Cathodoluminescence Investigations On Vein Quartz From The Far Southeast Porphyry Cu-Au Deposit, Philippines: Hydrothermal Quartz Alteration And Inheritance of Earlier Fluid Inclusion Assemblages

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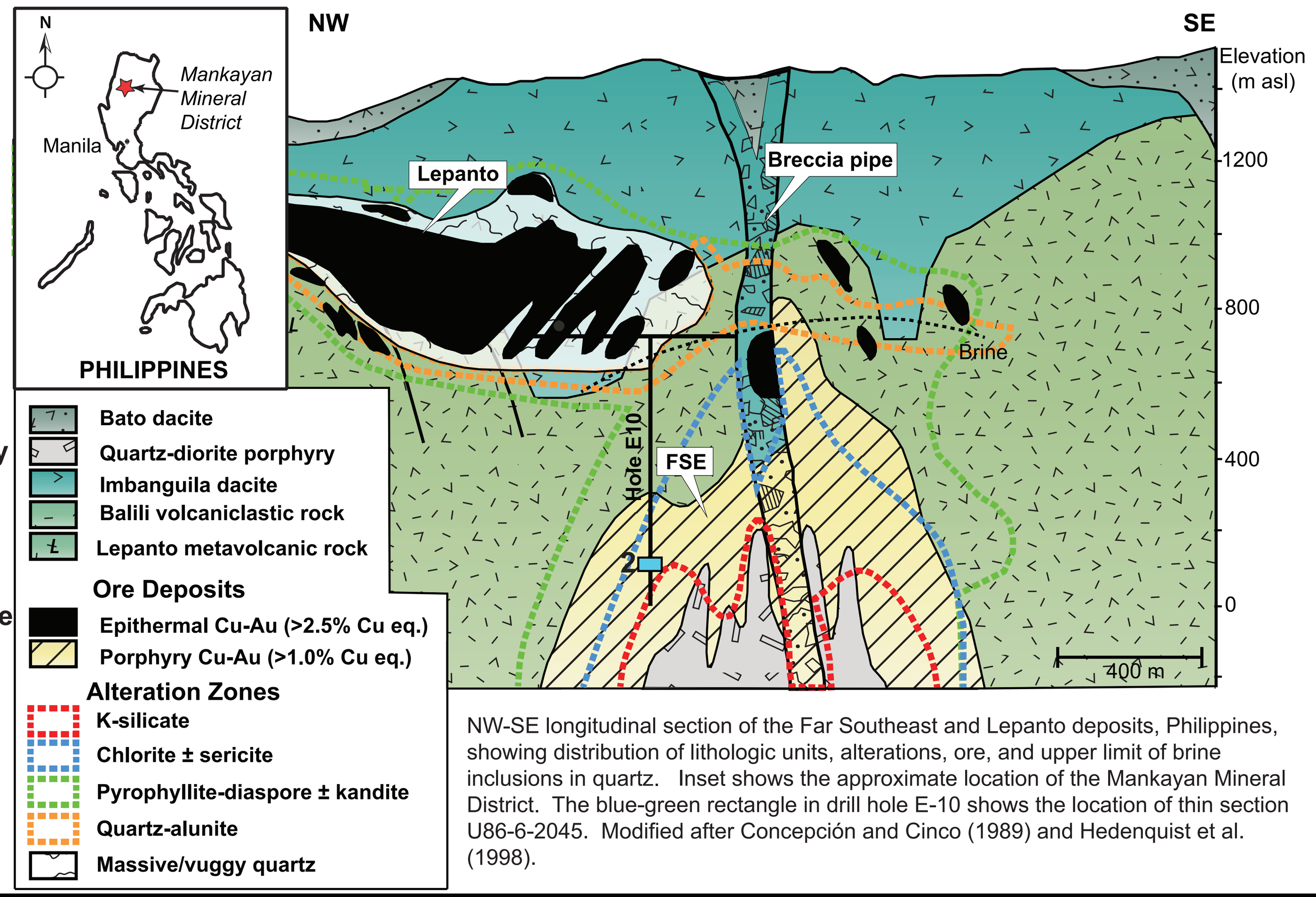
1. Introduction

