Geology, Petrology and PGE-Cu-Ni Mineralization of the NeoArchean Entwine Lake Intrusion, an Intermediate to Mafic Igneous Intrusion

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Introduction

The Entwine Lake intrusion (ELI) is an east west trending, tadpole-shaped, neo-Archean intrusion located 90 km south of Dryden, Ontario. The ELI is approximately 35 km long with a near circular, 10 km diameter western portion and a narrow tail extending to the east (Stone, 1999). The pluton has recently attracted attention due to PGE-Cu-Ni mineralization located in the northern portion of the intrusion by Champion Bear Resources. The presence of PGE mineralization is of particular interest as this intrusion has characteristics similar to that of a suite of mantle-derived monzodioritic intrusions (termed sanukitoid by Shirey and Hanson, 1984) that have not previously been examined for their PGE potential.

This M.Sc. thesis project, conducted under an Ontario Geological Survey/Laurentian University (MERC) collaborative project agreement, is designed to map the ELI at a scale of 1:20 000 and further our understanding of the nature and origin of the pluton and its mineral potential.

Regional Geology

In Ontario, the Superior Province of the Canadian Shield is divided into thirteen subprovinces based on recently identified tectonic boundaries (Thurston et al., 1991). Diagnostic to most subprovinces, including the Wabigoon, are granite-greenstone assemblages consisting of metavolcanic and subordinate metasedimentary units interleaved and cut by granite batholiths and late intrusions. The Wabigoon Subprovince, a 3.0-2.69 Ga, 900km long and 150km wide, northeast trending granite-greenstone belt, has been divided into eastern, central and western regions (Blackburn et al., 1991). The Entwine Lake intrusion occurs adjacent to the western boundary of the central Wabigoon region (Stone, 2000) (Fig. 1). The central Wabigoon region contains scattered remnants of meso-Archean (3.07-2.90 Ga) felsic gneiss and greenstone belts that have been intruded by neo-Archean (2.78-2.70 Ga) felsic batholiths and late stocks (Tomlinson, 1997, 1998). The Entwine Lake intrusion is one of these late stocks, which are often crescentic-shaped intrusions mantled by septa of mafic schist and amphibolite gneiss interpreted to be the remnants of older greenstone belt assemblages (Stone, 2000).

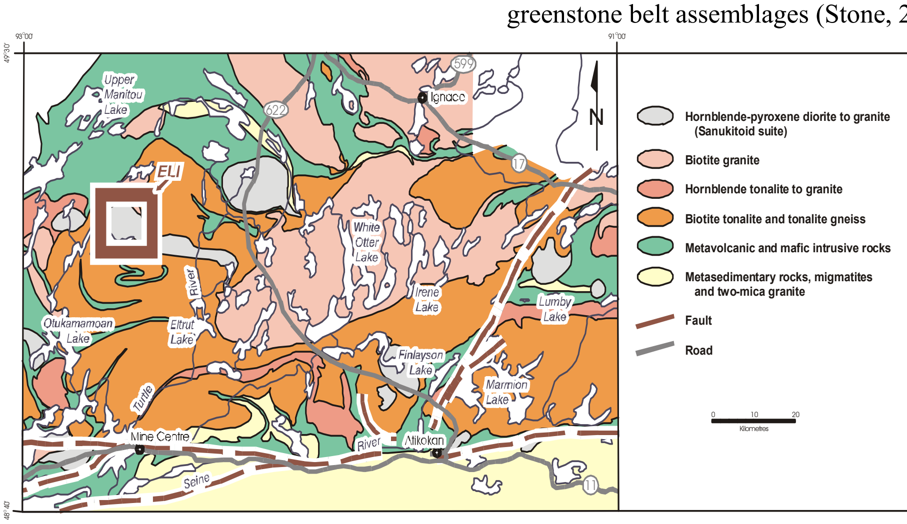

Figure 1. *Regional geology of the central and western Wabigoon and outlined study area.*

Entwine Lake Intrusion

The Entwine Lake Intrusion consists of four geological units. In chronological order these are: 1) an early, foliated meta-monzonite/ monzodiorite unit, 2) an amphibole-augite diorite/gabbro-gabbronorite suite that has been intruded by both 3) massive, and 4) K-feldspar megacryst-bearing, pyroxene monzonite/ monzodiorite.

