

Petrographic Implications for the Picket Pin PGE Deposit, Stillwater Complex, Montana

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The processes of transport and deposition of 'reef-type' platinum-group-element (PGE) deposits remain enigmatic although numerous models have been proposed. The Stillwater Complex contains reef-type, PGE-enriched, sulfide-bearing intervals including the J-M Reef and the Picket Pin deposit. The J-M Reef is located approximately 500 m above the upper contact of the Ultramafic Series with the Banded Series. The reef occurs within the Troctolite-Anorthosite Zone I (TAZ I), a complex lithologic unit that contains numerous subdivisions. The Picket Pin deposit, located approximately 3000 m above the J-M Reef, is hosted within the 570 m thick anorthosite (AN II) at the top of the Middle Banded Series. The lack of lithologic complexities within the Picket Pin deposit provides an excellent opportunity to investigate the PGE ore forming processes.

Preliminary field investigations of AN II proximal to sulfide mineralization reveals intricately varying compositions on a scale of centimeters to tens of meters. From Picket Pin Mountain to the easternmost exposure of the deposit, I sampled seven highly-mineralized areas. These grab samples were on a 2 m grid pattern with an average

dimension of 10 m x 20 m. After preliminary assays, a single 15 m x 25 m outcrop with the highest PGE values (~4.4 ppm combined PGE) was chosen for a detailed study of the PGE-bearing sulfide distribution within AN II.

The study area was divided by intercumulate pyroxene percentage into four groups: 0-5%, 5-10%, 10-15%, and 15-20% total modal pyroxene (fig. 1). Zoning of mineral percentage is evident within the pyroxene divisions. These zoning patterns can be grouped as: (15-20% group) olivine plus bronzite in the unmineralized zone, (10-15% group) bronzite>clinopyroxene, (5-10% group) clinopyroxene>bronzite, and (0-5% group) relict clinopyroxene in the mineralized zone. The pyroxene divisions also reveal an alteration trend from slightly altered olivine plus orthopyroxene (15-20% group) distal to mineralization to relict clinopyroxenes altered to chlorite, albite, clinozoisite, and quartz (0-5% relict pyroxene group) within the mineralized zone. This trend may suggest that hydrothermal ore-bearing fluids were constrained to the low-pyroxene group (see also fig. 2).

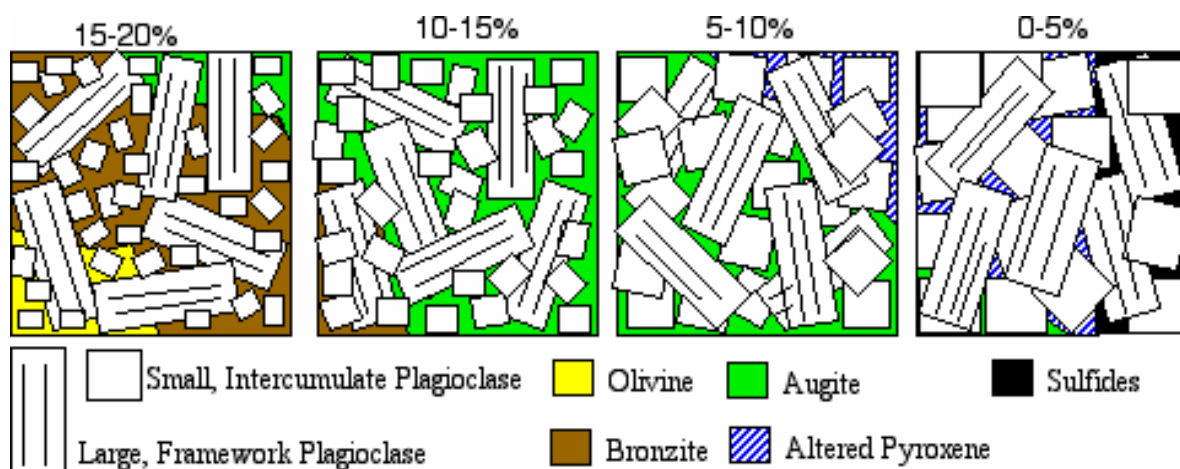


Figure 1. Idealized schematic of AN II by division of modal pyroxene content. The modal percent and increase in intercumulate plagioclase grain size are well illustrated, and was determined by point-count data. The pyroxenes and olivine grains occur as oikocrysts throughout the study area.

Mineralogical and textural evidence suggests three main events for the formation of the Picket Pin PGE deposit. In chronological order these events are: (1.) the formation of the large, framework plagioclase grains, (2.) crystallization of the intercumulate pyroxenes and plagioclase grains with resorption of the original framework plagioclase grains, (3) infiltration of hydrothermal fluids and subsequent precipitation of PGE's. Evidence for this sequence follows.