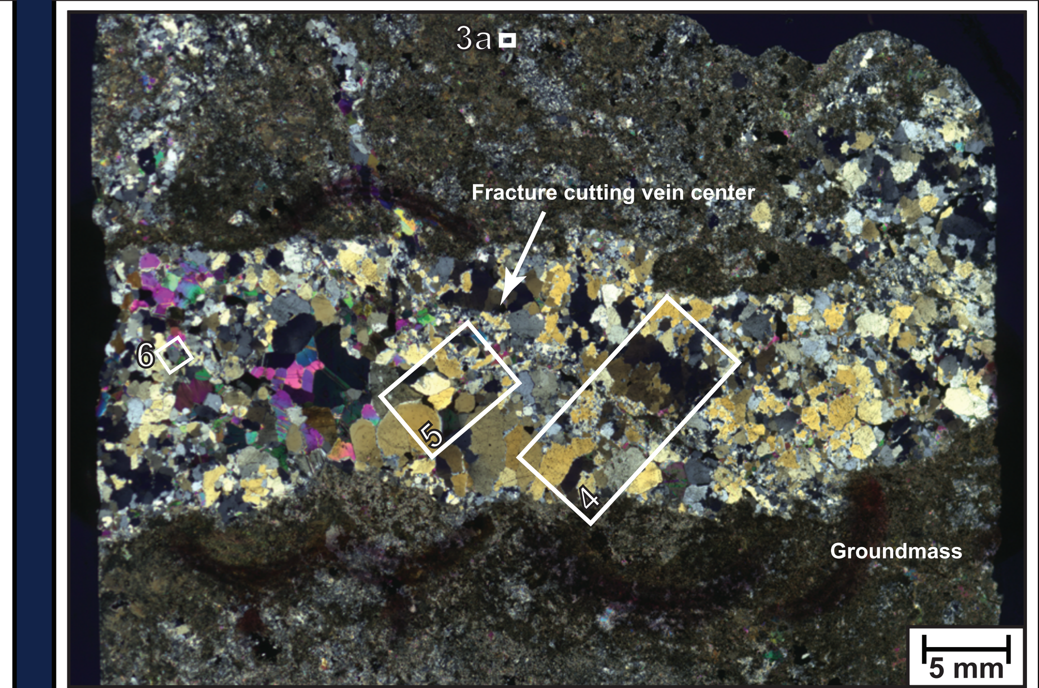
It is well established that the cathodoluminescence (CL) and fluid inclusion properties of quartz can be used to constrain the genetic conditions of quartz growth in a wide range of geological environments. The luminescence color of quartz is a direct reflection of the real structure of the crystal, and is affected by lattice defects and impurities within the crystal traditionally interpreted to have accumulated during quartz growth. It is shown through combined CL and fluid inclusion petrography that the CL properties of quartz can be modified by processes of hydrothermal alteration and that CL color alone cannot be used to reliably distinguish different quartz generations in porphyry deposits.

The present investigation is a followup to a previous study conducted by Hedenquist et al. (1998) on the Far Southeast (FSE) deposit, Philippines, which identified two quartz types in porphyry stockwork veins through careful fluid inclusion petrography. Early anhedral quartz (Q1) was observed to contain contemporaneously trapped brine and vapor-rich inclusions, and formed from the hydrothermal fluid that caused K-silicate and quartz-alunite alteration in the FSE and Lepanto deposits, respectively. Late euhedral quartz (Q2) was observed to contain NaCl-undersaturated liquid-rich inclusions and formed from a later hydrothermal fluid that caused chlorite-sericite alteration and deposited the bulk of the ore minerals present in the FSE and Lepanto deposits.