The foliated meta-monzonite/monzodiorite unit is the first major magmatic event of the Entwine Lake intrusion. It occupies all of the eastern, tail-like part of the intrusion. Petrographic data indicates that the fabric in this unit is metamorphic which decreases in intensity westward as it approaches the massive monzonite/ monzodiorite unit (3) that forms much of the western lobe of the intrusion. The average mineral foliation in these rocks strikes at 330^o and dips steeply to the north; adjacent to the massive monzonite/monzodiorite unit the fabric has a more northerly orientation.

The amphibole-augite diorite/gabbro-gabbronorite unit occurs in the northern and southern areas of the western lobe of the intrusion (west of unit (1)) where it forms dominantly cpx±opx bearing leucodiorite and leucogabbro-norite sequences respectively. In these areas this unit has been incorporated as large km size blocks and inclusions within the massive monzonite/ monzodiorite (unit (3)). The presence of weakly developed magmatic layering suggests these rocks are the remnants of a relatively flat lying basic sill; the steeply dipping orientation of the layering is evidence that this unit has been rotated, and the pervasive alteration of its mafic mineralogy is evidence of recrystallization accompanying intrusion of the later monzonite /monzodiorite rocks. Scattered metapyroxenite masses occur in the same areas as these rocks and are probably part of this geological unit. The diorite/ gabbro-gabbronorite unit is intruded by dykes of the massive monzonite/monzodiorite unit (3) and exhibits hornfelsed assemblages where it is in contact with the K-feldspar megacrystic monzonite.

The massive monzonite/monzodiorite (unit (3)) is restricted to the western part of the intrusion where it underlies more than half of the area. Dykes of the younger K-feldspar megacrystic unit intrude it. Locally along the western margin of the intrusion, this unit develops mylonitic fabrics, which are margin parallel and due to late local metamorphic events. Alternatively, these rocks are part of the older foliated monzonite/ monzodiorite unit of similar composition (unit (1)). In the central area of this unit, contacts with the potassium feldspar megacrystic unit are typically gradational rather than sharp. Meter-wide dykes of this unit cut portions of the marginal amphibolite unit that encloses much of the intrusion producing local hornfelsic assemblages.

The K-feldspar megacrystic unit (4) is the youngest unit of the Entwine Lake intrusion. Like the other units of the monzonite/ monzodiorite suite it is unlayered. It occurs as two large zones in the western part of the intrusion where it intrudes older rock units. The potassium feldspar megacrysts which are diagnostic of this unit, define a shallow, east-plunging lineation (Stone, 2000), that trends ~330^o subparallel to the metamorphic foliation in unit 1. The megacrysts are a late oikocrystic phase of the K-feldspar megacrystic monzonite so it is unlikely that their orientation is due to magmatic flow. A better explanation is that they formed in a stress field related to a post magmatic metamorphism that has caused variable greenschist alteration throughout units (3) and (4).

In the following section, detailed features of each of the four units of the intrusion are presented.

1. Foliated Monzonite/Monzodiorite Unit

This unit forms the eastern ~20 km tail of the intrusion. The pervasive foliation in these rocks is defined by secondary amphibole (actinolite) and biotite replacing primary pyroxene and iron oxide respectively. Primary igneous feldspars have been completely recrystallized and form a fine-grained assemblage of untwinned plagioclase and alkali feldspar; the whole rock normative feldspar composition averages $An_{14}Ab_{56}Or_{30}$. Magnetite and apatite are present as minor primary phases. No sulfide phases are present in this unit. These rocks are geochemically indistinguishable from the unfoliated monzonite/monzodiorites and potassium feldspar megacryst-bearing monzonites that form the main mass of the western part of the intrusion; SiO_2 =53-62 wt %, Mg#=0.37-0.41 and K_2O=2-5 wt %. REE trends show 115x chondrite enrichment in LREE's and 6.5x chondrite in HREE's. The REE patterns mimic the gabbroic suite, but are slightly more enriched.