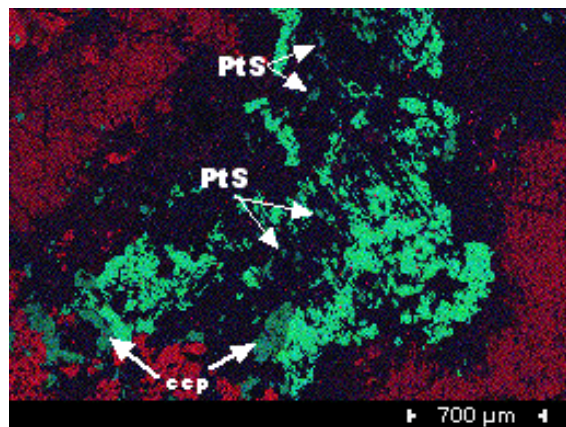


Figure 2. Energy Dispersive Spectrometry photomicrograph of a relict clinopyroxene grain. Dashed line represents the approximate grain boundary between the clinopyroxene and plagioclase grains. The PGE-bearing sulfide (blue-green) is unevenly distributed and follows the pyroxene lamellae. This distribution may suggest infiltration and subsequent deposition of PGE-bearing sulfides from a hydrothermal fluid. Ca = red, S = yellow, Pt = blue.

The plagioclase grains can be divided into large (0.5-2.5 cm), 'framework' grains, and small (<0.5 cm) intercumulate grains. The ratio of large 'framework' plagioclase to small intercumulate plagioclase grains increases near sulfide mineralization. Hence, the mineralized zones occur in the coarse-grained areas. This may suggest a physical constraint on the migration of fluids. Reverse zoning and resorption of the large plagioclase grains suggests a mixing of two compositionally different melts (fig. 3). Microprobe analyses reveal that the large plagioclase grains have a lower average An content (~75), where the intercumulate plagioclase grains are much more calcic (~80). The high An content along with the high Mg-number (>75) for the pyroxenes suggests that a primitive melt mixed with an evolved melt on its plagioclase solidus to form the anorthosite of AN II.

The sulfides occur as intercumulate grains

within the 0-5% pyroxene group. The sulfide grains are rimmed with albite, clinozoisite/epidote, apatite, and quartz. In the areas where the clinozoisite halo is less pronounced, the sulfide grains are still rimmed with albite (fig. 4). The PGE occurs as isolated grains of braggite (Pt, Pd, Ni) S, sperrylite (PtAs₂), and isoferroplatinum (PtFe₃). Unlike the JM Reef, only minor amounts of PGE occur within the pyrrhotite/pentlandite grains. The sulfides are compositionally zoned with pyrrhotite-pentlandite-chalcopyrite-braggite (PGE-bearing sulfides) in the most-altered zone, to ilmenite and magnetite (oxides) distal to the sulfides. This compositional zoning may suggest a fluid change in Eh/pH from oxidizing to a more reducing condition for precipitation of PGE-bearing sulfides. The major accumulation of PGE-bearing sulfides occurs between pyrrhotite-pentlandite and magnetite-ilmenite that may suggest a near neutral pH for deposition. This is further supported by the apparent spatial association between chalcopyrite and the PGE-bearing sulfides in the field.

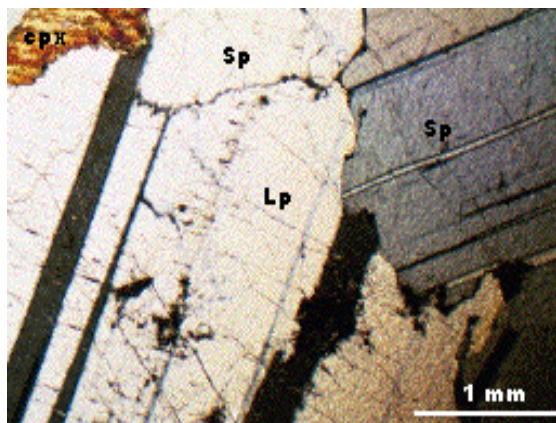


Figure 3. Resorption textures of plagioclase grains. The large plagioclase grain (Lp) has an average An content of 74, where the two smaller plagioclase grains (Sp) are more calcic (An~78). Note the lack of alteration. This sample is 2 m away from the most

Most authors have suggested that the clinozoisite/epidote assemblages are related to post-mineralizing events that range from simple greenschist facies metamorphism to fluids derived from the injection of mafic dikes. Detailed thin section analyses and point-count data suggest otherwise. The assemblage clinozoisite>>epidote occurs exclusively within the 0-5% pyroxene group, where the assemblage epidote>>clinozoisite occurs primarily in the 5-10% pyroxene group. The former being associated solely with and forms a halo around the sulfides, whereas the latter being associated with and forms a halo around the oxides.