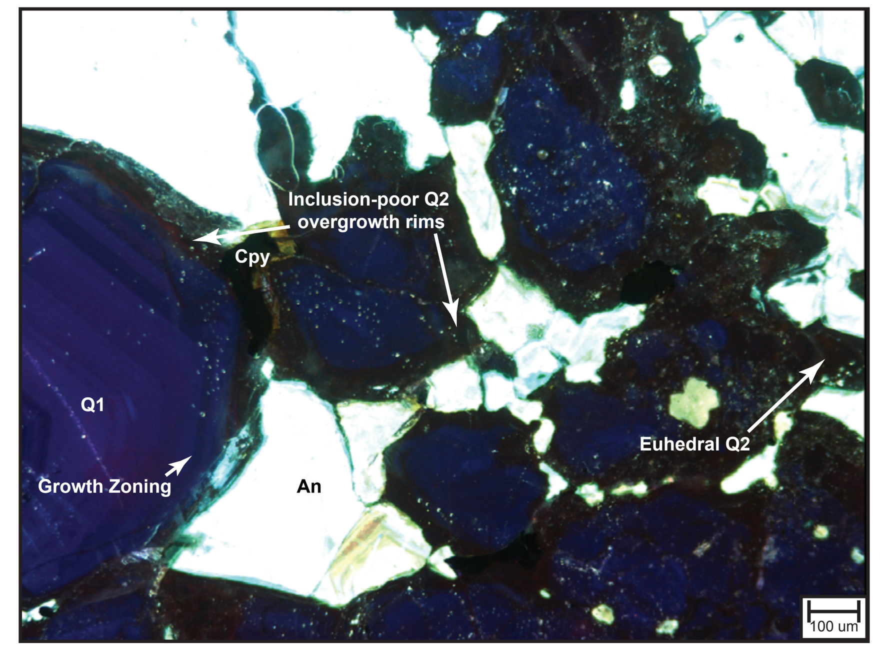
NW-SE longitudinal section of the Far Southeast and Lepanto deposits, Philippines, showing distribution of lithologic units, alterations, ore, and upper limit of brine inclusions in quartz. Inset shows the approximate location of the Mankayan Mineral District. The blue-green rectangle in drill hole E-10 shows the location of thin section U86-6-2045. Modified after Concepción and Cinco (1989) and Hedenquist et al. (1998).

2. Vein Map



Crossed-polars scan of thin section U86-6-2045 showing a 10 mm-wide vein containing quartz-chalcopyrite-sericite-anhydrite. White boxes mark the locations of photomicrographs shown in Panels 3, 4, 5 and 6. Both the vein and groundmass are cut by a small fracture that reopened the vein prior to Q2 quartz formation. Euhedral Q2 quartz, sericite, and sulfides are highly concentrated along this fracture and in vugs in the groundmass.