2. Leucodiorite - Leucogabbro Unit

PGE-Cu-Ni mineralization occurs only in the rafts and inclusions of gabbro/diorite suite rocks and is not observed in any other unit. These rocks have been metamorphosed to the upper greenschist facies. Subdivisions of this unit are based on normative An compositions. This data indicate that leucogabbro (An_{52-65}) forms the southern and leucodiorite (An_{40-50}) the northern part of this unit.

The PGE mineralized Campbell zone is hosted within the northern leucodiorite. Weak, meter-scale layering, mafic schlieren and associated leucocratic patches are common; the latter two are interpreted to be a result of immiscible felsic and mafic liquid phases within the magma. Primary phases are plagioclase feldspar, clinopyroxene and orthopyroxene, minor opaque phases, apatite and biotite. The pyroxenes are normally altered to actinolite, often rimmed by blue-green amphibole. Primary crystallizing sulfide phases include chalcopyrite, pyrrhotite, minor pentlandite and sphalerite. Magnetite and minor ilmenite are the oxide phases. Secondary pyrite is widespread consistent with the metamorphism of the magmatic silicate paragenesis. Geochemically, these rocks are characterized by SiO_2=45-55 wt %, Mg#=0.25-0.40 and K_2O=0.5-1.75. REE trends show 100x chondrite enrichment in LREE's and 3.5x in HREE's with steep LREE and flat HREE patterns.

3. Monzonite/Monzodiorite

The massive monzonite/monzodiorite unit forms the bulk of the ~8 km diameter western lobe of the intrusion. Scarce, discontinuous and disrupted centimeter-scale melanocratic layers are present in these generally massive rocks. Primary mineral phases include plagioclase, microcline, clinopyroxene, minor orthopyroxene, magnetite, apatite and biotite, accessory zircon and titanite. Secondary phases are mainly actinolite after pyroxene, biotite after iron oxide, and epidote and sericite after plagioclase. Whole rock normative feldspar composition averages $An_{28}Ab_{49}Or_{23}$. Optically zoned pyroxene is common and tends to alter to actinolite, rimmed by a second blue-green amphibole. No sulphides are present in these rocks. Chemical characteristics of this suite are SiO_2=50-60 wt %, Mg#= 0.22-0.41 and high K_2O concentrations ranging from 1.0-5.0 wt %. REE trends show 117x chondrite enrichment in LREE's and 7.5x enrichment in HREE's. REE patterns imitate the foliated monzonite to monzodiorite trends.

K-Feldspar Megacrystic Monzonite/Monzodiorite

This unit is compositionally similar to the monzonite/monzodiorite unit described above. Primary phases are potassium feldspar, plagioclase feldspar, clinopyroxene, orthopyroxene, minor magnetite, apatite, biotite, amphibole and accessory zircon, titanite and ilmenite. Secondary phases are actinolite after pyroxenes, biotite after magnetite, and minor white mica after plagioclase. In this unit zoned clinopyroxene are fairly well preserved, often with fresh cores, and rims of ubiquitous blue-green amphibole. Petrographic analysis of the potassium feldspars suggests they are a late magmatic phase as they often host inclusions of finer-grained plagioclase, apatite, and biotite. These megacrysts commonly show an alignment at ~330^o. Whole rock normative feldspar compositions average $An_{30}Ab_{50}Or_{20}$. Chemical characteristics of this suite are SiO_2=52-62 wt %, Mg#= 0.35-0.37 and high K_2O concentrations ranging from 2.3-4.7 wt %. REE trends show 120x chondrite enrichment in LREE's and 8x enrichment in HREE's. REE patterns are similar to the foliated monzonite to monzodiorite trends.

