Mineralogy of Cu-Ni-PGE ore and Sequence of Events in the Copper Cliff South Mine, Sudbury, Ontario

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The Sudbury Structure is the largest Cu-Ni-PGE producer in the world. It is an impact structure in rocks of the Superior Province to the North and the Southern Province to the South. The Sudbury Igneous Complex is subdivided into Main Mass and offset dikes (radial and concentric): the Main Mass is composed of the Contact Sublayer, norite, quartz gabbro and granophyre, from bottom to top. The offset dikes, composed of quartz diorite, intruded along fracture zones in highly brecciated areas created by the meteorite impact (Hawley, 1962). The Copper Cliff Offset, the host of 15 % of the sulfide ore (Cochrane, 1984), is one of the radial offset dikes in the South Range of the Sudbury Structure. It is subdivided into Copper Cliff North and Copper Cliff South offsets, separated by the Creighton fault. The Copper Cliff Offset intrudes metavolcanic and metasedimentary rocks of the Huronian Supergroup of Paleoproterozoic age. At Copper Cliff South the country rocks are Copper Cliff rhyolite and McKim metasediments.

The 800 and 810 ore bodies are the two major deposits in the Copper Cliff South mine, located at the opposite contacts of the quartz diorite dike with metapelite of McKim Formation. In several places the two ore bodies are connected through the center of the dike or there is another ore body parallel to the contact of quartz diorite and country rocks. The primary magmatic minerals in the quartz diorite in Copper Cliff South include plagioclase, quartz, amphibole and biotite. The quartz diorite is weakly to strongly altered in the whole area, with increasing degree of alteration toward the sulfides. The alteration minerals are biotite, Fe-rich amphibole, chlorite, epidote, garnet, quartz, stilpnomelane, calcite, ferropyrosmalite, all of which are richer in Fe with decreasing distance from the ore bodies.

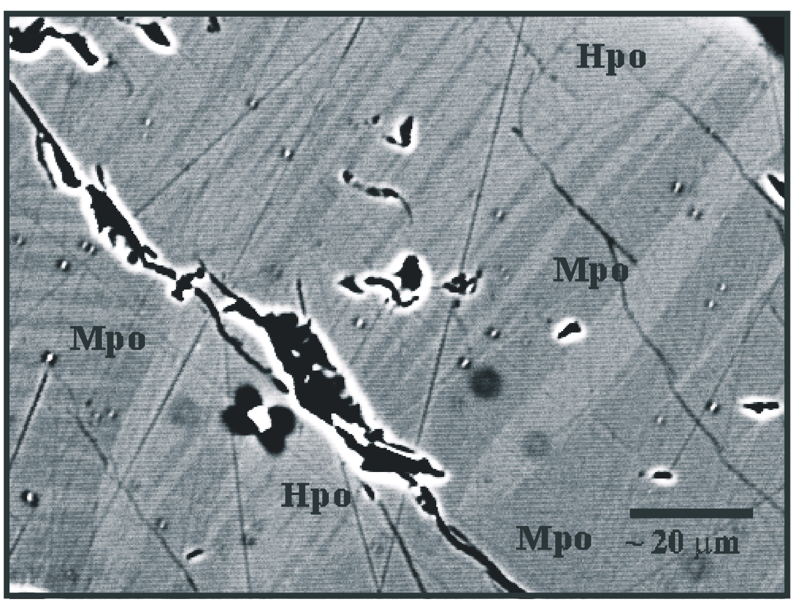

Figure 1. *Lamellae of monoclinic pyrrhotite in hexagonal pyrrohtite (Backscattered elsectron image).*

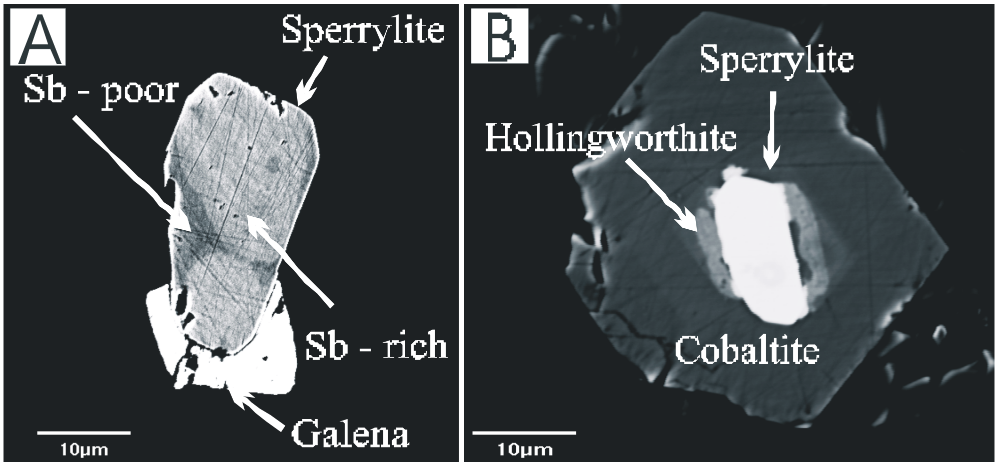

Figure 2. *A. Zoned sperrylite with galena. B. Sperrylite and hollingworthite in the center of a zoned cobaltite grain.*

