# SEM-CL Analysis of Hydrothermal Quartz: Case Histories in Fe-Cu(Au) Deposits

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*INTRODUCTION.*

SEM-CL (Scanning Electron Microscope - Cathodoluminescence) is a useful technique for the observation of microtextures in minerals that are not visible through conventional petrographic microscopy (transmitted light, TL) or BSE (Backscattered electron) images. The CL has been used to study a variety of geologic environments as sedimentary petrology, diagenetic processes, geochronology (zircon U-Pb), etc. Recent studies of hydrothermal quartz show that the combination of SEM-CL images with other techniques, such as fluid inclusion analysis, is a very useful technique for characterizing ore forming on events in ore deposits (Rusk & Reed, 2002). In fact, in most cases, individual quartz crystals contain fluid inclusions trapped at different moments and from chemically different fluids. The changes in CL response result from the intrinsic lattice defects such as translations, point defects, mineral inclusions, as well as extrinsic defects such as incorporations of trace elements (Götze et al., 2001).

In this study we show some case histories of 8 hydrothermal quartz (veins and phenocrysts) from 3 Fe-Cu-(Au) deposits in the SW of Spain (Cala, Sultana and La Berrona) and 2 Fe-Cu-(Au) deposits in the N of Chile (Silvita and Taltal). The images reveal textures of growth zoning, quartz-filled microfractures, truncation of concentric growth, splatter or cobweb textures, etc. These features represent independent processes in the complex history of quartz growth such as fracturing, dilation, growth into open space, dissolution and recrystallization, etc. In some cases, these quartz domains can be correlated with the hosted fluid inclusion assemblages (FIA´s, Goldstein & Reynolds, 1994).

*GEOLOGICAL SETTING AND SAMPLING.*

In order to explain a wide variety of environments, we have selected samples from: 1) Au and chalcopyrite-bearing quartz veins and 2) quartz from vugs within the Santa Olalla tonalite, 3) skarn-related quartz and 4) shear zone-related quartz from the Cala mine, 5) breccia quartz, and 6) vein quartz of the La Berrona deposit, and 7) and 8) late quartz associated to chalcopyrite in the Silvita and Taltal deposits.

*METHODS.*

SEM-CL analyses were performed at the CIC (Centro de Instrumentación Científica, University of Granada) (Spain). Doubly polished sections were coated with a film of carbon that was removed for the further fluid inclusion study. The images were taken in a SEM Leo 1430 VP equipment with the following analytical conditions: 15 kV, 2nA e-probe and a beam current of 80mA. The work distance was 16 mm.
The gray scales of SEM-CL images have been grouped in a color scale level: CL-bright (light to gray), CL-gray (gray), CL-dull (gray to dark) and CL-dark (dark gray to black).

*QUARTZ TEXTURES.*

Observed textures are grouped into 6 main categories: euhedral growth zoning of various intensities and parallel or perpendicular to c-axis, dark-luminescent patches, cobweb and splatter textures, corroded grains, truncated grains, late vein fillings and micro-cracks crosscutting earlier quartz. The first two are related to the precipitation of quartz into open spaces and the last 4 ones are interpreted as due to dissolution, recrystallization and fracturing processes after the precipitation of the quartz crystal.

*Sultana Mine: Euhedral Growing and Deformed Cores.*

Contrasting CL shows that vein infilling has two distinct phases of quartz crystallization: an early generation of quartz (Q1) is characterized by bright luminescent deformed core-quartz. Superimposing this Q1, takes place the precipitation of clear and well-defined bands of bright and gray luminescence quartz (Q2) of about 20 µm in width. The concentric growth points towards the center of the vein and are oriented parallel to c-axis of the crystals. Sulfides are associated to late stages of Q1 and early stages of Q2. Mosaics of adjacent images were used as a basis to map fluid inclusion assemblages and to establish a fine correlation between each FIA and different quartz domains.

The granite-hosted myaroles are filled with bright to dull luminescent quartz showing a very clear growth zone in the open space. The images do not show the earliest core and in this case the euhedral zonation is perpendicular to the c axis of quartz. The combination of the study of fluid inclusion assemblages with the images of these phenocrysts suggest a connection between the hydrothermal fluids circulating towards the vein and those exsolved from the host tonalite.

*Cala Mine: Dissolution and Deformation Processes in Sheared- and Skarn-Related Quartz.*

SEM-CL images of quartz associated with shear zone-related mineralization reveal complex textures with multiple superimposed stages of precipitation and recrystallization. Images show grain truncations and splatter or cobweb textures that are a clear evidence of intense fracturing. The correlation with FIA's is not straightforward due to the high deformation. However, CL images reveal some gray luminescent "shadow zones" with poorly defined growth zoning that contain suitable FIA's for further study.

