

Multiple Hydrothermal Processes in Footwall Units of the North Range, Sudbury Igneous Complex, Canada, and Implications for the Genesis of Vein-Type Cu-Ni-PGE Deposits

FERENC MOLNÁR,

Department of Mineralogy, Eötvös L. University, Budapest, Pázmány Péter sétány, 1/C, 1088 Hungary

DAVID H. WATKINSON, AND PETER C. JONES

Department of Earth Sciences, Carleton University, 1125 Colonel By Drive, Ottawa, Canada K1S 5B6

Abstract

Systematic regional sampling along the contact zone of the 1.85 Ga age Sudbury Igneous Complex with the Archean Levack Gneiss footwall in the North Range of the Sudbury structure revealed textural, mineralogical, and fluid inclusion systematics of post-Sudbury Igneous Complex hydrothermal processes that affected the various lithologies. At late stages of emplacement of the Sudbury Igneous Complex and formation of magmatic Fe-Ni-Cu sulfide deposits a partial melt from the Levack Gneiss invaded the contact zone. This partial melt is revealed by small microdikes and irregular bodies of granophyric quartz-plagioclase with megacrysts of hornblende, clinopyroxene, and titanite. Plagioclase-hornblende equilibrium was established at 750° to 800°C and 1.10 to 1.55 kbars pressure, corresponding to about a 4- to 6-km depth under lithostatic conditions. F/Cl wt percent ratios around 15 for accessory apatite and hornblende indicate that a Cl-rich fluid phase separated during the crystallization of the footwall granophyre: this is expressed as miarolites. The Cl-rich fluid (50 wt % NaCl equiv salinity) was trapped as primary fluid inclusions in quartz at around 480°C minimum temperature and around 1.1 kbars minimum pressure during supercooling. These inclusions are rich in Ca, Fe, Mn, and K, as well as Na chloride. This fluid may have interacted with earlier primary magmatic sulfide, causing remobilization and reprecipitation of Cu-Ni-platinum-group elements (PGE) in veins and disseminations in the footwall. These veins are parallel to the Sudbury Igneous Complex-footwall contact and are characterized by chalcopyrite, pentlandite, millerite, magnetite, stilpnomelane, ferropyrrosmalite, epidote, and chlorite. Michenerite, moncheite, merenskyite, froodite, insizwaite, sobolevskite, gold, and Bi-Ni sulfides are associated with sulfides. Epidote, quartz, actinolite, and chlorite are common in the alteration selvages of the veins. Compositions and assemblages of platinum-group minerals (PGM) indicate their precipitation below 575° to 485°C. Primary, highly saline fluid inclusions (about 40 wt % NaCl equiv) in quartz indicate crystallization at 400° to 480°C and around 1.6 kbars minimum T and P, respectively. Late carbonate-epidote-actinolite-chlorite veins and alteration overprinted the earlier assemblages at about 300° to 400°C, with some bornite, millerite, native silver, and other Bi sulfides.

The second stage of hydrothermal activity is characterized by regional carbonic-aqueous (NaCl-CO₂-CH₄-H₂O-type) immiscible fluids that were trapped as secondary inclusions in quartz from various lithologies. No mineralization is related to this stage along the North Range. Boiling of these fluids took place during a pressure drop from lithostatic to hydrostatic conditions during uplift from about a 5- to 6- to a 3- to 4-km depth at 300° to 350°C. High- (20–26 wt % NaCl equiv) and low-salinity (6–12 wt % NaCl equiv) fluids coexisted with different carbonic species contents. The predominant north-south and northwest-southeast orientations of fluid inclusion planes reveal that mobilization of carbonic-aqueous solutions may be related to the northwesterly oriented thrusting in the Sudbury structure during the late stages (1.8–1.7 Ga) of the Penokean orogeny and to predominantly north-south faulting in the North Range.

The third stage of fluid mobilization also took place mostly along northerly and northwesterly oriented fractures. Aqueous fluids were Ca-rich brines (20–40 wt % salinity) with temperatures between 150° and 250°C. Some of these fluids also circulated in fractures parallel to the Sudbury Igneous Complex-footwall contact (NE-SW); thus, they locally may have interacted with the earlier sulfide assemblages and are also responsible for formation of late veinlets with chalcopyrite-epidote-quartz-chlorite assemblages. Mobilization of these fluids took place under litho- and hydrostatic conditions at about a 4- to 6-km depth. This hydrothermal activity is related to a regional tectonothermal event during emplacement of northwesterly oriented Sudbury dikes (1.24 Ga).

Regional-scale fluid inclusion studies along the North Range highlight the role of multiple hydrothermal processes in the metallogenic evolution of the Sudbury Igneous Complex and especially in the distribution of copper and precious metals in the footwall units.