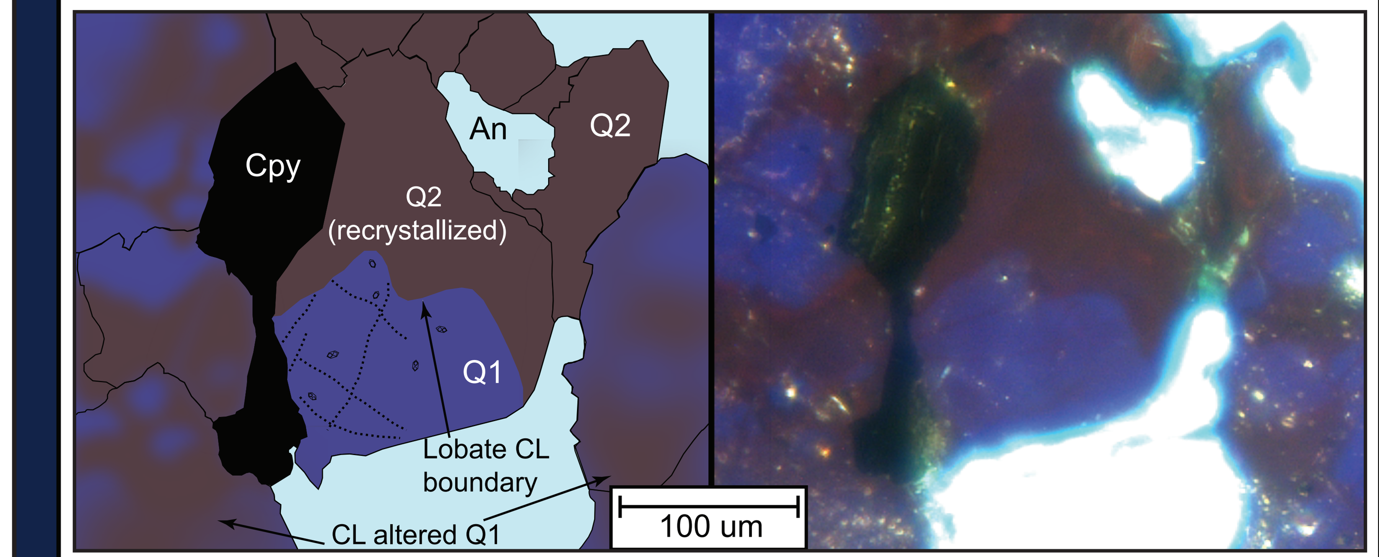
5. Q2 Quartz Overgrowth Rims on Q1



Abbreviations: An=anhydrite, Q1=early quartz, Q2=late quartz, Cpy=chalcopyrite

CL image of early anhedral Q1 quartz with well developed oscillatory growth zoning and syntaxial overgrowths of late Q2 quartz. Q2 quartz overgrowths are inclusion-poor, but rarely contain L_{Q2} inclusions. Euhedral Q2 quartz is visible with increasing abundance near the vein center, and is generally inclusion-poor.

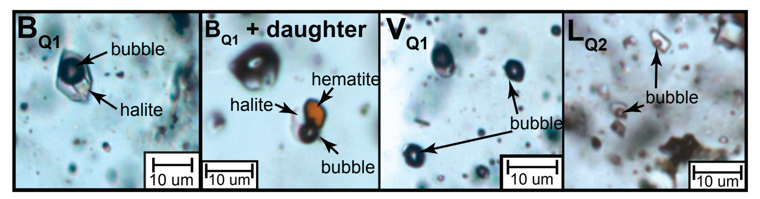
6. Inclusion-Destructive Replacement



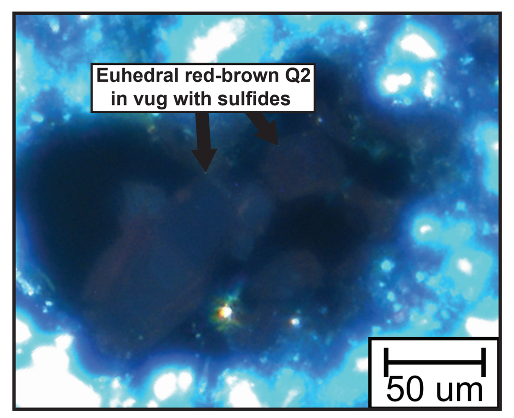
Abbreviations: An=anhydrite, Q1=early quartz, Q2=late quartz, Cpy=chalcopyrite

Photomicrograph of a quartz crystal near the vein center adjacent to a large sulfide grain. There is a sharp, lobate boundary dividing the crystal, across which both the CL response and fluid inclusion inventory of quartz change drastically. The schematic diagram depicts the divided quartz crystal and adjacent sulfide, showing the fluid inclusion inventory of both CL zones. The bright blue zone of the crystal (Q1) contains several B_{Q1} and V_{Q1} inclusions, in addition to several secondary L_{Q2} inclusion trails. L_{Q2} inclusion trails terminate at the lobate CL boundary. Fluid inclusions are absent within the red-brown sector of the crystal, suggesting this CL texture formed via inclusion-destructive replacement of Q1 quartz by Q2 quartz. Similar textures are rare in the thin section, suggesting this is a minor process involved in the formation of Q2 quartz.

