ONTARIO'S NEWEST KIMBERLITE CLUSTER – THE PAGWACHUAN CLUSTER

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Introduction

The Pagwachuan kimberlite cluster is located ~55km southeast of the community of Geraldton on the southern Archean Superior Craton in Northwestern Ontario, Canada. A total of five kimberlites were discovered during the period of late 2015 to early 2016 after sediment sampling, structural mapping, glacial mapping, airborne geophysics and core drilling. Initial exploration in the Pagwachuan Lake area took place during two periods of the early 1960's and the mid 1980's where regional sediment samples yielded kimberlitic indicator mineral grains (KIMs). Samples collected in 2002 near the samples containing kimberlitic grains did not repeat the earlier results. Targeting and desktop review by De Beers in 2011 triggered a renewed interest in the area due to its geological setting, the presence of proximal surface textures on garnets and ilmenites from till samples and the presence of chrome diopsides with mineral chemistry that suggests they are derived from within the diamond window. A small field work program in 2012 repeated the KIM grains. Detailed glacial mapping, ice flow reconstruction and focused till sampling (tightly spaced fences) in 2014 identified multiple mineral dispersal trains with up-ice cut-offs. Till samples at the head of the mineral dispersal trains contained abundant KIMs with remnants of kimberlite preserved on the grains. Mineral chemistry of the kimberlite indicator mineral grains from samples showed lherzolitic and harzburgitic garnets as well as multiple and distinct populations of ilmenite suggestive of multiple kimberlite sources in the area.

Bedrock and Structural Geology

The Pagwachuan kimberlite pipes are located within the Quetico Terrane of the Western Superior Province. The kimberlites are emplaced into a strain flattened, fold thrusted belt of deformed and metamorphosed basement rocks of Neoarchean (~2.7 Ga) age. The terrane represents an east-west trending belt of greenstones and arc-related (meta) sedimentary rocks that that have reached amphibolite and granulite facies resulting in partial melting along with the intrusion of numerous syn- to post-tectonic feldspathic granites and pegmatites (Percival et al., 2006). This was followed by a phase of Paleoproterozoic orogenesis which culminated in the collision of the Superior Craton with neighboring micro continents (e.g. Hearne-Rae and Nain) during the Trans-Hudson Orogen at ~2.0-1.8 Ga. Further periods of active margin orogenesis during the Neoproterozoic and Phanerozoic are likely to have transmitted tectonic stresses resulting in intraplate reactivation and disturbances to isotopic systems along major crustal structures across the region. This is supported by low temperature apatite fission track thermochronometry data from the southern and western Superior Province (Kohn et al., 2005). The area around the central Quetico belt is conducive for kimberlite emplacement due to the presence of thick lithosphere, high strain tectonic corridors of the Trans-Superior Tectonic Zone and the presence of an array of upper crustal reactivation structures such as faults, shears and dykes possibly connected to a lower crustal plumbing pathway. Highly faulted internal architecture of NW-SE, NE-SW and E-W trending intersecting lineaments form complexly overprinted structural wedges which may disperse ascending melts and produce dyke-related bodies and smaller feeder pipes during emplacement events. Drilling results show that some of the kimberlite bodies are plunging suggesting emplacement may be guided by fold-thrust structures of the complexly deformed metasedimentary accretionary sequences. Other known occurrences located ~50km south of the cluster consist of carbonatites, diamond bearing kimberlite dykes and para-lamproites.

