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New observations by X-ray fluorescence microscopy provide insights for the origin of Aguablanca sulfide-matrix breccias in SW Spain

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INTRODUCTION

Sulfide-matrix breccia ores are common features of deposits hosted within mafic conduit-style intrusions. They account for a large proportion of Ni-Cu sulfide-rich ores in a number of deposits including the sub-layer and offset dyke deposits at Sudbury (Lightfoot, 2016), deep portions of the feeder dyke system and margins of the Ovoid and Eastern Deeps orebodies at Voisey's Bay, (Barnes et al., 2017), Nebo-Babel (Seat et al., 2007) and particularly in the subject of this contribution, the Aguablanca deposit in SW Spain (Piña, 2019). Genetic interpretations of sulfide matrix breccias have fallen into four main categories (Barnes et al. 2019): tectonic "durchbewegung" origins, upward emplacement of sulfide-rich slurries due to late stage compression in intrusive complexes, downward emplacement as sulfide-rich gravity flows during backflow in sill-dyke complexes or into footwall offset dykes, and gravity-driven downward percolation of sulfide liquid through the matrix of original silicate-matrix intrusion breccias.

This study presents microbeam XRF mapping to reveal petrographic features, textures and chemical zoning patterns in Aguablanca sulfide-matrix breccia ores at a scale of mm-cm.

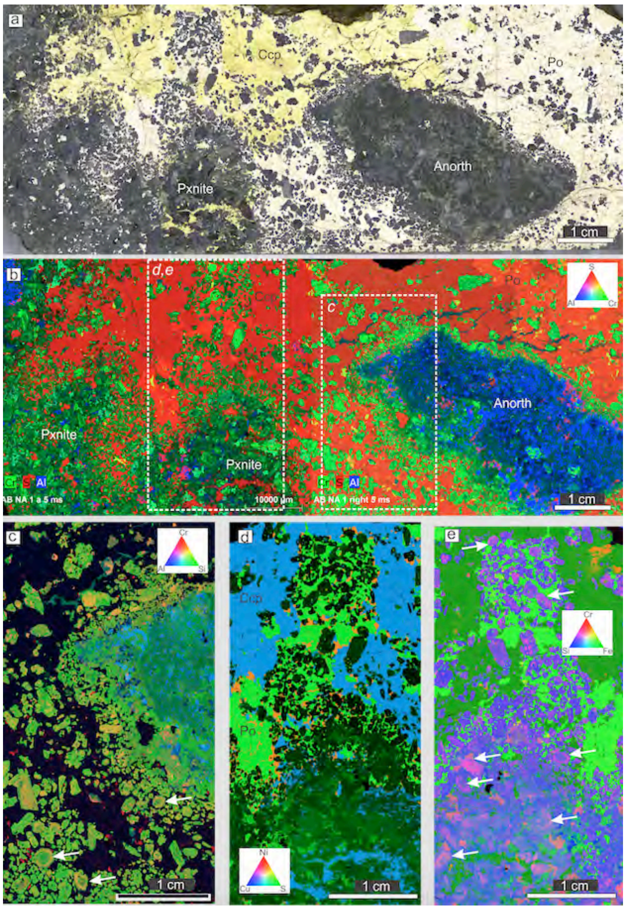
THE AGUABLANCA SULFIDE-MATRIX BRECCIA

The economic Aguablanca Ni-Cu mineralization occurs as a subvertical elongate funnel sulfide-matrix breccia (about 250–300m wide N-S, about 600m long E-W, a dip of 70-80ºN) located in the northern part of the Aguablanca stock. Within the breccia, the sulfide mineralization is concentrated in northward dipping and E-W-trending subvertical orebodies characterized by a variably mineralized matrix hosting unmineralized mafic-ultramafic igneous and host country rock inclusions. Two main types of ore mineralization are distinguished: semi-massive (up to 85 vol. % sulfides) and disseminated ores (< 20 vol. % sulfides). In the semi-massive ore, sulfides poikilitically enclose euhedral to subhedral crystals of olivine, pyroxene and/or plagioclase. Typically, the semi-massive ore occurs in the core of the breccia surrounded by the disseminated ore, which grades outwards without changes in the silicate mineralogy to sulfide-free gabbronorite.