Late Granitic Dykes

Aplitic and pegmatitic granitic dykes are observed to cut all phases of the Entwine Lake intrusion, and strike a consistent NE-SW direction. The similar orientation of these dykes with two shear zones that displace major parts of the intrusion suggests that shearing played a role in controlling the emplacement of the dykes.

Faults

Two regional NE-striking brittle faults are manifest by offset of the contact of the pluton and the sheath of mafic metavolcanic rocks. No brittle faulting has been recognized within the pluton, but hematite alteration observed in outcrop and aeromagnetic data delineate these structures.

PGE-Cu-Ni Mineralization

Past mineral exploration has led to the identification of a number of Cu-Ni sulphide mineral occurrences within the gabbro/diorite suite of rocks. Recent exploration carried out by Champion Bear Resources Ltd. has identified a PGE-bearing reef-like zone that can be traced for ~1 km at surface, sub-parallel to magmatic stratigraphy in the northern leucodiorite. Field observation of PGE mineralization within the Campbell zone shows that the it occurs as irregular shaped pods ranging from 2-10m in maximum dimension, gossanous, and containing as much as 5-10% disseminated sulfides in a variably altered leucodiorite. Varitextured leucodiorite occurs proximal to the mineralization in very localized areas, and is irregular in distribution. The PGE tenor of the varitextured leucodiorite is unknown. Stone (2000) reported an average grade of 1.0 g/t combined Au, Pt and Pd, 3.8 g/t Ag and 0.5% Cu for samples from the Campbell zone. In addition to chalcopyrite, pyrrhotite ± pyrite, the Campbell zone mineralization contains Pd-Bi tellurides and electrum (Stone, 2002). Sulfide mineralization is often associated with greenschist-facies mineral assemblages (epidote, chlorite, sericite and carbonate), but fresh, relatively unaltered opx ($Wo_2En_{62}Fs_{36}$), cpx ($Wo_{42}En_{42}Fs_{15}$) and plagioclase ($Ab_{53}An_{46.7}Or_{0.3}$) have also been documented in these same mineralized rocks (Stone, 2000). A strong correlation exists between Cu and Pt+Pd for samples from the Campbell zone (Fig. 2). Preliminary assessment of sulphide mineral textures and distribution, along with Pd:Pt ratios of 1.5:1, suggest the Pegs are magmatic in origin.

Summary

The Entwine Lake intrusion is a neo-Archean polyphase intrusion, consisting of four magmatic units. The earliest of these units (meta-monzonite/monzodiorite) was metamorphosed prior to emplacement of the remaining units. The next youngest phase of the intrusion is the leucodiorite – leucogabbro unit that is host to magmatic PGE-Cu-Ni sulfide mineralization. It has been disrupted and altered by intrusion of a second phase of monzonite/monzodiorite magmatism, which occurs as weakly altered, pyroxene bearing massive and K-feldspar oikocryst bearing units. PGE mineralization occurs only in the leucodiorite – leucogabbro unit. The Campbell zone consists of stratabound, pod-like disseminated sulphide mineralization in a layered leucodiorite sequence and averages 1.0 g/ton Pt+Pd (Stone, 2000). Pd+Pt shows a strong positive correlation with Cu in this zone indicative of a magmatic origin for the mineralization.

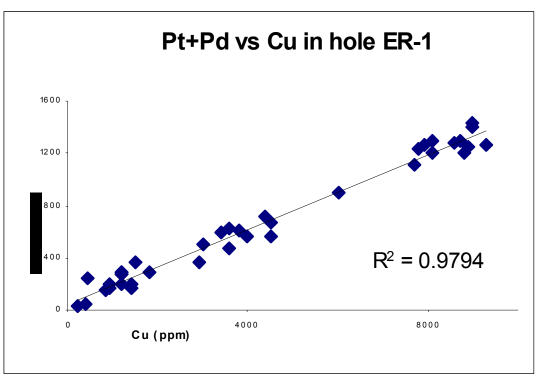

Figure 2. *Correlation between Pt+Pd versus Cu for Campbell zone mineralization.*

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