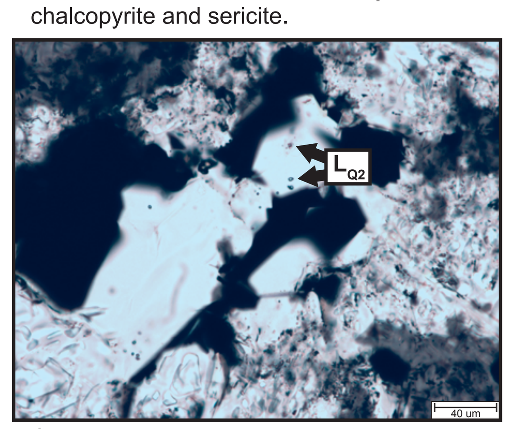
3. Fluid inclusion Assemblages and Fluid Cooling Paths



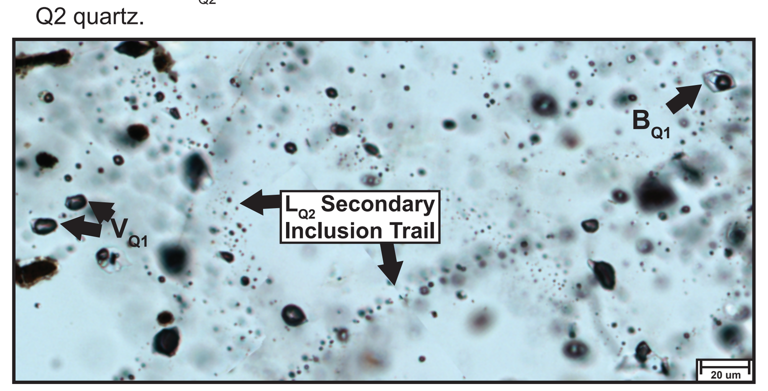
Brine (B_{Q1}), vapor-rich (V_{Q1}), and liquid-rich (L_{Q2}) fluid inclusions observed in Far Southeast porphyry vein quartz Q1 and Q2.



Euhedral red-brown Q2 within vug with chalcopyrite and sericite.

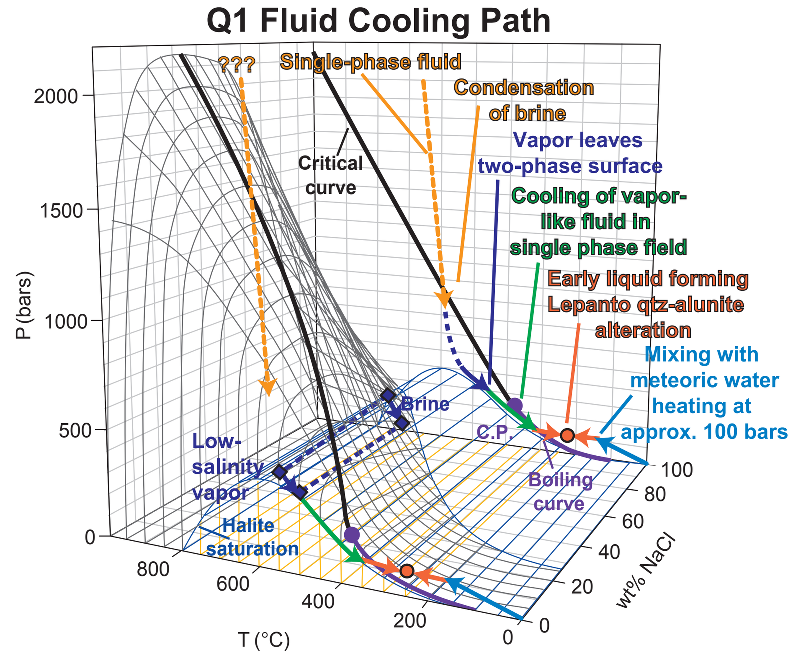


Characteristic L_{Q2} inclusions within euhedral Q2 quartz.



