Structural and Stratigraphic Controls on Ore Shoot Orientation, Raúl-Condestable Iron-Oxide-Cu-Au (IOCG) Deposit, Perú

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Introduction

The Raúl-Condestable mineral deposit is located in the coastal cordillera of Peru about 90km south of Lima. It is a variety of iron-oxide-Cu-Au (IOCG)-style deposit, and consists of Cu(Au) mineralization hosted predominantly in Lower Cretaceous sedimentary and volcanic rocks (homoclinal dip ~40° SW), and locally in quartz diorite dikes and stocks. Host rocks, intrusions, and mineralization all formed between ~114-116 Ma (de Haller et al., 2006; de Haller and Fontboté, 2009). Mineralization occurred at a paleodepth of ~2 km and was related to a coeval tonalitic intrusion located between the two deposits (Raúl and Condestable). Alteration consists of a core of potassic (biotite) alteration near the tonalite intrusion, deep calcic (actinolite-magnetite) alteration associated with Cu, and sericite-chlorite alteration in the upper part of the system. Some veins contain gray silica gangue banded with, or cut by, sulfides; carbonate veins are both syn-mineral and late-stage.

Chalcopyrite-dominant mineralization occurs as 1) mantos (≤15 m thick) of replacive mineralization (both massive and disseminated) formed in permeable or chemically-reactive sedimentary and volcanic rocks, and 2) veins (≤4 m thick) in faults and related extension fractures. Geochemical and mineralogical zonation indicate that the veins were feeders to the mantos. Veins are hosted in a conjugate system of two fault sets: 1) steep, NE-strike, dextral strike-slip faults, and 2) moderately-steep (60°-70°), NW-strike, sinistral-normal faults (Fig. 1). Almost all veins are fault-veins as they have slickenlines on the vein margins or on internal planes generally parallel to the margins. Mineralized breccias (combined tectonic-hydrothermal origin) locally occur within, or along the margin of, the sulfide-rich veins. Quartz-diorite dikes are parallel to, and/or host, many NE-strike fault-veins.

Structural Model

Consistent fault kinematics on NE-strike and NW-strike structures and analysis of cross-cutting relationships suggest a structural model in which protracted faulting and fracturing occurred under the influence of a consistent stress field orientation. Events began with early NE-strike fault formation, then dolerite dike intrusion along NE-strike faults, reactivation of the NE-strike faults as fault-veins and development of NW-strike fault-veins during mineralization, and continued late-stage fault reactivation synchronous with late-stage carbonate alteration (veinlets). Paleo-stress modeling shows a consistent shortening direction (maximum principal stress axis, σ_1) oriented ~15°/255°, extension direction (σ_3) oriented ~0°/348°, and the predicted dilational ore shoot orientation (σ_2) nearly vertical (Fig. 2). Map patterns indicative of extensional strain (*en echelon* and horsetail structures) occur where NW-strike fault-veins change strike to approach the predicted estension fracture strike (~255°).

Ore Shoot Models

Ore shoot orientation models, using simple stereonet constructions (Fig. 3), were developed for 3 possible ore shoots types in the district: 1) dilational openings with the long axis in the fault-vein and perpendicular to slickenlines (Nelson, 2006), 2) intersection lines between faults and mantos (type 1 intersections), and 3) intersection lines between two faults (type 2 intersections). All modeled type 1 intersection ore shoots plunge to the west (NW, W, or SW), and rakes are consistent in NE-strike veins (Fig. 3e; rake ~30° in veins, and ~56° in the manto), but are variable in NW- to SW-strike fault-veins (Fig. 3f). One modeled type 2 intersection ore shoot plunges moderately to the west. Modeled dilational ore shoots rake steeply in NE-strike fault-veins (Fig. 3b), and have variable rakes in NW-strike fault-veins, with low-angle rakes in dip-slip dominant systems and high-angle rakes in strike-slip dominant systems (Fig. 3c).

