Internal Structure and Petrography of the Mineralized Faults in the Radomiro Tomic Deposit

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Abstract. The interaction between faults and hydrothermal fluids is studied observing the internal characteristics of the faults in RT deposit. Distribution and petrography of fault-related rocks, grouped in units (studied with optical microscope and XRD) unravel their timing and genesis. Subsequently, nature of pore fluids and evolution of mechanical properties of faults are deduced. Both rock deformation and circulation of fluids in the deposit were conducted through the successive reutilization of the same structures (N30-60E/-90). Initially quartz veins and afterwards fault planes. During the nucleation of faults, phyllic fluids permeated the deposit, adding pyrite (+chalcopyrite) to the fractures and transforming feldspar to illite in the haloes. Subsequently, these faults were sheared by cataclasis, forming black gougges and pyrite breccias. Later on, gouge was cemented by quartz becoming cataclasite. Finally, hydrothermal illite and remaining feldspars were partially converted to kaolinite. Mechanically, the deformation started as semi-plastic hydro-fracturing, but as the temperature decreased, deformation evolved to a brittle regime of fracturing and shearing. Sericite alteration, by phyllic fluids, weakened the rocks and facilitated the slip on faults. Finally, silicification hardened the faults locking the slip. Later formation of kaolinite may have weakened the rocks, however no deformation is recorded after it.

Keywords: Radomiro, Tomic, Fault-Fluid, Interaction

Objective

Knowledge about fluid-rock interaction within faults of the Earth’s crust is key to understanding a wide range of geological processes, such as earthquake generation, crustal strength and distribution of economic minerals.


Here, we present mineralogical (XRD) and petrographic (micro- and macroscopic) analysis of fault-related rocks within a crustal-scale hydrothermal system. In one of the largest ore-bearing fault systems in the world (DFS). Aimed to unravel the temporal and genetic relationship between faulting and fluid-induced alteration, in order to understand their effects on the evolution of the crustal rheology.

Case of study

The case of study RT, is located within a fore-arc trench-parallel fault system, called Domeyko Fault System (DFS). The location of several porphyry deposits along it suggest high permeation of hydrothermal fluids through the crust, at 3-5 km depth (subsequently exhumed). The deposit is hosted by granitic porphyric rocks from the Chuquicamata Intrusive Complex, 35-34 Ma (U/Pb zircon dating) (Cuadra & Rojas 2001, Diaz et al. 2009). The hydrothermal alteration in the deposit is separated in three stages. (1) Early K-Silicate Alteration or Background Potassic Alteration (32.7 Ma). (2) Quartz/Sericite Alteration (31.8 Ma). (3) Ardillic Alteration (youngest). Both metallic mineralization and hydrothermal alteration products are spatially related to sub-vertical faults striking N30-60E. These faults conform the main structural system in the deposit, and are of second order with respect to the two major regional-scale faults: Messabi Fault and West Fissure (N00-10E/sub-vertical).

Methodology

After checking, the available in-mine routes and observe the accessible outcrops, two sites where selected for analysis. Both selected sites are mine walls perpendicular to the fault strike and bellow the oxidized zone. In order to characterize the internal structure of the faults, outcrop-scale maps were conducted and samples taken. The observed rocks were grouped according their macroscopic petrographic properties, defining "Fault-related Units". Samples of each unit where then analyzed under petrographic microscope and XRD.

Petrographic Description

The components of the studied faults are separated in 5 Fault-Related Units and the surrounding rocks are grouped into a Granitic Protolith Unit. Even though the protolith is not fault-related, it is analysed in the same terms as the fault-related units, in order to compare and understand background process. Distribution of these units is shown in Figure 2.
Granitic Protolith: Igneous porphyric and euhedral texture. Composed of quartz (25-40%), plagioclase (20-30%), orthoclase (25-35%), clays (5-20%) and biotite (5-10%). Overgrowth orthoclase exhibit inclusions of quartz and plagioclase.

Clay-Altered Granit: Igneous porphyric and euhedral texture. Composed of quartz (30-40%), k-feldspar (25-35%), clays (25-30%) and pyrite (~1%). Plagioclase is replaced by illite and kaolinite, forming pseudomorphs. Orthoclase is only partially replaced to clay.

White Proto-cataclasites: Igneous porphyric to aphanitic texture, fragmentally deformed. Composed of quartz (50-80%), clay (15-50%) and pyrite (~1%). Quartz phenocrystal is euhedral and unaltered, all the other minerals are replaced by patchy quartz, kaolinite and sericite.

Quartz Vein: Composed of euhedral and anhedral quartz (95%), pyrite (3%) and molibdenite (2%). Quartz is banded parallel to the walls interlayered with metallic sulphides. Irregular crystal boundaries and sub-grains (plastic deformation) are heterogeneously distributed. Metallic sulphides (molibdenite, pyrite, chalcopyrite) are filling the spaces between euhedral quartz crystals and some are striated.

Black Cataclasite/Gouge: Fragmental foliated texture. Composed of quartz (50%), clays (20-40%), pyrite (5-15%) and chalcopyrite (~1%). Illite is foliated and deformed by shear. Quartz is found as fragments of quartz-vein and as cement (between fragments and clays). Pyrite is distributed in bands of comminuted fragments. The foliation and sigmoidal asymmetries indicates right-lateral kinematics.

Pyrite Breccia: Coarse fragmental texture, roughly foliated. Composed of quartz (30-45%), clays (20-40%) and pyrite (10-30%). Fragments are 0.1-5mm size: Quartz vein, squared blocks of clay (undeformed plagioclase pseudomorph), pyrite (with jigsaw puzzle texture) and fragments of foliated gouge.