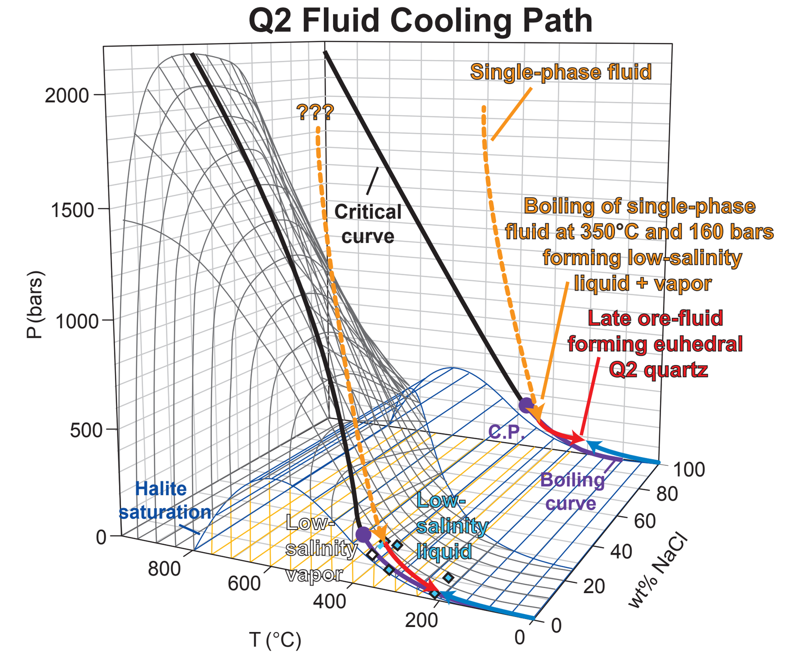
Typical distribution of fluid inclusions through a portion of the Q1c quartz shown in Panel 4.

