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GEOLOGY AND VOLCANOLOGY OF THE A418 KIMBERLITE PIPE, NWT, CANADA

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INTRODUCTION

The A418 kimberlite pipe is a member of the Lac de Gras kimberlite field located on the northern Canadian Slave Craton (Figure 1). The pipe is Eocene in age, 55-56 Ma (Amelin, 1996; Moser and Amelin, 1996) and was emplaced into late Archean granitoid rocks (Stubley, 1998; Graham et al., 1999). A418 is currently being actively mined as part of the Diavik Diamond Mine (DDM) which is a joint venture between Diavik Diamond Mines Inc. (60 %) and Harry Winston Diamond Mines Ltd. (40 %). The A418 kimberlite has a proven and probable reserve of 6.2 million tonnes at 3.7 ct/t (DDMI, 2010). The A418 kimberlite pipe is characterised by finely bedded deposits containing abundant ash aggregates; ash aggregates are rarely reported in kimberlite pipes. Detailed drill core logging and mapping of surface exposure of the active open pit show the deposits to be continuous at depth. A combination of thin section and XRF analysis has been utilised to understand the detailed componentry and probable origins of these deposits. Progression from a distinct vent clearing phase to a vent filling phase of the eruption has been determined, with the latter vent filling phase characterised by phreatomagmatic eruptive activity.

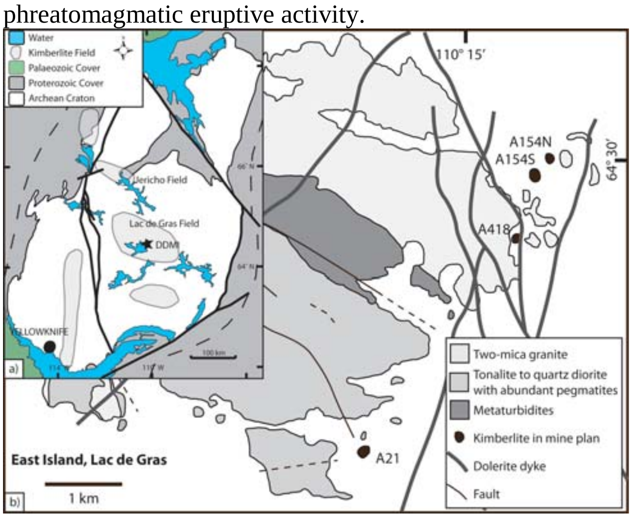

Figure 1. Location maps; a) location of the Lac de Gras Field and DDMI; b) geology of East Island showing location of A418 from Stubley (1998)

GEOLOGY

Pipe morphology

At the present-day surface, the A418 pipe is roughly ovoid in shape, has a diameter of ~125m, and is proven to ~600 m depth by drilling, where it tapers to ~50m in diameter (Figure 2). Observations in the open pit show the steeply dipping pipe walls (~88º) to be scalloped and smoothed with little to no country rock breccia along the contact. The dominant country rock comprises a two mica granite (Figure 1; 2590-2580 Ma, Stubley, 1998), which hosts xenoliths of older metaturbidites and is cross-cut by proterozoic dolerite dykes in the pipe region. The A418 pipe itself is filled mainly by volcaniclastic material comprising four main lithological units: 1) a finely bedded ash aggregate-rich lapilli tuff (FBLK); 2) a massive, poorly sorted mud-clast and olivine rich lapilli tuff (MFKB); 3) a diffusely to well bedded lapilli tuff which is transitional in character between 1 and 2 (VBMK); and 4) a massive kimberlitic mudstone (MUDX). Minor coherent kimberlite (CK) and pyroclastic kimberlite (PK) are observed in drill core, however, these are not very continuous and the emplacement origins are undetermined.

FBLK

The FBLK is a diffusely to well bedded, ash-aggregate and olivine rich, volcanicalstic kimberlite. Bedding occurs at mm to cm scale and is defined by variations in grain size and componentry (i.e. vol %) (Figure 3). The individual beds are moderately well sorted and preserve depositional structures such as grading and cross bedding. The major components in order of abundance are olivine grains (broken to unbroken, fresh to moderately altered, <0.5 – 10 mm); ash aggregates typically defining bedding (1-5 mm, coated ash pellets, ash pellets and accretionary lapilli (Figure 3c), including broken rim fragments); black mudstone clasts (1-40 mm, with fluidal morphologies). Minor components include kimberlite indicator minerals and mantle xenoliths, clasts of volcaniclastic kimberlite, granite clasts, metasediment clasts and wood fragments. Crustal lithic fragment abundance is generally <5-10 %, and is dominated by kimberlitic mudstone.

