SEG 100 Conference: Celebrating a Century of Discovery

ST.089

Geology, Mineralogy, and Geochemistry of the Intrusion-Related Polymetallic Quartz Veins at Laodikino, Serbo-Macedonian Massif, N. Greece

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Polymetallic Cu-Au-Bi-Pb-Ag-Te ± Au-bearing quartz veins occur at Laodikino in the Serbo-Macedonian Massif in northern Greece. They are shear-related and hosted in metamorphic rocks, including two-mica gneisses and schists, biotite gneisses, and amphibolites. Barren aplites, pegmatites, and quartz veins are parallel or intrude along the main schistosity of the metamorphic rocks. Magmatic rocks are not exposed in the broader area. Ductile deformation episodes that affected the area include the pre-Alpine to Alpine D1 to D3 phases, and the post-Alpine D4 phase, which was followed by brittle deformation. The D3 deformation event is associated with Jurassic to Early Cretaceous amphibolite facies metamorphism, while the D4 deformation event is related to Late Cretaceous to Eocene retrograde greenschist facies metamorphism. Brittle deformation is mainly characterized by NW- and NE-trending normal to oblique faults. The D4 and the brittle deformation phase resulted in the Late Cretaceous to Miocene extensional collapse of the Serbo-Macedonian Massif and the onset of the main Cenozoic magmatic and mineralizing event that affected the region during the Oligocene-Miocene. The polymetallic quartz veins are generally <1 m wide and crosscut D3 folds, and are subparallel to or crosscut the D4 folds. Locally the metallic mineralization appears discontinuous and forms lenses. Exploration drilling during the early 1990s revealed that these veins reach a depth of 200 m and locally exceed 3 m in width. They exhibit typical hydrothermal characteristics including massive, comb, and breccia textures (Fig. 1A-C). The main metallic assemblage includes pyrite, arsenopyrite, chalcopyrite, sphalerite, tetrahedrite, and galena, and minor amounts of pyrrhotite, magnetite, ilmenite, rutile, cobaltite, Bi-tellurides, electrum, and native bismuth (Fig. 1D-G). Restricted disseminations, aggregates, and pods of magnetite, pyrite, chalcopyrite, rutile, ilmenite, along with minor galena, arsenopyrite, xenotime, and bastnäsite occur in the host rocks (Fig. 1H, I). The alteration mineral assemblage includes quartz, sericite, chlorite, and minor calcite and barite. Hematite, goethite, malachite, chalcocite, covellite, cuprite, and native copper formed due to supergene oxidation. The polymetallic quartz veins are enriched in Ag (<2,433 ppm), Au (<3 ppm), Co (<166 ppm), Bi (<83 ppm), Se (<58 ppm), and In (<53 ppm), while the disseminated assemblage is relatively more enriched in rare earth elements, including Ce (<57 ppm), Nd (<31 ppm), La (<30 ppm), Sm (<7 ppm), and Dy (<5 ppm), as well as in Ga (<10 ppm). Tetrahedrite, chalcopyrite, and electrum are carriers of silver and gold. Bismuth and Te enrichment is mainly related to inclusions of pilsenite hosted in chalcopyrite. In the disseminated mineralization, Dy occurs in xenotime, while Ce and Nd are hosted mainly in bastnäsite. The Laodikino mineralization shares in common mineralogical, geochemical, and structural characteristics with other Cu-Au-Bi-Pb-Ag-Te-enriched intrusion-related deposits in northern Greece (e.g., Koronouda, Drakontio). These deposits constitute future exploration targets for rare and critical metals.