MICROBEAM XRF OBSERVATIONS

Microbeam XRF mapping has revealed a number of distinctive features of the Aguablanca breccia: a) the matrix of the breccias is a bimodal mixture of pyroxenite or pyroxene gabbro and sulfide, with variable degrees of disaggregation of pyroxenite or anorthosite clasts (Fig. 1) along original grain boundaries accompanying infiltration by sulfide liquid. In these cases, margins of pyroxenitic inclusions show a progression into "clouds" of individual crystals that become progressively dispersed into the sulfide matrix. These common textures are referred as "soft-wall" breccias. b) Silicate fragments and disaggregated pyroxene grains are preferentially enclosed in former MSS (now pyrrhotite-pentlandite) relative to chalcopyrite (Fig. 1d). c) The pyroxenitic gabbro contains euhedral clinopyroxene grains that show reverse zoning in Cr (Cr poor cores, Cr-rich rims) (Fig. 1c). Some gabbroic clasts also contain such grains, implying that the zoning pre-dates formation of the breccias. Identically zoned pyroxene grains of similar habit and size are observed entirely enclosed in sulfide around the edges of the inclusions. Significantly, the most Cr-rich zones of these pyroxenes are not located at the outer contacts with sulfide, further arguing that this zonation is not the consequence of reaction with sulfide.

Fig 1*. Sample AB-NA1. a) Polished slab, Anorth=anorthositic gabbronorite, Pxnite=pyroxenite. b-e) Tornado false-color 3 element maps*



from microbeam XRF mapping. Assignment of elements to channels (red, green, blue) indicated on color triangles on each image. b) whole slab, S-Cr-Al, sulfides show up red. c) Cr-Si-Al – plagioclase in turquoise-blue shades, pyroxene orange (Cr-rich) to green; reverse Cr-zoned pyroxenes highlighted (arrows); note pyroxenite rind around anorthositic gabbro clast, lower right. d-e) same field of view, Ni-S-Cu and Cr-Fe-Si respectively; note cluster of disaggregated pyroxene grains enclosed in pyrrhotite (Po, top center) compared with adjacent inclusion-poor chalcopyrite (Ccp). Cr-zoned pyroxenes arrowed. (Barnes et al. 2018)

This indicates that the "crystal clouds" surrounding the inclusions are derived by disaggregation of original pyroxene orthocumulate with preferential removal of an original interstitial silicate component. d) The country rock clasts show varying but generally very minor degrees of marginal chemical interaction where in contact with gabbroic matrix, evident as narrow (mm-scale) zones of enrichment of Fe (calc silicates), Cr (some calc silicates), and K (metapelites). These zones are restricted to the outer few mm at most. e) None of the country rock clasts contain sulfides, which are restricted to interstitial or patchy net-textured domains within the pyroxenitic melagabbro matrix.

ORIGIN OF SULFIDE-MATRIX BRECCIA

From the foregoing observations, we suggest that the sulfide matrix breccias at Aguablanca, like those at Voisey's Bay (Barnes et al. 2017), are the result of sulfide liquid infiltration into pre-existing, probably still partially molten, silicate-matrix intrusion breccias. This descending sulfide infiltration probably caused the upward displacement of relatively buoyant silicate melt component and partial melting of silicate clasts and pyroxene matrix promoting their disaggregation along original crystal boundaries. The sulfide-matrix breccia may have formed as a result of downward gravity flows into the neck of the funnel-shaped Aguablanca intrusion during a period of back-flow, at the waning stage of the final magmatic episode in a long-lived conduit system, following the earlier accumulation of gabbroic cumulates with disseminated sulfides inwards from the margins of the intrusion (Barnes et al. 2018). These gravity flows may have incorporated sulfide liquid along with silicate magma and a "sludge" of variably digested xenoliths, or the sulfide liquid may have been added later as a result of downward flow of gravitationally unstable pools of sulfide liquid originally deposited higher in the system. This mechanism suggests that the Aguablanca ore breccias formed by essentially passive in-situ processes, and there is no necessity to invoke high-energy processes analogous to hydrothermal explosion breccias, or tectonic processes such as seismic pumping. From a point of view of exploration, assuming the model of gravity-driven percolation of sulfide liquid into a pre-existing silicate-matrix breccia, the Cu-rich sulfide liquid could have drained out from the semi-massive sulfides toward at some point below the current breccia, waiting to be discovered at depth.

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