Energetic Magma Emplacement, Fluxing Fluid and Palladium Mineralization at Lac des Iles, Ontario

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North American Palladium Ltd. operates its Lac des Iles open pit mine 85km north of the city of Thunder Bay, Ontario. Palladium resources were expanded significantly from 1998 to 2001 as a result of conducting 200,000m of diamond drilling on a deposit (Roby Zone) and discovering the adjacent Twilight Zone. As of December 31, 2001, the measured and indicated resources for the deposit total 159.4 million tonnes grading 1.55 g/t Pd, 0.17 g/t Pt, 0.12 g/t Au, 0.05% Cu and 0.05% Ni at a palladium cut-off grade of 0.7 g/t. In addition, inferred resources are 73 million tonnes grading 1.57 g/t Pd, and include 6.1 million tonnes grading 5.20 g/t Pd. An expanded mining operation completed in 2001 will result in an increase in average annual production to 250,000 ounces of Pd. The Roby Zone occurs in a mafic -–ultramafic intrusion known as the Lac des Iles Intrusive Complex (LDI-IC).

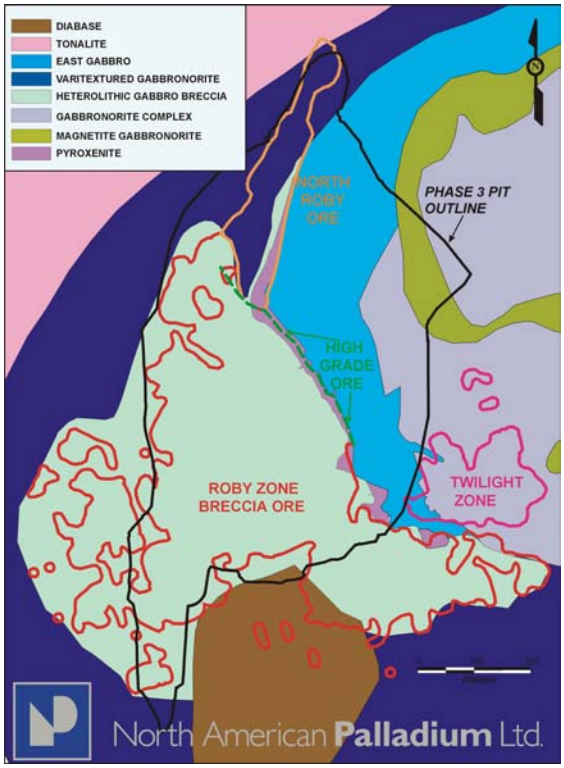

Figure 1.

Geological Setting of the Lac des Iles intrusive complex

The Archean Lac des Iles Intrusive Complex is one of many similar intrusions that define a 30 km diameter ring. Multiple magmatic pulses of varying composition within several closely spaced chambers created the LDI-IC. The rarity of rhythmic layering, chaotic distribution of rock types, and the presence of magmatic breccia suggest a dynamic intrusive environment with disruptive magma pulses. The complex may be divided into three distinct units: ultramafic intrusives- North Lac des Iles Intrusion, chaotic gabbroic intrusives - Mine Block Intrusion, and a relatively homogeneous hornblende gabbro - Camp Lake Intrusion. These units are partially separated by tonalite septa and are therefore considered to be three separate chambers.

The North Lac des Iles Intrusive Complex (NLDI-IC) is ultramafic in composition with a minor mafic component. Outcrop-scale rhythmic layering is uncommon. Observations at recently created bedrock exposures greater than 2500m^2 each revealed that proportions of orthopyroxene, clinopyroxene, and olivine vary considerably, randomly, and gradually in massive rock.

The Mine Block Intrusion (MBI) is texturally and compositionally complex. Rock types range from anorthosite to clinopyroxenite, leuco-gabbronorite to melanonorite and include magnetite-rich gabbronorite. Textures include equigranular fine to coarse grained, porphyritic, pegmatitic, varitextured units and heterolithic gabbro-noritic breccia. Rocks with the latter three textural types are the most common hosts to PGE mineralization. The most laterally continuous unit is the varitextured gabbro rim on the perimeter of the intrusion that is host to the Roby Zone. Varitextured gabbro and heterolithic gabbro breccia are commonly found together throughout the deposit.