Q1 Fluid Cooling Path

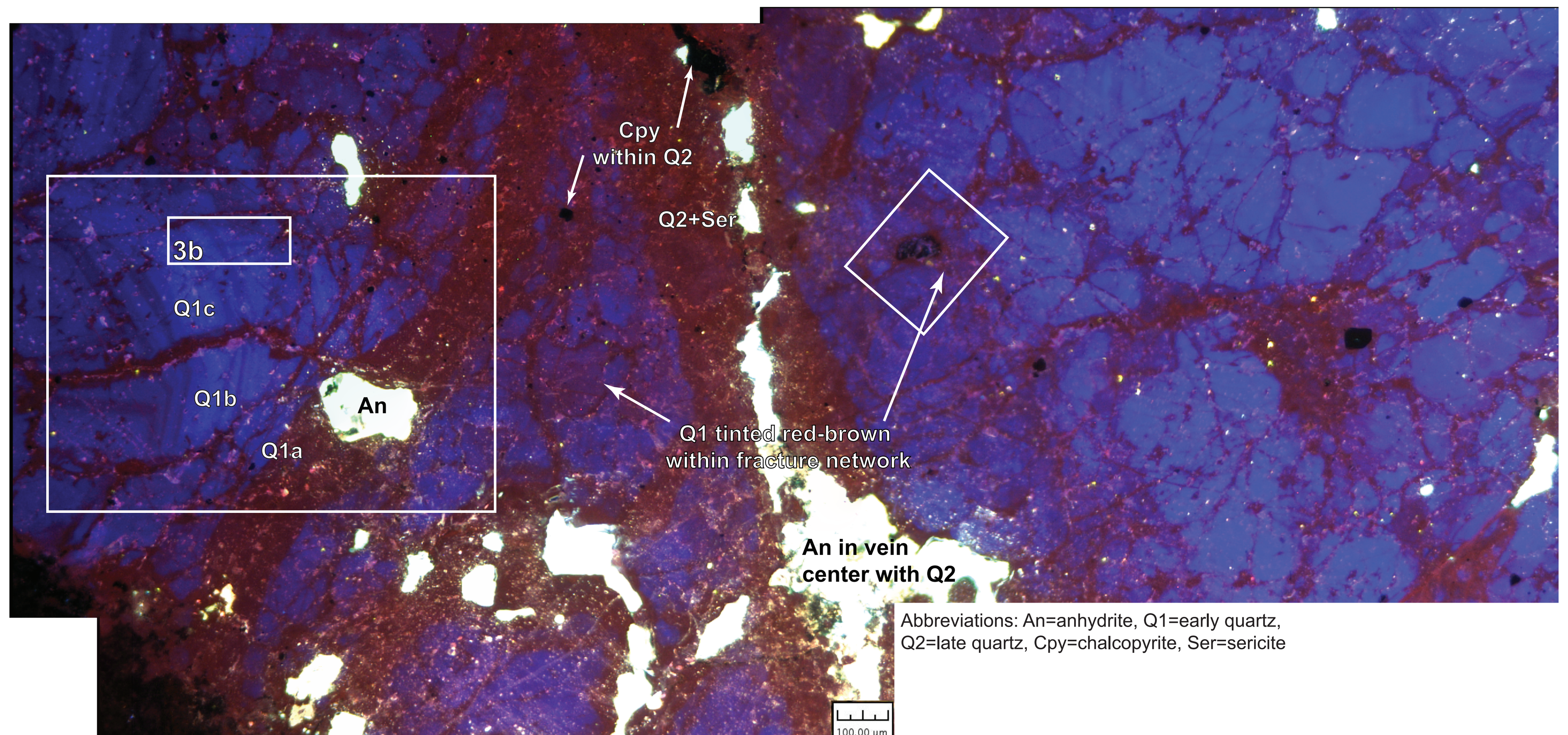


Fluid cooling paths for early fluid forming Q1 quartz, potassic alteration at FSE, and quartz-alunite alteration at Lepanto (above) and late fluid forming Q2 quartz, chlorite ± sericite alteration at FSE, and ore mineralization (below). Cooling trends are plotted in P-T-X_{NaCl} space (foreground) and in P-T space (back panel). Cooling trends are constrained by P-T-X_{NaCl} data from fluid inclusion microthermometry (diamonds) and mineral equilibrium temperatures (Hedenquist et al., 1998). Dashed arrows indicate uncertainty in fluid pressure, temperature, and/or composition. Diagrams modeled after Driesner and Heinrich (2007) and Muntean et al., (2011).