The images of quartz within cavities in the prograde garnet-rich show a first generation of gray luminescent grains (Q1) with euhedral growths and local dissolution zones (corroded grains). There is a second generation of dark luminescent quartz developed along

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microfractures that crosscut Q1. Boiling fluid inclusion assemblages are found in Q1 while the Q2 domains hosts healed fractures with secondary fluid inclusions.

### *La Berrona: Early Zoned Quartz and further Deformation Processes.*

In the La Berrona deposit there is an intensive hydrothermal brecciation where fragments of the magmatic albitite are supported by actinolite and magnetite with later quartz infilling. The SEM-CL images show an early gray to dull luminescent zoned (20 to 200 µm width) quartz. This early generation is clearly affected by later fracturation shown by the existence of a dense network of micro-cracks and fractures healed by dark luminescent quartz. Early veins hosted by albitite and interpreted as formed in a still partly ductile rock show an important truncation of gray luminescent grains, a feature probably due to the absence of enough space for euhedral growing. The growth of these grains clearly correlates with the hosting FIA's, indicating that they are synchronous and predate the nearby magnetite mineralization.

### *Silvita Mine: Late Quartz Growing in Several Stages.*

SEM-CL images from Silvita are probably the best examples of the superposition of hydrothermal processes represented by a wide range of textures. In the sample shown in the figure 1 there is an early concentric growth zone of a first generation of gray- bright luminescent quartz (A) perpendicular to the c-axis (pointing out of page). Afterwards, there was a process of dissolution, with precipitation of new bright luminiscent quartz. Grain growing continued, and after several zones formed in the absence of deformation, some microfaults displaced quartz banding about ca. 200 µm. These fractures generate space now filled with dark luminescent quartz. The quartz continued growing until the precipitation of chalcopyrite, nowadays replaced by atacamite and cuprite.

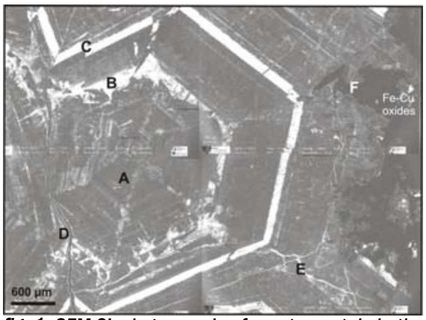


*fig. 1. SEM-CL photomosaic of quartz crystals in the Silvita mine (N Chile). See the text for explanation.*

### *Taltal Deposit: Hydrothermally-Altered Igneous Quartz Textures.*

Samples of the Taltal IOCG deposit have a particular SEM-CL texture related with the hydrothermal alteration of igneous quartz. Bright to gray luminescent quartz show corroded grain boundaries and was followed by the precipitation of dark quartz in the created cavities, suggesting an intermediate stage of quartz dissolution. In fact, the ore assemblage precipitated synchronously with this second generation of quartz. In some grains, there are embayed cores of bright luminescence quartz with euhedral gray overgrowths, being cores and rims optically continuous. This texture could be caused by the precipitation of core quartz, followed by the dissolution and precipitation of euhedral quartz from a cooler fluid.

## *DISCUSSION.*

Comparative study of quartz textures by SEM-CL reveals complex histories of growing and fracturing that are not visible in transmitted light microscopy and can give clues critical for understanding hydrothermal processes and ore formation. Euhedral growth zones of various intensities are due to growth of quartz into open space as well as concentric banding within individual grains. Embayed cores with euhedral overgrowths and mosaics of grains are due to the dissolution along fractures and grain boundaries. Cobweb and splatters, networks and microfaulting textures form in response to mechanical fracturation. The origin of CL in euhedral zones is not well known but may result from cyclic incorporation of trace elements during precipitation (Penniston, 2001; Landtwing, 2005). Potential causes for dissolution textures of quartz in hydrothermal systems are fluctuations in pressure, temperature and fluid composition (Rusk and Reed, 2002), as shows the fluid inclusion study. Some textures can be related with the ore precipitation stage as in Sultana or Cala mine. The study of fluid inclusion assemblages in the different quartz domains definitely help to understand the evolution of fluids within the hydrothermal system.

## *CONCLUSIONS.*

The SEM-CL technique has been successfully used in the study of different geological environments. As we show in this study, this technique is critical for the thoughtful petrographic study that must precede any fluid inclusion study in order to obtain consistent and realistic results. In this case, SEM-CL images show numerous textures of quartz related to the history of fluid evolution, textures that have been unnoticed in these Fe-Cu (Au) deposits.

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