The Camp Lake Intrusion is dominantly a medium-grained hornblende gabbro, with lesser leucocratic, melanocratic, porphyritic, varitextured, and monolithic breccia. Minor PGE contents occur along its northern edge.

PGE-enriched zones of the Mine Block Intrusion (MBI)

PGE enrichment is widespread throughout the MBI and to date, diamond drilling has delineated several economic and sub-economic zones: the Roby Zone, Twilight Zone, Baker Zone, and Moore Zone.

The Roby Zone is a bulk mineable deposit with a minimum strike length of 918m and 815m width (including Twilight Zone); drilling has intercepted mineralized rock at a depth of 1000 metres. The zone remains open at depth, and to the southeast and west. The Roby Zone contains three distinct ore types: "High Grade Ore" (7.6 vol.%) also known as "Shear Ore", "North Roby Ore" (5.3 vol.%) and "Breccia Ore" (87.1 vol.%).

"High Grade Ore" is mostly confined to part of a 15-25m thick, semi continuous unit of pyroxenite in the east-central part of the Roby Zone, in contact with barren East Gabbro. A 400m highly altered, often schistose segment of the pyroxenite is PGE-bearing, and the on-strike extensions are low grade to barren, unaltered, and massive. The pyroxenite is planar, trends at 341°, and is subvertical to a depth of 250m with a shallower dip to the east at depth. Higher PGE grades (mean: 7.89 g/t Pd, maximum: 55.95 g/t Pd) occur in those parts of the pyroxenite that are altered to an assemblage of amphibole (anthophyllite-actinolite-hornblende)-talc-chlorite. This rock is often schistose. The high-grade zone is mainly located within the western part of the pyroxenite with grade and alteration intensity decreasing toward the contact with barren East Gabbro. High-grade ore is not controlled or confined by pyroxenite as it straddles the pyroxenite / gabbro-breccia contact. At depths exceeding 250m, the volume of "High Grade Ore" contained in the adjacent heterolithic gabbro-breccia is greater than in pyroxenite.

Grade distribution, when viewed in plan, shows that the higher-grade segment of the pyroxenite is juxtaposed with the higher-grade rock in the adjacent breccia ore. The PGE tenor of pyroxenite decreases dramatically on strike to the south and across strike to the east and is coincidental with a decrease in the intensity of alteration; the tenor decreases coincidentally in the adjacent breccia ore.

The sulphide content of pyroxenite, including the contained "High Grade Ore", is 0.25% to 3% with local net-textured patches with up to 10% sulphide. The PGE tenor is not proportional to the sulphide content and samples free of visible sulphides often contain more than 10 g/t Pd. The dominant sulphides are pyrite, pyrrhotite, chalcopyrite, pentlandite, and millerite.

The "North Roby Ore" is a tabular zone north of the pyroxenite, whose gradational boundaries are defined by assay. It is 20–40m thick, and 200m long. The zone strikes at 20° with the footwall dipping to the east at 45° to 60° and the hanging wall steeper. At surface, it is dominated by coarse-grained leucogabbro containing irregular masses of varitextured gabbro, and medium to coarse-grained gabbronorite. The proportions of noritic rock and heterolithic breccia increase with depth. The alteration of the silicates is weak to moderate. The sulphide content ranges from trace amounts to 4%, and typically is less than 0.25%. The sulphide-poor ore cannot visually be distinguished macroscopically from barren wallrock. The dominant sulphides are pyrrhotite, pentlandite, chalcopyrite and pyrite. The PGE distribution is erratic with a mean of 1.7 g/t Pd, and maximum assay value of 39.74 g/t Pd that decreases in a NE direction.

Southwest of the "High Grade Ore", the central mass of "Breccia Ore" is contained within a complex that is 550x350m. The mean grade of this zone is 1.2 g/t Pd, with maximum values of 36 g/t Pd. The rock ranges from clinopyroxenite to anorthosite to norite with textures of equigranular fine- to coarse-grained, porphyritic, pegmatitic, varitextured, and heterolithic gabbroic-breccia. The eastern boundary to the central part of the "Breccia Ore" is well defined by the subvertical contact with pyroxenite. The other boundaries are not as well defined. Pd is distributed in higher-grade pods (>3.5 g/t Pd) surrounded by lower grade material. The largest of these high-grade pods has a northeast trend and terminates against the "High Grade Ore". Higher-grade pods coincided with heterolithic gabbro-breccia with a gabbro / melagabbro matrix that contains Cu-Ni sulphides and high-grade Pd mineralization.