Q2 Fluid Cooling Path

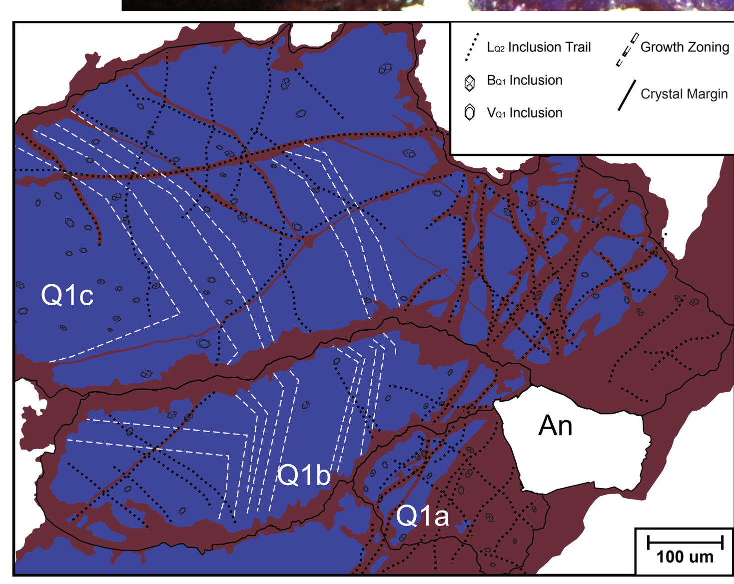


4. Microbreccia and CL Alteration

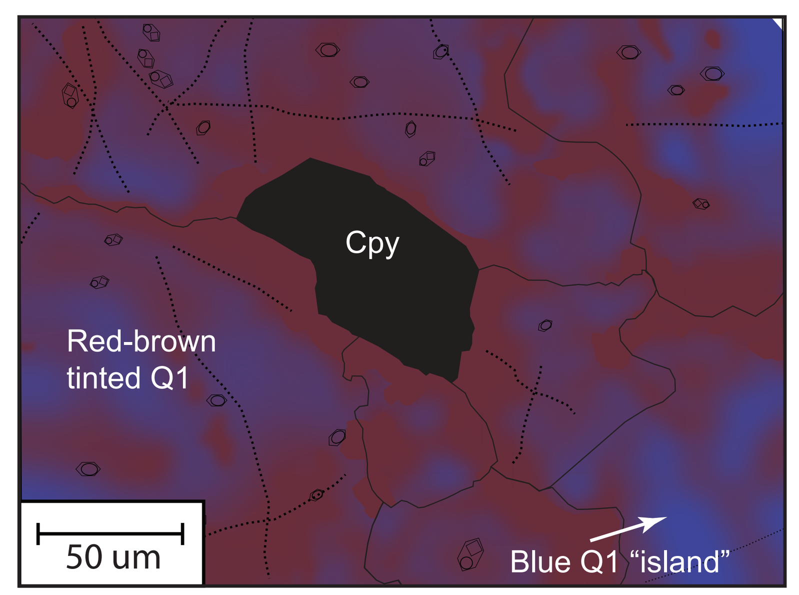


Composite image of three cathodoluminescence photomicrographs spanning an area across the vein center. Blue luminescing anhedral Q1 quartz exhibits oscillatory growth zonation, and is cut by red-brown luminescing euhedral quartz, which fills microfractures formed from vein reopening. The infilled fracture network results in a breccia-like texture with blue quartz occuring as clasts and red-brown quartz as a matrix. Blue quartz adjacent to and between large fractures shows a slightly altered CL response towards red-brown. Anhydrite, sericite, and sulfides are concentrated within red-brown quartz at the vein center.

Abbreviations: An=anhydrite, Q1=early quartz, Q2=late quartz, Cpy=chalcopyrite, Ser=sericite



Schematic diagram showing fluid inclusion distribution relative to CL textures in Q1a, Q1b, and Q1c. B_{Q1} and V_{Q1} inclusions are present throughout Q1 quartz, and are also present within the red-brown luminescing sectors of crystals Q1a and Q1c. Schematic inclusions are enlarged to enhance visibility. Secondary L_{Q2} inclusion trails in red-brown luminescing quartz filling microfractures terminate within red-brown overgrowths.



Schematic diagram showing fluid inclusion distribution relative to CL textures in red-brown tinted Q1 quartz adjacent to isolated sulfide. Alteration intensity decreases outward from fractures and crystal margins. Several "islands" of unaltered blue luminescing quartz are visible within the CL altered quartz. B_{Q1} and V_{Q1} are present in both red-brown tinted quartz and in blue quartz islands, indicating that inclusions are preserved through the alteration process.

7. Preliminary Conclusions

-The study of fluid inclusion inventories in quartz of different CL properties suggests that apparently simple CL textures are more complex than they appear.

-Combined fluid inclusion and CL petrography reveal that two unique generations of quartz exist in the FSE porphyry deposit. The first (Q1) exhibits bright blue luminescence and contains coexisting B_{Q1} and V_{Q1} inclusions, and the second (Q2) exhibits dull red-brown luminescence and contains L_{Q2} inclusions.

-Alteration of the CL response of quartz is recognized by identification of inherited early B_{Q1} and V_{Q1} inclusions in red-brown luminescing quartz. Alteration of Q1 quartz is most intense near fracture planes and grain margins that facilitate interaction with late hydrothermal fluids. Intensely altered zones adjacent to these features grade into weakly altered red-brown tinted blue quartz, again with early B_{Q1} and V_{Q1} inclusions. These CL responses and their associated fluid inclusion inventories are regarded as a modification of early Q1 quartz, and do not represent a new quartz generation.

-Great care must be taken when interpreting quartz CL textures and quartz generations in porphyry deposits. CL color alone cannot be used to identify a generation of quartz growth, as hydrothermal alteration can reset quartz CL properties without causing wholesale recrystallization.

References

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