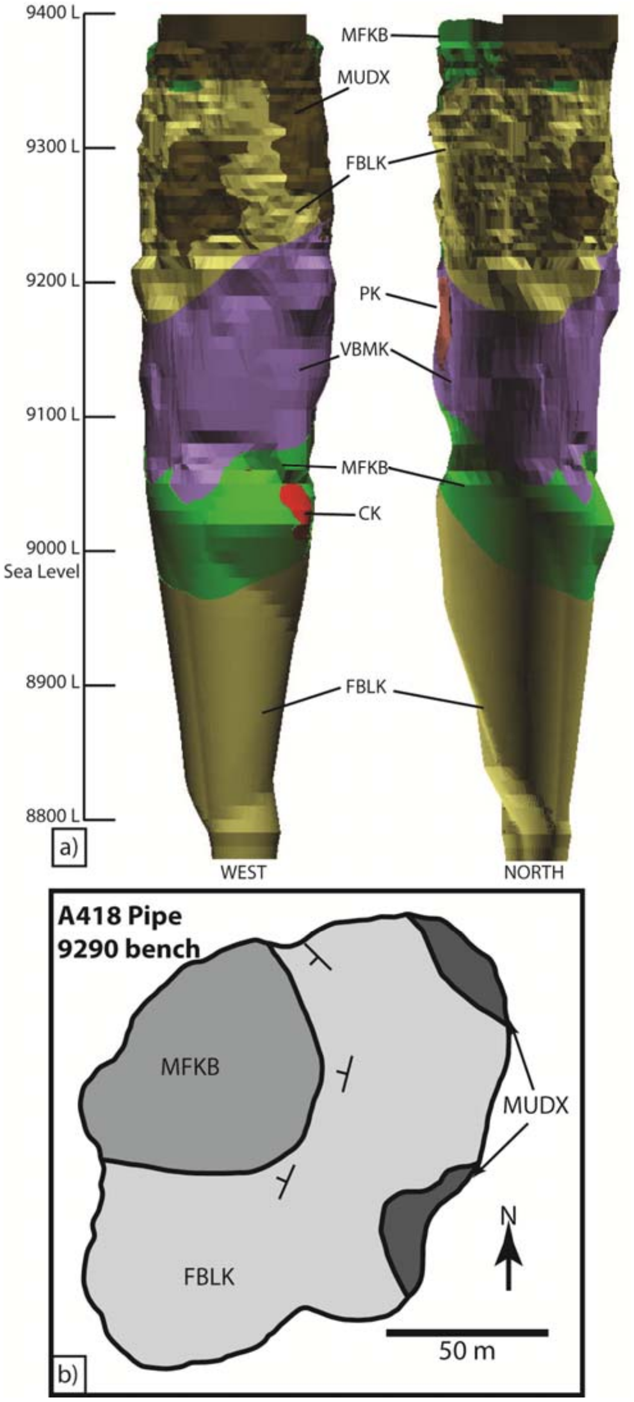

Figure 2. Geology of the A418 pipe; a) distribution of the lithological units taken from the 3D model looking east and north towards the pipe; b) map of the pit from the 9290 L bench.

Two stratigraphic units of FBLK occur within the pipe, the uppermost is exposed within the open pit. Here the bedding is steeply dipping (~45º but up to 80º) and minor slumping and syn-depositional faulting are observed, beds dip inwards towards the in-pit exposure of MFKB (Figure 2b). A second FBLK unit is also observed at depth within the pipe where the fine-scale bedding and steep dips persist, though the exact orientations cannot be determined from drill core. Underground exposure in mine workings has revealed sub-vertical bedding. The finely bedded character of this lithology and the pervasive abundance of ash aggregates suggest transport and deposition by pyroclastic surge and fall combined with volcanic recycling and resedimentation, this strongly supports a phreatomagmatc origin.