The modal amount of clinozoisite/epidote diminishes radically from more than 14.0 modal percent in the 0-5% pyroxene group (mineralized) to less than 1.0 modal percent in the 15-20% pyroxene group (unmineralized). This may suggest a physical constraint for the transport of hydrothermal fluids. Relict clinopyroxenes altered to albite and chlorite occurs tens of meters down-section from mineralization (fig. 5). This may suggest migration of hydrothermal fluids to the mineralized areas.

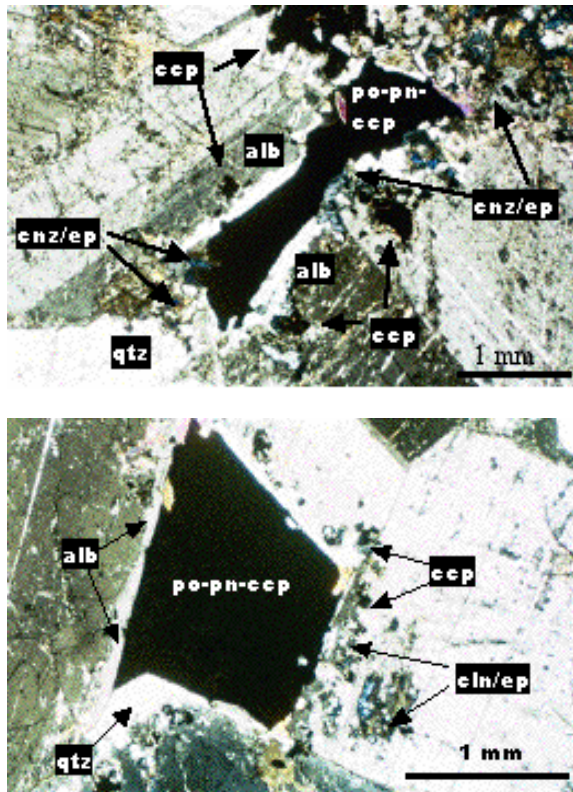


Figure 4. Polarize photomicrographs of two sulfide grains. The grain on the top is less altered than the grain on the bottom. However, both grains are rimmed by albite and contain intergrowths of clinozoisite. po = pyrrhotite, pn = pentlandite, ccp = chalcopyrite, alb = albite, qtz = quartz, cnz/ep = clinozoisite/epidote.

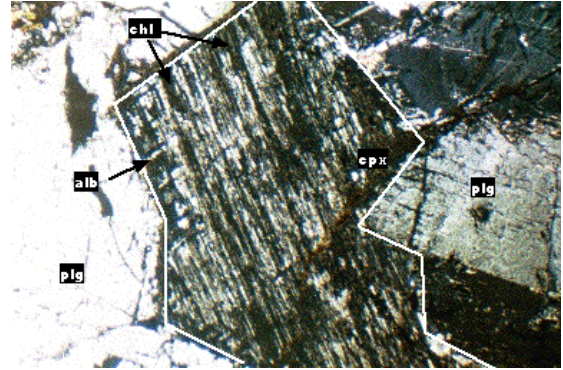


Figure 5. Relict pyroxene (0-5% group) altered to albite (light areas) and chlorite (dark area). Alteration follows the original lamellae of the clinopyroxene. This sample was taken 50 m down section and may suggest movement of fluids.

Anhedral clinozoisite and epidote enclose and are intergrown into the sulfides and oxides and appear to be contemporaneous with precipitation (fig. 4). If the clinozoisite is contemporaneous, then the temperature of precipitation would range from 500 to 550°C based on the quartz-clinozoisite system assuming a pressure between 1 and 2 kilobars. Isolated patches (2 x 2 cm) of clinozoisite form stringers that lead up-section to sulfide mineralization. Random samples (5 kg) of these patches away from visible sulfide mineralization contain an average total PGE content of 600 ppb. This may suggest a link between clinozoisite and PGE mineralization that further supports hydrothermal transport of the PGE's.

The evidence presented suggests a strong case for the role of hydrothermal fluids in the transport and deposition of the PGE within the Picket Pin deposit. The above mineralogic evidence suggests that these fluids contained (OH), Na, Cl, and Fe^{+++} and were constrained within the pyroxene-poor, coarse-grained zones of AN II. This oxidized hydrothermal fluid may have scavenged and transported PGE's. The PGE's were then deposited and concentrated when the fluids encountered the reduced environment of the sulfide horizon.