits are characterised by massive Fe-ore, dominantly magnetite although locally haematized. Apatite crystals vary in length. At Carmen Mine, they are up to 50 cm long, and are spectacularly zoned with rose pink cores grading to white rims. Apatite commonly occurs as individual coarse crystals floating within a matrix of magnetite, although it also occurs as acicular needles located within apatite-rich veins within which the apatites grew perpendicular to walls of opening fractures. Such fractures are often located within homogenous magnetite zones, the apatite crystals nucleating on a magnetite substrate. At Carmen the country rock has been clearly brecciated. Each block of country rock has a selvedge of magnetite on which needles of apatite and actinolite have nucleated. While both apatite and actinolite grew perpendicular to block faces and vein walls at the vein margins, they are randomly oriented within vein cavities. Large ragged apatites contain incursions of both actinolite and magnetite, but are frequently fractured with the fractures infilled by magnetite ore.

Country rocks are intensely epidotised and chloritised. The textures are characteristic of country rock hydrothermal brecciation of country rock sequences, with fractures and brecciated voids having been infilled initially by magnetite ore with growth of apatite and actinolite postdating the earliest precipitation of Fe-ore. Apatite, actinolite and magnetite must all have formed a stable paragenetic assemblage within the hydrothermal environment over a period of time, although the late stage fracturing of apatite with fracture infilling by magnetite implies that towards the end of the mineralisation period apatite was no longer stable.

APATITE CHEMISTRY.

Apatite crystals are strongly zoned. Light rare earth elements are enriched in cores with respect to rims. More significantly, apatite chemistries show extensive solid solution between hydroxy-, flour- and chlor-apatite end members. Up to 6.82%Cl and 3.09%F have been recorded. The former represents 100% of the end-member chlor-apatite and the latter 82% of the end-member flour-apatite. No carbonate end member is recorded within

the apatites and concentration of the hydroxy-end member is calculated by difference. Apatites are commonly zoned. F-poor crystals have higher Cl, and hence lower OH, contents in cores than rims, whereas F-rich crystals have F-rich and Cl- and OH-poor cores with F-poor and Cl- and OH-rich rims. The data sets and methodology of Korzhinskiy (1981) and Yardley (1985) can be used to calculate fugacity ratios between the halogens (F and Cl) within a hydrous fluid. If apatite chemistry is a reflection of halogen and water fugacities within the hydrothermal fluid, there is a clear trend from fluids with high f_F/f_{Cl} and f_F/f_{OH} ratios, through fluids with low f_F/f_{Cl} and high f_F/f_{OH} ratios to fluids with low f_{Cl}/f_{OH} and f_F/f_{OH} ratios. Although these trends are apparently incompatible with those described by Candela (1986), the initially high ratios of halogen to hydroxyl fugacities must reflect fundamentally halogen enriched magmas parenting the hydrothermal fluids.

DISCUSSION.

Two questions need to be answered. Firstly, what controls the widespread magnetite rich mineralisation? Secondly, what causes the occurrence and localisation of small numbers of magnetite-apatite deposits within an area dominated by Fe-rich and Fe-Cu bearing hydrothermal deposits?

Granite margins, originally ductilely deformed during transtensional emplacement, are frequently brittlely deformed within Fe-mineralised fault zones. Thus, mineralisation is a post-magmatic feature that affects a region in which the localised thermal softening due to granite emplacement has been largely dissipated. The hydrothermal fluids were likely to represent a mixing of magmatic and meteoric fluids within a regionally developed hydrothermal convective system. The concentration of iron suggests that the fluids were both acidic and highly reduced, compositional features probably influenced more by the magmatic than the meteoric contribution. Mineralisation, however, must represent interaction between oxidised near surface fluids and deeper level reduced fluids, at a particular, although as yet unspecified, crustal level. The dominant influence of the magmatic contribution may imply that the fluid chemistry reflects processes along the subduction interface, a supposition supported by the trench parallel position of Fe-rich deposits within the well defined pattern of metallogenic zonation within the Andean region (Sillitoe 1976).

Although these observations go some way to resolving the first question, they do not significantly relate to the problem as to why apatite bearing deposits are present at all, let alone as a small number of discrete bodies. The rapid changes in relative values of the halogen and hydroxyl fugacities are significant. Either these have to reflect extremely localised variations in halogen content in rocks being scavenged for iron by the circulating acid and reduced hydrothermal fluids, or they represent

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