MFKB

The MFKB is a massive poorly sorted mudstone clast- and olivine-rich volcaniclastic kimberlite (Figure 3). Diffuse layering is also observed. Major components in order of abundance comprise olivine grains (broken to unbroken, fresh to altered, <0.5 – 20 mm); mudstone clasts (1-500 mm often with fluidal morphologies); juvenile pyroclasts (thin to thick rimmed olivine grains); ash aggregates scattered throughout (1-5 mm, coated ash pellets, ash pellets and accretionary lapilli, including broken rim fragments); volcaniclastic kimberlite clasts (4-100 mm, often containing ash aggregates, sub-rounded to fluidal); granite clasts (5-450 mm, angular to sub-rounded). Minor components include kimberlite indicator minerals and mantle xenolits, metasediment clasts, dolerite clasts and wood fragments. Crustal lithic fragment abundance is generally 10-20% and is dominated by kimberlitic mudstone.

Two stratigraphic units of MFKB are found within the pipe. The uppermost forms a downward tapering deposit which appears to cross-cut and overlay the finely bedded kimberlite, though contacts are not well preserved. A second body of MFKB occurs deeper within the pipe underlying the VBMK and overlying the lowermost unit of FBLK. The eruptive and depositional processes for these lithological units are somewhat ambiguous, as is whether they represent the same depositional event or not. Recycling of earlier kimberlite deposits through, mass wasting or ongoing vent-in-vent eruptions is indicated by the massive poorly sorted nature of the deposits and clasts of volcaniclastic kimberlite.

MUDX

The MUDX is a black to dark grey, massive, silt to fine sand containing low, but variable, abundances of kimberlite components including olivine and other indicator minerals. Faint outlines of ash aggregates are occasionally observed. Several MUDX deposits occur along the upper pipe margins (Figure 2a) and as large domains (or mega clasts) within the pipe at depth. The composition of MUDX is highly variable; however, there is always a pervasive kimberlitic component. Fluidal black mudstone clasts found within MFKB and FBLK appear to be composed of the

