FLUID EVOLUTION OF THE CU-NI±PGE-SULFIDE MINERALIZED BATHTUB INTRUSION (DULUTH COMPLEX, MINNESOTA, U.S.A)

Raič, S.[1], Mogessie, A.[1], Krenn, K.[1], Hauzenberger, C.A.[1] & Tropper, P.[2]

[1]University of Graz, NAWI Graz Geocentre, Petrology and Geochemistry, Universitätsplatz 2, 8010 Graz, Austria

[2]University of Innsbruck, Institute of Mineralogy & Petrography, Innrain 52, 6020 Innsbruck, Austria

sara.raic@edu.uni-graz.at

The troctolitic Bathtub intrusion (Duluth Complex, NE-Minnesota) hosts the sub-economic Cu-Ni-sulfide Babbitt deposit, which is characterized by disseminated sulfide ores (pentlandite, pyrrhotite and chalcopyrite) that locally contain anomalous platinum-group element (PGE) concentrations. Platinum-group minerals (PGMs) are either hosted by primary magmatic sulfides (first generation PGMs) or associated with areas of hydrous silicate alteration (secondary generation PGMs). Petrographically two apatite generations are observed in these samples, which were used to track magmatic and metasomatic processes: (i) earlier crystallized apatite I inclusions in clinopyroxene; and (ii) later formed, LREE-enriched apatite II along grain boundaries of cumulus and intercumulus silicates, associated with hydrous mineral assemblages (such as sericite + chlorite + amphibole). Based on fluid inclusion studies in cumulus phases and apatite II, as well as textural and compositional variations of apatite, the following predominant fluid systems, which were active during magmatic, subsequent metamorphic and late metasomatic events, are reconstructed:

(i) An early fluid evolution stage, characterized by a homogeneous H_2O-CO_2-CH_4 fluid, indicated by negative-crystal shaped CH_4-CO_2-rich fluid inclusions (FIs) in cumulus plagioclase and multiphase solid inclusions (MSIs) in igneous olivine (e.g. graphite, REE+Y-bearing phosphate minerals, hydrous silicates and carbonates). Identified MSIs represent early FIs that show modifications after entrapment.

(ii) A later fluid system is documented by two types of FIs in LREE-enriched apatite II (types A and B): Heterogeneous aqueous, saline type A FIs, aligned parallel to the crystallographic c-axis, with end-member homogenization entrapment temperatures around 280°C. The close association of apatite II with hydrous mineral assemblages of greenschist- to amphibolite-facies conditions suggests a metamorphic origin for type A FIs. Type B FIs define secondary unmixed carbonic-aqueous fluids entrapped along cracks. This later fluid generation can be correlated with the bright REE-enriched domains in apatite II. During cooling, fluid phase separation into aqueous and carbonic inclusions generated a modified fluid system [H_2O–$NaCl(\pm CaCl_2 \pm MgCl_2)$–$CO_2$] near solidus conditions.

(iii) The latest fluid-induced processes include the nucleation of monazite along apatite II rims or in cracks, and Cl-rich domains (up to 4.93 wt.% Cl) in altered apatite II. Since secondary generation PGMs and other precious phases are abundant in these alteration patches, we suggest the presence of a Cl-rich fluid phase, which may have served as a transporting medium during PGE remobilization.