For one economically-important NW-strike vein system (Karina), models of ore shoot orientation were plotted on true longitudinal (long) sections of fault-veins and compared with geological data projected onto the sections (Fig. 4). Such geological data include contours of Cu-grade(%), vein thickness, strike, and dip, and intersection lines of dikes, mantos (bedding), or other faults or veins. Karina ore shoots defined by vein-thickness contours rake ~20° NW, and are best matched by bedding-vein or vein-vein intersection models and not by dilational ore shoot models (Fig. 4a, b). These intersection line models have a relatively large uncertainty. The modeled dilational ore shoot orientation rakes ~10° SE, not to the NW; however the modeled orientation of Karina dilational ore shoots also has a large degree of uncertainty, as it is based on an average orientation (rake) of only three slickenlines.

This type of analysis is very important to undertake for all deposits with structurally-controled fault-veins and stratigraphically-controlled (but structurally-related) mantos. The structural orientation data required for this type of analysis must be gathered and compiled, and be plotted to produce contours of strike and dip of the veins, which are needed to test for dilational ore shoot models. In addition, all long sections should have intersection lines of other faults, fault-veins, and dikes projected onto them, as well as the stratigraphic units that form econoimc and sub-economic mantos.

References

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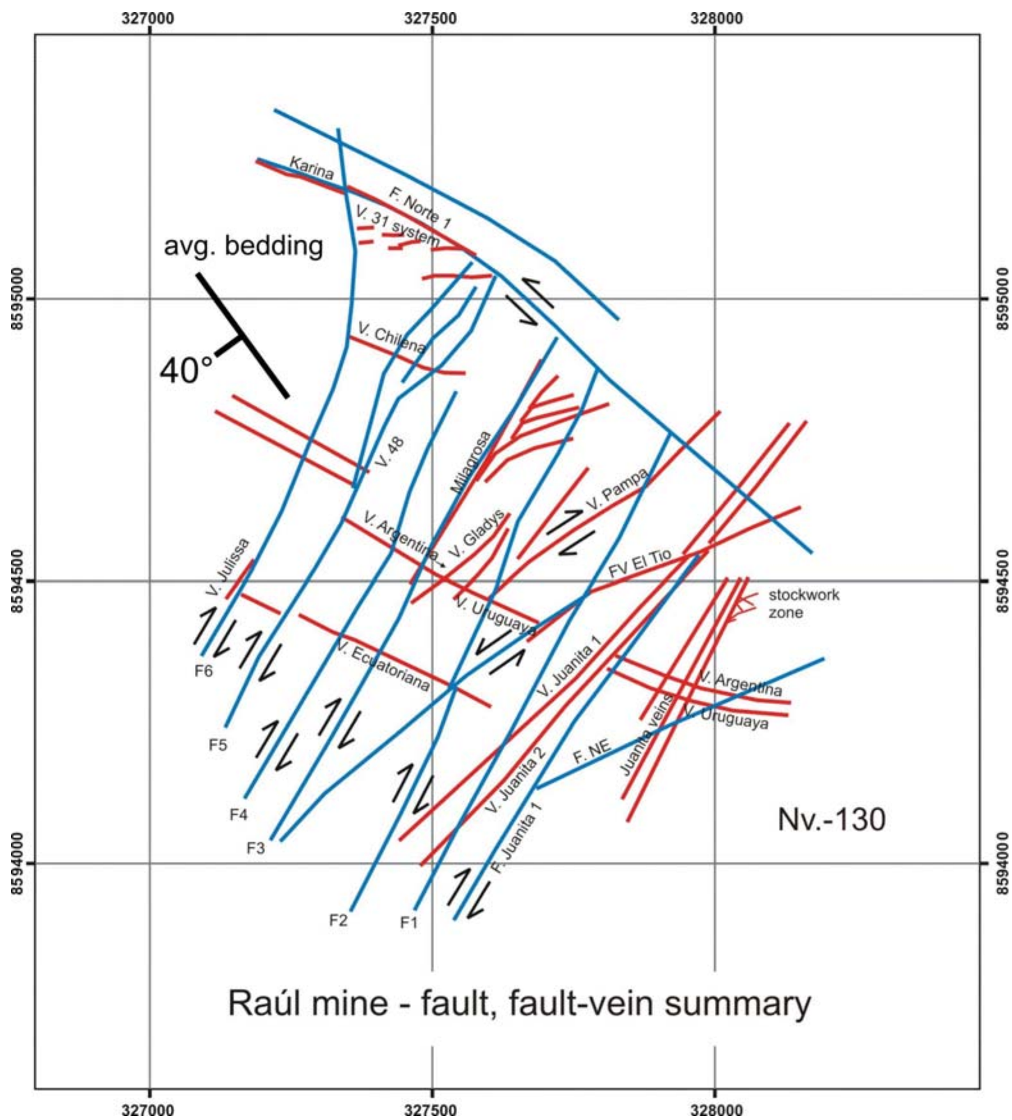