Glacial Geology and Mineral Dispersal

The Pagwachuan area has a flat to rolling topography dominated largely by ground moraine till and lesser amounts of bedrock knobs, eskers, outwash plains and lacustrine plains. Approximately 60% of the Pagwachuan area is covered by silty to sandy till veneer which is conducive for sampling. The Nakina end moraine is present in the northeast part and consists of fine sand, followed by lesser amounts of coarser outwash sand and gravel. The area was influenced by glacial Lake Barlow, post glacial Lake Minong and ice-marginal Lake Nakina (Temiskaming Interstadial period 9000 - 8500 BP) as evidenced by varved silts and clays existing in isolated pockets throughout the north part of the area. The lakes were short lived and did not influence grain dispersal. Mapping of ice flow indicators, verification of surficial material types, identification of tills and reconstructing former ice flows helped in the identification and behaviour of mineral dispersal trains and provided constraints for outlining areas for detailed geophysical surveys. Four ice advances during the Mid-Late Wisconsinan (28,000-9500 BP) confirmed by measuring striations on bedrock in the field flowed towards the south-southwest (200^o - oldest), west (271^o), southwest (216^o) and west-southwest (249^o - youngest). Based on drilling, the Pagwachuan kimberlites are covered in 10-35m of glacial drift consisting of 3 types of tills: 1) the oldest Sandy till dominated by Precambrian clasts and lesser amounts of Paleozoic clasts, 2) the sandy-silty Bankfield till dominated by Precambrian clasts and lesser amounts of Paleozoic clasts and 3) the youngest silty-sandy Matheson till dominated by Paleozoic clasts and lesser amounts of Precambrian clasts. The fine silt-clay rich Cochrane till is absent in the Pagwachuan area. Till recognition was made possible by the analysis of grain size, carbonate content, clast lithology and till chemistry. Mineral dispersal trains emanating from the kimberlites show a very dominant NE-SW trend and a lesser but notable ENE-WSW trend. The fan shaped trains range in length from 1 to 20km and this variation in length within the cluster may be a function of one or a combination of the size of the kimberlites, variable thickness in drift cover and mineralogical abundance within the kimberlites.

Airborne and Ground Geophysics

During the spring of 2015, the Ontario Geological Survey released a geophysical airborne magnetic dataset known as the Lac des Mille, Lacs-Nagagami area survey. The survey covered ~22,500km^2, with line spacing of 200m and 100m mean terrain clearance. It produced a number of high grade magnetic anomalies which were subsequently staked. During the summer of 2015 De Beers commissioned a high resolution heliborne magnetic and frequency domain electromagnetic (DIGHEM/Resolve) survey, the Pendant Creek survey, over a cluster of high grade anomalies and over the heads of mineral trains in the Pagwachuan Lake area. This 347km^2 survey with 50m line spacing and 35m mean terrain clearance confirmed the interest level of the anomalies picked from the Lac des Mille magnetic survey and yielded additional high interest targets. The Pagwachuan kimberlites were discovered by drilling discrete magnetic highs with associated weak electromagnetic responses. Ground magnetic surveys were conducted over the kimberlites to confirm the 2D size of the kimberlite. Ground gravity surveys were completed over three of the kimberlites to identify any new facies not seen in the magnetic and electromagnetic surveys, but did not increase the 2D size of the pipes. Results from petrophysics on the kimberlite core and the host rock confirmed the contrasts seen in the geophysical surveys. All five kimberlites exhibit high magnetic susceptibilities compared to the host rock resulting in anomalous amplitude magnetic signatures. Three of the five kimberlites tested have lower densities than the host rock, these bodies manifest as gravity low signatures in follow-up ground gravity surveys. Inversion modeling of the detailed ground magnetics over the kimberlites resulted in modelled subcropping sizes for the pipes ranging from 0.5 to 2.5 ha.

Core Drilling

During late 2015, core drilling discovered the first kimberlite in the Pagwachuan Lake area. One HQ diameter core hole was drilled into the center of each magnetic high anomaly of interest to a depth of approximately 400m. Five kimberlites were discovered: Arriba, Bronco, Caliente, Domino and El Nino. Of the five kimberlites drilled, the Arriba kimberlite is the largest with a 2D size of 2.5ha and the Caliente kimberlite is the smallest at 0.5ha. Four of the five kimberlite discovery holes ended prematurely in country rock thereby suggesting the deposits have complex shapes not common to typical kimberlite pipes. It is also speculated that the pipes are structurally controlled and may be plunging but this is not fully supported by the geophysics.