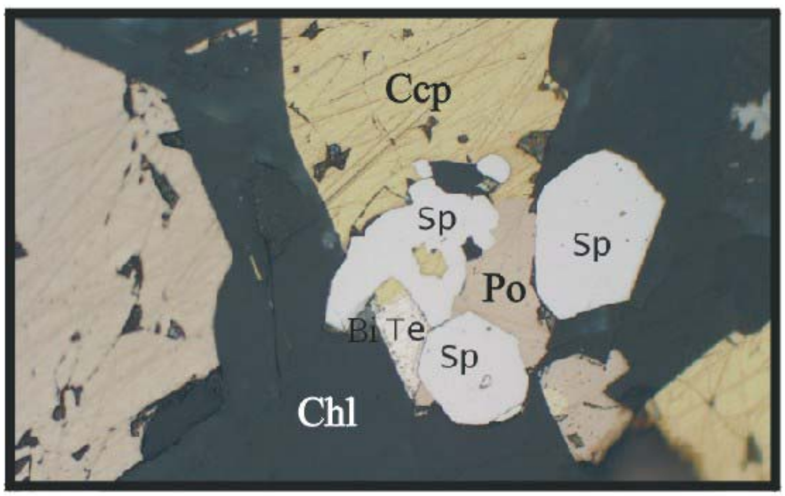

Figure 3. *Sperrylite with tsumoite in chlorite, chalcopyrite and pyrrhotite.*

The ore occurs as massive, inclusion massive, net-texture, "blebby", disseminated sulfide and veins. It is composed of variable proportions of monoclinic and hexagonal pyrrhotite, chalcopyrite and pentlandite. Most of the samples from Copper Cliff South mine contain both monoclinic and hexagonal pyrrhotite in approximately equal amounts. Monoclinic pyrrhotite occurs as lamellae that range in thickness between 0.2 and 40 μm even within one grain (Fig. 1). Most pyrrhotite grains become richer in monoclinic pyrrhotite toward the edges, which according to Naldrett and Kullerud (1967) may be explained by the exsolution of pentlandite that has a relatively lower sulfur:metal ratio, thus increasing the sulfur content of the host pyrrhotite and stabilizing monoclinic pyrrhotite. Interaction with a Fe-rich and/or S-poor fluid is indicated by conversion of monoclinic pyrrhotite to hexagonal pyrrhotite along galena and sphalerite veinlets in massive pyrrhotite and also at the edges of pyrrhotite "blebs" and grains (Lianxing and Vokes, 1996). Minor and trace metallic minerals include magnetite, sphalerite, cubanite, galena, tsumoite, gersdorffite/cobaltite, hessite, melonite and PGM.

The most common PGM in the Copper Cliff South mine is sperrylite ($PtAs_2$). It occurs in every textural type of ore, enclosed by chalcopyrite, pyrrhotite, pentlandite, cobaltite, and hydrous silicates such as chlorite, amphibole and epidote (Fig. 2). Sperrylite may be homogeneous, zoned (Sb-rich center and Sb-poor rim), with hollingworthite and cobaltite, and inclusion-bearing. The Pd-bearing minerals are froodite ($PdBi_2$) and michenerite (PdBiTe) that are most commonly enclosed by silicates (chlorite, biotite, quartz) or chalcopyrite. Hollingworthite invariably occurs in the center of zoned cobaltite grains in veins or in disseminated sulfide. Argentian gold ($Au_{0.56}$ $Ag_{0.44}$) occurs as small grains in chalcopyrite and in a veinlet that also contains calcite in the wall rock of a large vein in the center of the quartz diorite dike, with parkerite ($Ni_2Bi_3S_2$). The most common trace minerals spatially and genetically associated with PGM are tsumoite, galena, hessite, gersdorffite – cobaltite, melonite and native Te.

A large quantity of metals including PGE have been remobilized by hydrothermal fluids. This is revealed by the presence of PGM in large veins in quartz diorite and metapelite and also in chlorite, amphibole, epidote, biotite, and quartz that often enclose PGM (Fig. 3). The temperature at the time of this event was estimated in samples containing garnet and biotite in equilibrium to be 327 to 540° C. Pressure estimated using amphibole chemistry may have been as high as 3 kbar. The fluid responsible for the transportation of metals was rich in Cl and oxidizing. Elements transported by the fluid include S, Cl, Cu, Ni, Fe, Pt, Pd, Ag, Au, Bi, Te, As, Sb, Pb, Ca, Mn, K, and Rh. The fluid composition changed with time, suggested by the presence of zoned minerals including sperrylite and gerdorffite – cobaltite. Also, based on the textural relationships, the sperrylite precipitated before tellurides, galena, and after or the same time as michenerite.

The Copper Cliff South area was also affected by retrograde metamorphism and deformation of the Penokean Orogeny, that occurred probably simultaneously with the first hydrothermal event that remobilized PGE and most of the metals. This is suggested by metamorphic and deformational features in sulphides from massive ore and large veins, such as layering, megacrysts and lenses of pentlandite, kink banding and twinning in pyrrhotite. The peak of metamorphism occurred before the Sudbury Event. Later hydrothermal events affected the area, but most of these events were more local, driven by the heat of younger dikes or concentrated along major and minor faults that may have been reactivated several times.

References

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