Fault evolution and interaction with fluids

According to the distribution and boundary relationships of the described rocks and minerals, the petrogenetic processes are inferred and arranged in a time sequence. This sequence represents the mechanical and mineralogical evolution of the faults in RT.

The first interpreted processes are (a) the replacement of amphibole by biotite and (b) the overgrowth of plagioclase and orthoclase, surrounding quartz crystal. Both mineralogical process are related to the Early Background Potassic Alteration (Cuadra & Rojas 2001). During this stage, temperatures around 450-550°C are expected (Sillitto 2010), allowing crystal plasticity of quartz and subsequent ductile creeping at relatively slow strain rates. This plastic deformation is the responsible for the subgrains in quartz and plagioclase and irregular wavy shapes of quartz veins. The repetitive brittle extension (banded quartz veins) is consequence of flashing pulses of ascending fluids. These pulses suddenly increase the fluid pressure and the strain-rate, favouring the brittle fracture over the plastic creep at the same temperature (Fournier 1999). Figure 1A.

The euhedral crystals of quartz reflect precipitation under enough fluid pressure to prevent the walls from yielding to lithostatic pressure and close (between the pulses). Those intercrystalline spaces are mainly aligned parallel to the walls, providing the highest permeability direction. Some of these spaces are partially filled with euhedral crystals of molibdenite, brought by posterior fluids pulses. Figure 1B.

Striation on molibdenite crystals, and the abundance of Quartz Vein fragments in the Black Cataclasites/Gouge are consequence of brittle faulting after the vein was fully formed. Most of the shear bands are located along the quartz veins. This is consistent with a mechanical anisotropy induced by a relatively strong vein crossing through a weaker rock (Propagating fractures across the veins require more energy than along them). This indicate that the structures started as opening fractures (Mode I) and subsequently were sheared to become faults. This requires a relative rotation of the faults with respect to the stress field. (Figure 1c).

At the time when the fractures started to form along veins and walls, hydrothermal fluids were channelled along them, considerably increasing the mineral alteration and precipitation. Pyrite is spatially related to the shear bands and fractures, suggesting that sulphide rich hydrothermal fluids penetrated the faults during brittle shearing. A minor amount of pyrite is also disseminated within intercrystalline spaces of the porphyric host-rock, suggesting that previous pyrite mineralization could have also occurred before the main one. However, as the major amount of sulphides is related to fractures and zones of cataclasism, brittle shearing is considered the main process driving the precipitation of hydrothermal sulphides. Illite (and smectite) from Quartz-Sericitic alteration is also spatially related to the faulted veins. In the haloes: (altering feldspars) and within the cataclastic bands (white fringes, ductily deformed porphyroclasts, and in the matrix of the black bands). This suggest that, on a deposit scale, illite was formed associated to brittle deformation but subsequently, on a fault-core scale, it was deformed under ductile regime (cataclastic flow).

Considering the close spatial relationship between illite and pyrite, both can be considered relatively syngenetic: Formed after the precipitation of the quartz vein, during brittle shearing. This timing, involves a genetic
relationship between precipitation of large amounts of pyrite and the quartz-sericite alteration. This relationship is consistent with previous research on hydrothermal deposits, grouped in the term Phyllic Alteration (Beaumont and Meunier 1983; Meyer & Hemley 1967). Figure 1d represents the start of brittle deformation and the subsequent formation of a quartz-sericite halo and precipitation of pyrite in fractures. The advanced deformation state of illite and pyrite crystals within cataclasites indicates that shear along structures was important after their formation. It is not clear when started the shear, but is clear a that phyllic fluids indirectly enhanced the sliding of the structures.

Along with the development of shear strain: More gouge was formed and accumulated in the faults; comminution reduced fragment size of pyrite and quartz; ductile deformation of illite rich fragments formed lenses and parallel bands; volume of cataclastic rocks and dextral displacement was accommodated by the faults. Figure 1e. In the last stage of this period, in zones lower strain zones, the pyrite was less deformed. Resulting in larger grain size rocks, named Pyrite Breccias, represented in Figure 1f.

After the formation of Black Gouge and Pyrite Breccias no more shear was accommodated by the faults, however they suffered two other important mineralogical modifications: Silicification of fault gouge (transforming gouge to cataclasite) and replacement of feldspars and illite by kaolinite. Observation of small quartz crystals (under optical- cathodoluminescence microscope) surrounding and cementing larger quartz fragments indicates that gouges where cemented by crystalline quartz. In turn, undeformed kaolinite (in Hazo and White Protocataclasite) indicates that an important clay forming event, after the shear deformation, was the final petrogenetic process affecting the faults.

References


![Figure 1: Schematic section of the inferred evolution of the faults of Radomiro Tomic (from centimetres to meters scale)](image-url)
Figure 2: Outcrop-scale maps of the internal structure of fault exposed in a South-facing bench wall at the bottom of Radomiro Tomic Mine (ca. 370 m depth in October 2009). Pie plots show semi-quantitative XRD analysis. Qz: Quartz, Plg: Plagioclase, Ort: Orthoclase, Kao: Kaolinite, Ill: Illite, Sme: Smectite, Py: Pyrite, Cpy: Chalcopyrite, Ch: Chalcanthite, Gy: Gypsum, Al: Alunite, Nal: Natroalunite, Bio: Biotite. A: General view of the bench. Showing the presence of a larger fault at west and two smaller ones towards the east, all the faults have White-Green Haloes and the presence of an adjacent quartz vein. B: Detail of the internal structure of the westernmost fault. Note the presence of Pyrite Breccia and Black Gouge containing with fragments of highly altered protocataclasite. C: Middle fault is made of a thin fringe of black gouge adjacent to an obliquely fractured quartz vein. D: Easternmost fault, cutting trough an irregular arrangement (plastic) quartz veins. In orange is a volume of fine massive pyrite.