Fig. 1. Map of faults (blue) and fault-veins (red); 130m level in mine.

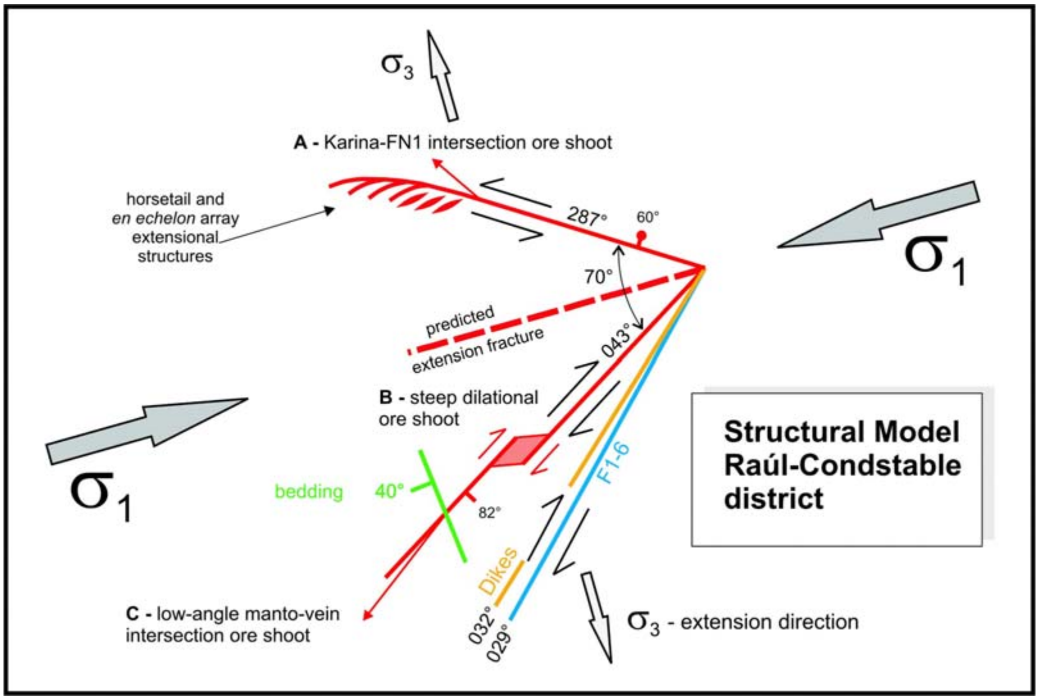

Fig. 2. Schematic map showing structural model of Raul-Condestable district and possible ore shoot orientations (A, B, C). F1-6 = average strike of steep faults F1, F2, …F6).