Kimberlite Petrology and Age of Emplacement

The Pagwachuan kimberlites are multi-phased with up to three different facies identified through drill core, thin section and whole rock chemistry investigations. Overall, typical crater-facies volcaniclastic kimberlites suggesting phreatomagmatic explosions are identified in Arriba and Bronco pipes. The Caliente, Domino and El Nino pipes comprise kimberlites which combine apparent coherent textures with emplacement style of fragmental rocks suggesting both magmatic and phreatomagmatic eruptions. Interestingly, the coherent textured-kimberlites indicate high temperature metasomatic reaction with contained felsic country rocks, atypical for pyroclastic rocks. The Arriba and Bronco kimberlites are comprised of different volcaniclastic kimberlites emplaced by combined, primary pyroclastic and resedimentation processes. Debris flows are interlayered with grain flows and fallout or base surge deposits are typically identified in Arriba. The Arriba kimberlites demonstrate differences in olivine abundance, primary carbonate and mantle component, typically eclogite xenoliths and ilmenite. The Bronco kimberlites indicate mostly resedimentation, entraining exceptionally large and abundant crustal blocks and locally grain flows which concentrate abnormally high abundant ilmenite. The Caliente, Domino and El Nino kimberlites are typically low abundant fine grained olivine and almost devoid of indicator minerals. The rocks testify to spatters, lava lakes and even intrusions, but also to highly energetic explosive events. Crustal contamination of different mafic and felsic compositions impacts on the mineralogy and chemistry of the kimberlites. The Caliente kimberlites typically show strong metasomatic reactions with felsic crustal rocks which obliterate most of the primary composition. Rubidium strontium (Rb-Sr) dating of the phlogopite from the Arriba, Bronco, Caliente and Domino kimberlites yields an average age of 252.9 ± 2.4 Ma (Late Permian). Uranium lead (U-Pb) dating of the perovskite from the Caliente and Domino kimberlites yields an average age of 220 Ma ± 7.8 Ma (Early to Middle Triassic) (De Beers data, 2016-2017).

Mineral Chemistry Characteristics and Diamonds

Core samples for each of the Pagwachuan kimberlites were processed to quantify the abundance and composition of mantle derived indicators present (i.e. garnet, clinopyroxene, spinel and ilmenite). The general trend of recovered indicators for all kimberlites is of garnet (46%) > clinopyroxene (25%) > ilmenite (20%) > spinel (8%). The predominant size fraction of the recovered indicators is +0.5mm (47%) followed by +0.15mm (29%) and lastly +0.3mm (23%). However, variations in grain recoveries and proportions of indicators from the various size fractions do occur between kimberlites. The principal compositional features of the garnet populations recovered from the Pagwachuan kimberlites are a high proportion of megacrystics (53% G1) followed by lherzolitic (28% G9) and Ti-metasomatised (5% G11) compositions (classification scheme after Grütter et al., 2004). The remaining garnet compositions consist of low proportions of eclogitic (4% G3), pyroxenitic (3% G4, G5), harzburgitic (2% G10), and wherlitic (2% G12) garnets. The presence of diamond-facies like compositions is rare (<0.5% of all garnets recovered) with most derived from the eclogitic, pyroxenitic and then harzburgitic compositions. Mantle barometry using the Cr/Ca-in-pyrope barometer of Grütter et al., (2006) shows a maximum P_{38} of 57 kbar indicating sampling of thick lithosphere, however, very few garnets fall above the 43 kbar “graphite diamond constraint” (GDC) which indicates sampling within the diamond stability field. The Arriba and Domino kimberlites were sampled for micro diamonds. Arriba returned one 0.104mm broken and highly resorbed dodecahedron diamond that is colourless, translucent, and has possible graphite inclusions. Domino returned one 0.074mm broken and translucent octahedron diamond that is colourless, and has maccle twinning.

Conclusion

Geophysics and sediment sampling are effective exploration methods in the discovery of the Pagwachuan kimberlites. The multi-phased Pagwachuan kimberlites located in the Quetico terrane are structurally controlled, have sampled thick lithosphere and are diamond bearing. Unfortunately, they are considered to be uneconomic due to their small sizes, complex shapes, unique but low interest petrology and poor microdiamond recoveries. They however represent the first discovery of a Late Permian to Early Triassic aged kimberlite cluster in Ontario.

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