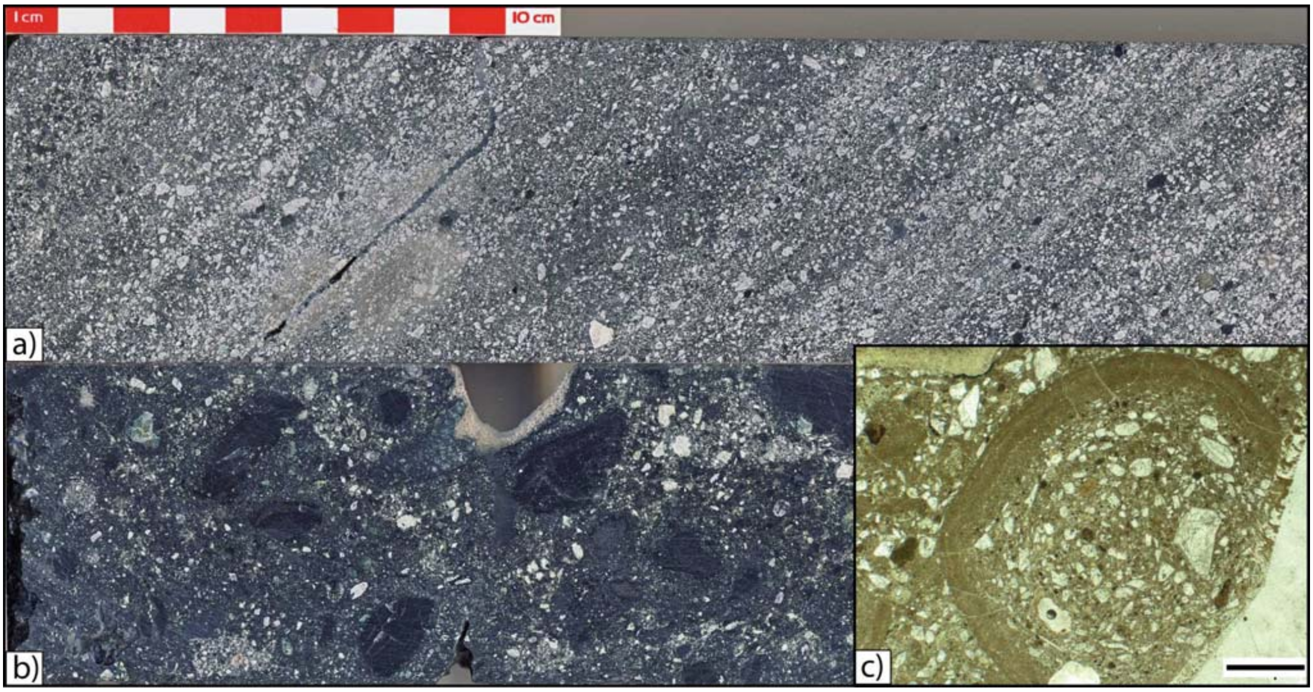

Figure 3. Polished slabs showing examples of FBLK (a); MFKB (b); and a photomicrograph showing an accretionary lapillus.

same (i.e. kimberlite derived) material. It is unclear whether this material is related to the eruptive sequence at A418 or whether it represents pre-existing kimberlitic ash and mud associated with the surrounding volcanic centres, though the occurrence of clasts of MUDX within all other lithologies supports the latter suggestion.

ANALYSIS

A total of 150 samples of MFKB, FBLK, MUDX and host rock granite were analysed for their whole rock major element chemical compositions by X-Ray fluorescence (XRF). Of these 117 are samples collected from the 285 level bench. The remaining 33samples are drill core samples taken from varying depths and were also analysed for trace element contents. The geochemical dataset includes ten samples of granitic host rock; the average is presented in Figure 4. The composition of the average coherent kimberlite (CK) from other Lac de Gras kimberlites as given by Nowicki et. al (2008) is also presented for comparison.

XRF results

In general, the chemical compositions of the MFKB samples show much less variable than displayed by samples of FBLK and MUDX (Figure 4). The MFKB samples show a slight enrichment in both Al_2O_3 and SiO_2 compared to the average CK composition. The SiO_2 and Al_2O_3 contents of the FBLK and MUDX are much more variable than the MFKB and form an apparent trend from CK to the average host rock granite composition. However, when considering the Na_2O abundance in these samples, the influence of granite on the composition is negligible. The source of SiO_2 and Al_2O_3 is not from incorporation of granite but more likely a surficial mudstone such as that invoked by Nowicki et al. (2008) to account for similar observations in the Ekati kimberlites. Importantly this trend supports the observed low abundance of granite clasts within these deposits and does not indicate the presence of any finely comminuted granite.

All of the analysed samples are depleted, compared to the average CK, in incompatible elements such as Ti, Nb and V with the exception of two MUDX samples which are significantly elevated in V contents. A slight enrichment in Ni compared to the average CK is observed in the MFKB samples (Figure 4) with a more variable Ni content in the FBLK and MUDX samples. Elevated Ni content indicates an increased abundance of olivine, and depleted incompatible elements are thought to correspond to a loss of groundmass or melt component in the form of fine ash (Nowicki et al., 2008).

DISCUSSION

The bed forms of the FBLK suggest a phreatomagmatic eruptive origin with deposition from tractional surges combined with minor reworking and resedimentation. The abundance of ash aggregates also supports the involvement of external water during the eruption enabling the aggregation of fine ash, and indicates that sub-aerial dilute eruption clouds were present. The absence of granite within the FBLK deposits as shown macroscopically and through the geochemical signature of the rocks, indicate that the eruption/deposition of the pipe filling deposits must have occurred subsequent to the pipe opening and excavating stage of the eruption. This implies that the source of the water involved in the phreatomagmatic phase was most likely free standing within the pipe as opposed to contained within aquifers in the host granites. Deposits recording this earlier event are not found within the pipe. The steeply dipping nature of these beds and their presence at depth could be the result of primary deposition, or as the result of large intact blocks of crater rim material falling into the open and empty pipe. The latter implies a significant time break between eruption and deposition of the blocks, during which lithification of crater rim material occurred and the pipe remained empty. Vertical beds are known to occur in phreatomagmatic deposits where surges have encountered obstacles, ramped up and over them, and plastered deposits against the obstacle (Brand and Clarke, 2009), and a similar depositional process is favoured here.