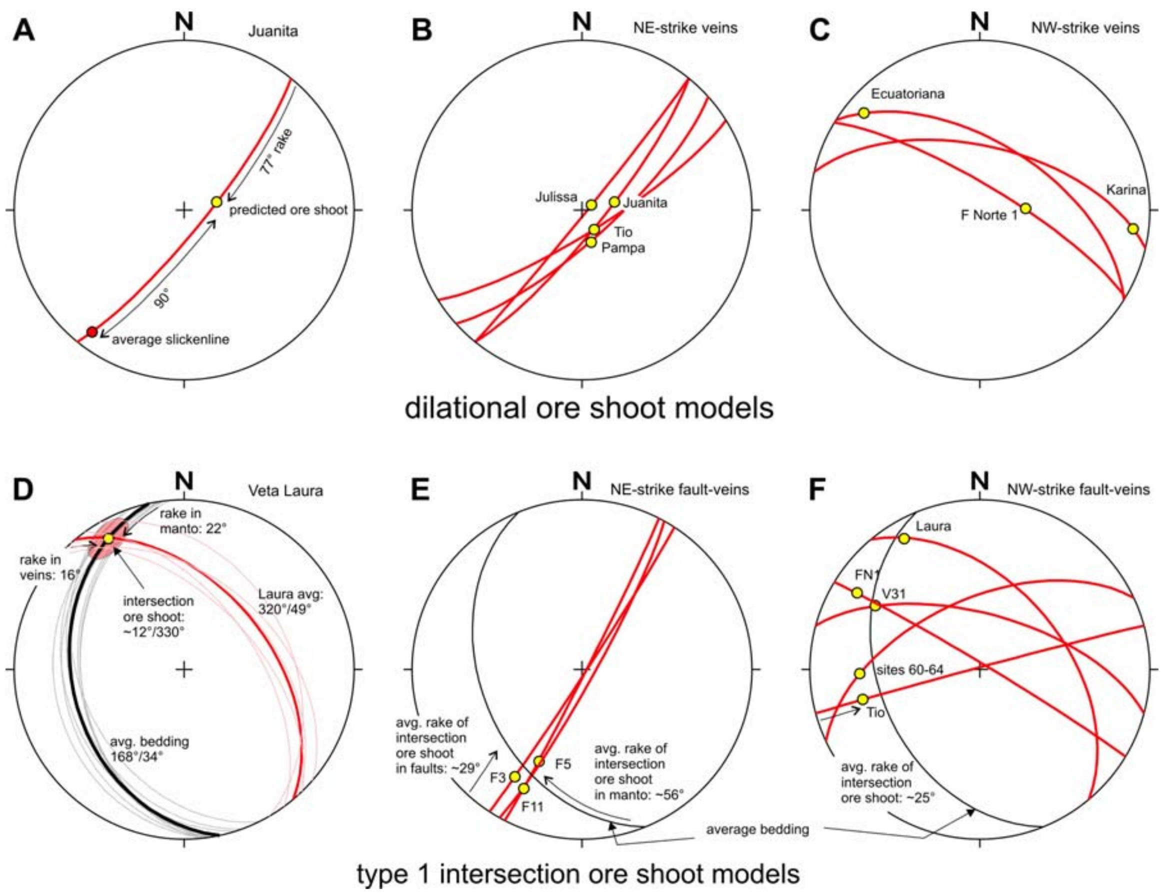

Fig. 3. Lower hemisphere equal area nets showing ore shoot orientation models (yellow dots). Red great circles = average orientation of fault-veins; black great circles = bedding (bold is average). A and D show examples of the modeling method of dilational and type 1 intersection ore shoots, respectively. Other nets show summary of models.