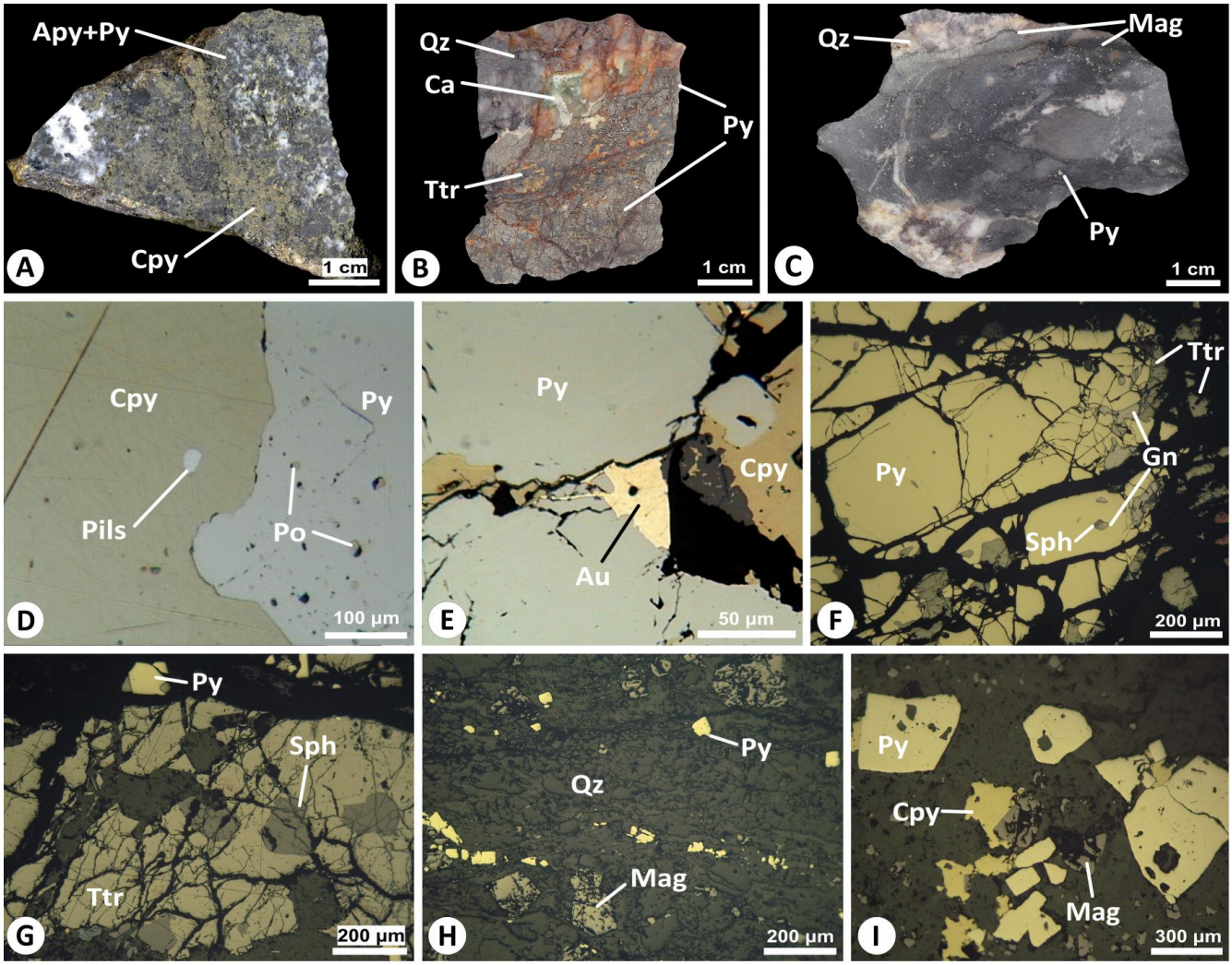

Fig. 1. Photographs of hand specimens of the studied mineralization styles (A-C) and photomicrographs of the metallic assemblages (D-I: plane reflected light). (A) Pyrite (Py) and arsenopyrite (Apy) from a polymetallic quartz vein exhibiting massive texture. (B) Pyrite (Py) and tetrahedrite (Ttr) rimmed by quartz (Qz) in a mineralized quartz vein. Calcite (Ca) is found in quartz interstices. (C) Quartz (Qz), magnetite (Mag), and tiny pyrite (Py) disseminations in a pod hosted by the metamorphic rocks. (D) Pilsenite (Pils) included in chalcopyrite (Cpy) and pyrrhotite (Po) inclusions in pyrite (Py) from a polymetallic quartz vein. (E) Native gold (Au) associated with pyrite (Py), and chalcopyrite (Cpy) from a polymetallic quartz vein. (F) Pyrite (Py) replaced by sphalerite (Sph), galena (Gn), and tetrahedrite (Ttr) in a mineralized quartz vein. (G) Sphalerite (Sph) in tetrahedrite (Ttr) and pyrite (Py) in a mineralized quartz vein. (H) Pyrite (Py) and magnetite (Mag) in quartz (Qz) from a pod hosted by the metamorphic rocks. (I) Pyrite (Py), magnetite (Mag), and chalcopyrite (Cpy) from a pod within the metamorphic rocks.