The origin of the MFKB and VBMK is somewhat more enigmatic. The uppermost unit of MFKB appears to form a vent-like structure within the surrounding FBLK, with the FBLK bedding dipping towards the in-pit exposure of MFKB. Recycled clasts of FBLK within the MFKB and the presence of juvenile lapilli could be indicative of a second explosive eruption through the existing pipe-filling volcanic pile, or a represents the vent deposits for the FBLK forming eruption. How this would relate to the lower MFKB and VBMK units is uncertain.

The MUDX units which appear attached to the pipe walls are also enigmatic in their origin. Geochemical evidence indicates that this fine grained material, though variable, contains a significant kimberlitic component. Fluidal clasts of MUDX-material are incorporated within the MFKB and FBLK deposits indicating that this material, or at least an equivalent facies, was present within the pipe and immediate surroundings prior to the FBLK forming eruption.

The eruption of A418 is considered to have occurred in several phases: 1) a vent opening and clearing phase which removed the majority of the granite from the pipe and system, and shaped and smoothed the pipe walls, deposits associated with this phase are not preserved so the style of the eruption is unknown; 2) the first mapable deposits, the FBLK, record post-conduit forming eruptive products which have a phreatomagmatic signature; 3) a third possible phase which transitioned to a drier eruption forming the crosscutting MFKB which includes juvenile lapilli.

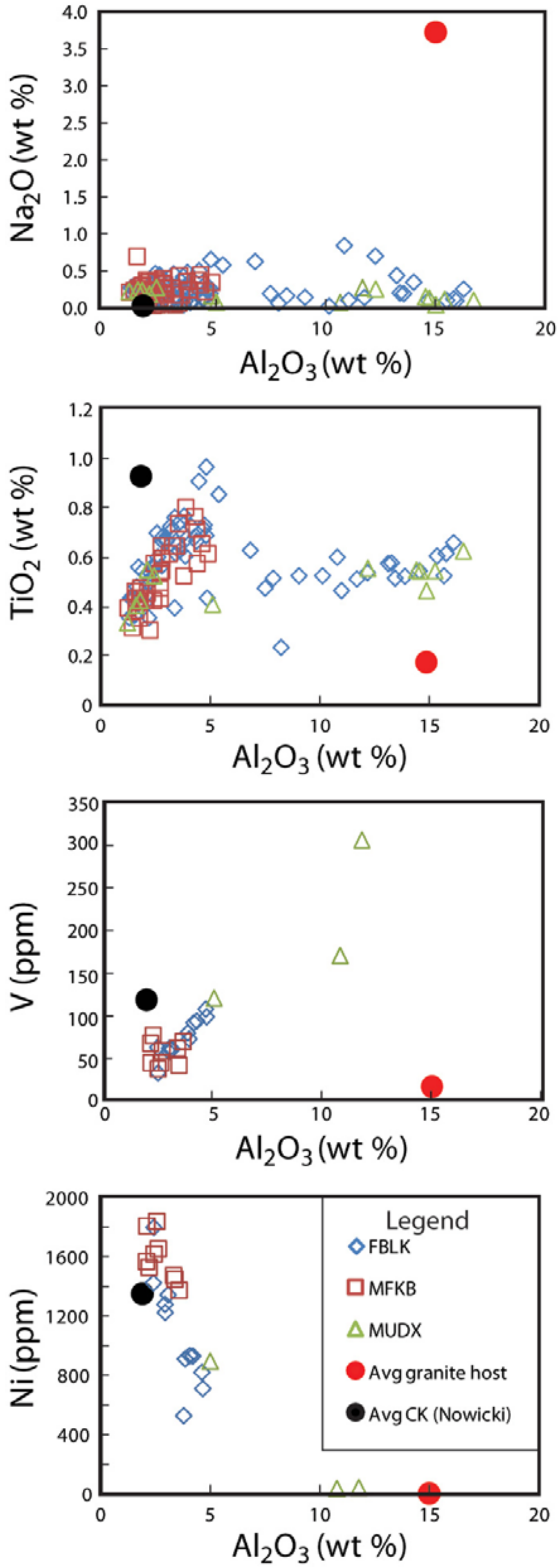

Figure 4. Plots showing the geochemistry of the A418 samples.

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