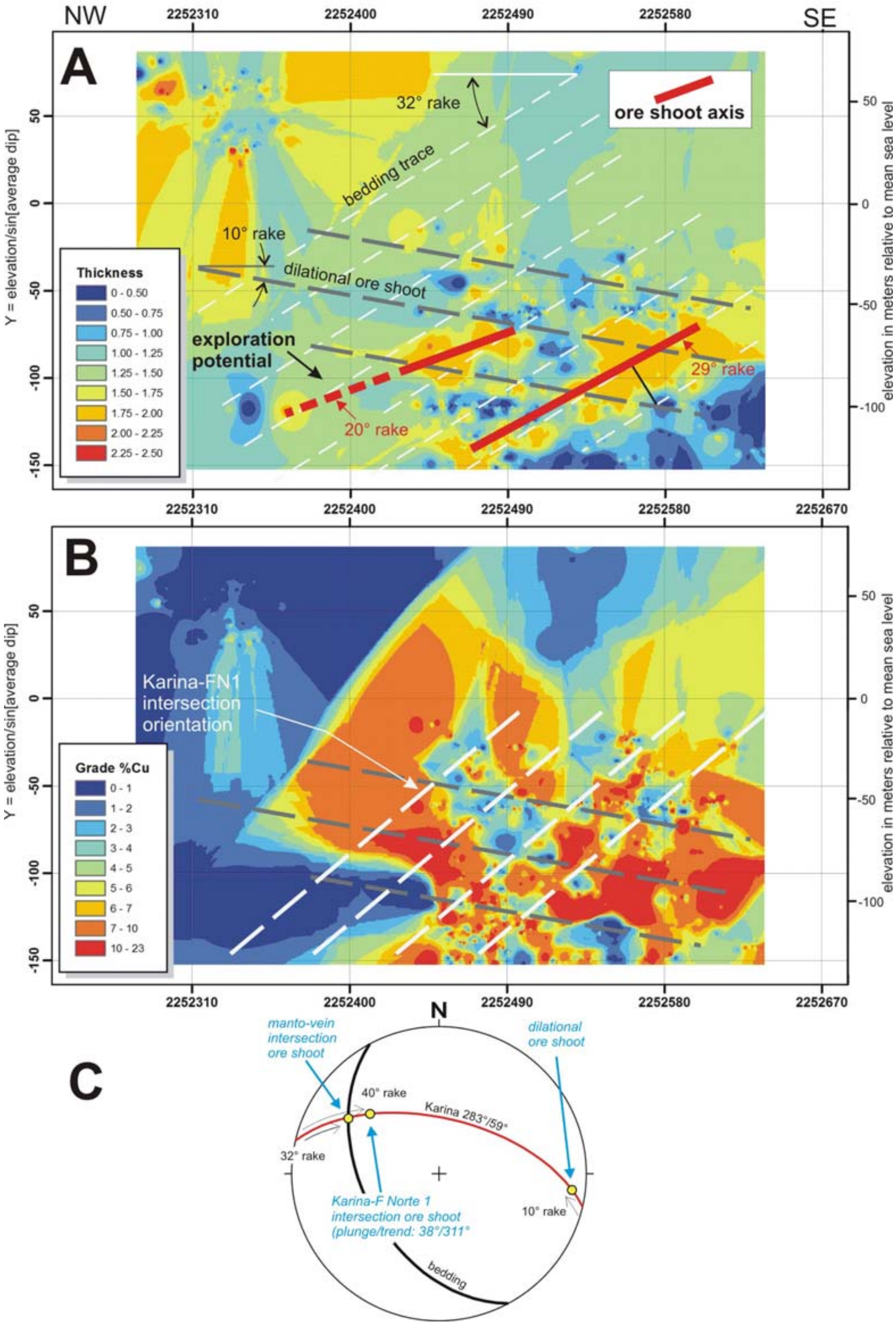

Fig. 4. Longitudinal sections of Karina fault-vein showing contours of thickness (A) and Cu% grade (B). Red lines on (A) show interpreted ore shoot orientation; other lines on (A) and (B) show ore shoot model orientations taken from (C) which is stereonet showing models (yellow dots).