The most definitive lithological control on PGE grade within the "Breccia Ore" is the presence or absence of heterolithic gabbro-breccia and accompanying varitextured gabbro. The breccia is always ore, except on the margin of the Roby Zone, and other rock types are only ore grade when in proximity to breccia. Also, with the exception of post mineralization dykes, every rock type, regardless of sulphide content, may be ore grade. Heterolithic gabbro-breccia is composed of fragments a few centimetres to several metres in diameter that are representative of most rocks in the complex, as well as a few exotic clasts. It may consist of sub-angular fragments with very little matrix and may grade to a breccia consisting of

10% sub-rounded fragments (digested xenoliths) and 90% matrix. Where selectively assayed, the matrix contains 8 g/t Pd, and the fragments 0.8 g/t Pd. This explains the observation that matrix-poor breccia is usually low grade. Pegmatitic gabbro occurs on the rims of some of the xenoliths and as irregular patches.

Varitextured gabbro ranges from leucocratic to melanocratic, fine-grained with medium-grained patches and veinlets, medium-grained with coarse and pegmatitic patches and veinlets, and coarse-grained with pegmatitic patches and veinlets. In some locations varitextured gabbro contains relict xenoliths, spherical domains with varying composition and texture with diffuse borders. Some large blocks ~60m - of equigranular leucogabbro have rims of varitextured leucogabbro. In some cases, varitextured gabbro containing relict xenoliths is transitional into breccia. The pegmatitic component of the varitextured gabbro is more abundant in the central Breccia Ore where it occurs as convex multiple layers, dykes and lenses as wide as several metres but is laterally discontinuous. The coarser patches and veins have nearly identical mineralogy (plagioclase, orthopyroxene, clinopyroxene) to the equigranular host, consistent with fluid involvement at high temperature. The common juxtaposition of breccia and varitextured gabbro, and associated pegmatitic gabbro, is not only a key to interpreting the process that created the ore, but also serves as an important guide in exploration.

"Breccia Ore" containing as much as 5 vol. % chalcopyrite, pentlandite, pyrrhotite, and pyrite, occurs as fine-grained disseminations, and as coarse blebs interstitial to pegmatitic clinopyroxene and plagioclase. The fine-grained sulphides define streaks within the clinopyroxene pseudomorphs that are now composed of actinolite, chlorite, and talc.

The Twilight Zone is separated from the Roby Zone on its western boundary by the 50-70m thick East Gabbro and separated from the southeastern extension of the Roby Zone by a 50-300m thick barren, post-mineralization gabbro dike. This area has the same style of lithological complexity as does the Roby Zone, but is dominated by less heterolithic gabbronorite-breccia, with 75% gabbronorite and 25% gabbro fragments, and contains minor varitextured or pegmatitic gabbro; silicate alteration is weak to absent. These rocks contain 0.25-0.5 vol.% pyrrhotite and chalcopyrite.

Hypotheses of origin for PGE ore, Lac des Iles mine

Overburden removal generated continuous exposure of the Roby Zone and detailed mapping of the ore zones at Lac des Iles reveals that rather than a nearly stratiform magmatic concentration of PGE, the ore occurs as a PGE- and base metal-rich magmatic matrix of breccia, as lower-grade varitextured units, and as high-grade material associated with intense silicate alteration, as exemplified by "High Grade Ore". The close spatial association of the mineralized breccia with both varitextured units and alteration generating hydrous silicates indicates that magma had a high content of dissolved fluid. Its exsolution as deuteric fluid occurred at high temperature, migrated through crystal mush, enhanced crystallization along its pathways, and resulted in variable coarse-grained to pegmatitic textures of the igneous rocks. This high-temperature transformation produced sulphide-poor, PGE-bearing, varitextured gabbro exemplified by the North Roby Zone. The association of hydrous silicate alteration with PGE and low sulphide content may be explained by continuous fluid migration during cooling and associated metal transport. This process is consistent with observed grade distribution. It is probable that the more ductile pyroxenite, backed by the thick and rigid East Gabbro, acted as a barrier during brecciation to restrict the accompanying mineralizing event to the adjacent rock to the west. The pyroxenite was impregnated by PGE bearing fluids exsolving from the invading magma that produced breccia. The initial high temperature of this process was superseded by the lower temperature transformation of pyroxene to hydrous silicates.