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Upward Ancillary Kimberlite Pipe Growth in the Venetia Cluster

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Current kimberlite pipe development models strongly advocate a downward growth process as the pipe cuts down onto its feeder dyke by means of volcanic explosions (e.g. Lorenz, 1975; Sparks *et al*., 2006). Evidence is presented from a detailed study of the K08 pipe within the Cambrian Venetia kimberlite cluster, Southern Africa, that some pipes or sub-components of pipes develop upwards. This paper investigates the growth history of the K08 pipe and the mechanics of pipe development based on observations in the pit, drill core and thin sections, from geochemical analyses, particle size distribution analyses, and 3D modeling.

Observations

The K08 pipe is presently exposed over a height of 136 m from surface and consists of > 90% mega-breccia of country rock clasts (gneiss and schist) with < 10% intruding, coherent kimberlite. Mapping shows a sharp contact between a breccia pipe and intact country rock gneisses and schists. The contact typically cuts sub-vertically across the metamorphic fabric, and only very rarely follows the fabric. It is irregular from bench to bench, apparently influenced by pre-existing joints. There is no sign of increased fragmentation on the country rock side of the contact, and breccia clast sizes in the pipe seldom show an increase towards the contacts.

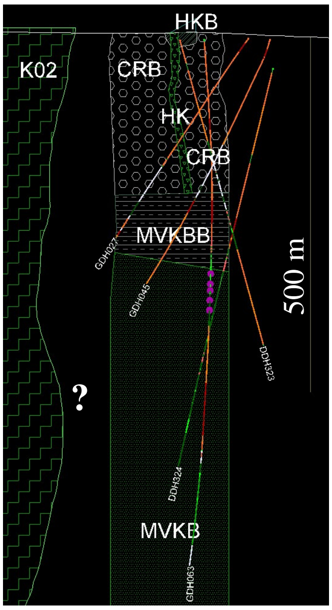

Fig.1: E-W section through the K08 pipe. Facies below CRB are inferred from limited drill holes.

The bulk of the breccia comprises clast-supported, angular, gneiss and schist clasts, ranging in size from microscopic to over 10 m, and is completely devoid of kimberlite. This breccia can be divided into two facies (Fig.2). The first facies (CRB_1) visually appears coarser, and has either a carbonate matrix or no matrix (void with free growing carbonate crystals). The clasts typically, but not exclusively, have a preferred alignment. The alignment is generally orientated sub-horizontally, but local variations can be more extreme, resembling slump structures. The second facies (CRB_2) visually appears finer-grained, with both angular and sub-angular clasts (i.e. increased rounding), and often includes a sandy matrix infill of local origin. CRB_2 appears more poorly cemented than CRB_1. The preferred clast orientation is stronger in CRB_2, typically dipping towards the centre of the pipe between 0 and 20°. Specific discrete, thin (several centimeters) zones and fracture planes can be identified associated with CRB_2 that dip away from the contacts into the breccia at between 10 and 30° (Fig.2). The structures represent shear planes and shear zones that have geometries indicating a normal shear sense.

Fig.2: Photograph of K08 CRB. CRB_1 (bottom left) and CRB_2 (top right) are divided by a partially sheared contact (red highlight).

A third facies is an intrusive breccia, consisting of coherent kimberlite-matrix supported lithic-blocks (HKB). The blocks are angular and occasionally have a preferred alignment, visually appearing to be entrained in the magma with the orientation perpendicular to an upward and outward expanding flow pattern. The HKB was mapped only in the top 30 m from surface, where at least two distinct phases of cross-cutting HKB intrusions were observed, along with a late lithic-free coherent kimberlite phase (HK). A study of 9 thin sections of the various HK lithofacies types suggests that almost all samples classify as HK *sensu stricto*. A few samples show incipient segregationary textures with carbonate in the groundmass. The presence of multiple intrusive kimberlite batches is evident by the variable abundance, size and proportions of olivine macrocrysts and phenocrysts, as well as the occurrence of relatively coarse spinel in the groundmass.

The last mapped intruding phase is a coherent kimberlite dyke up to 10 m wide, that follows a sub-vertical, sinuous path roughly through the centre of the pipe and cross-cuts all previous phases. The dyke generally strikes NNE and has a protruding 4 m high, 51 m long horizontal sill at a depth of 60 m. Carbonate veining is common at the fine grained chilled contact with the enclosing breccia. Within the dyke, there are internal textural variations, largely defined by variation in the size and distribution of crystals throughout the rock and the presence of clear internal structure (i.e. flow banding). Microscopically the rock is described as coherent in texture, with partially to completely altered olivine macrocrysts set within a groundmass of serpentinised olivine phenocrysts, coarse spinel, phlogopite, perovskite, rare serpentinised monticellite and microlitic apatite.

Five drill holes have penetrated the pipe (Fig.1). Below a depth of about 225 m the drill core intersections indicate that the CRB includes increasing quantities of kimberlite. The kimberlite component is described in drill logs sometimes as a coherent HK-like facies, and sometimes as massive volcaniclastic. In thin section two facies are evident. The first facies has a coherent to transitional texture dominated by variably altered olivine macrocrysts and partially altered lithic fragments. Patchy pools of carbonate and serpentine are common. Very localised clastic textures are characterised by domains of carbonate and serpentine that separate crystals that are rimmed with a dirty altered irresolvable brown material that is often necklaced by abundant oxides. The second facies has an inequigranular distribution of crystal and lithic debris that give the rock a distinctly fragmental appearance. Olivine macrocrysts are altered to carbonate and serpentine and vary from anhedral and rounded, to angular and broken. Many of the ash to lapilli sized olivine grains have a thin (mm) coating of dark altered material (serpentine, talc and cpx). Calcite is common in local patches and pools between framework grains. The rock matrix is predominantly serpentine, carbonate and clay. Rare lapilli-sized fragments, exhibiting local but distinctive -mm thick coatings are observed. These coatings are extremely altered and are dominated by serpentine, but small (<0.5 mm) olivine, phlogopite and spinel crystals are recognised, with patches of carbonate. The modal abundance of spinel is significantly higher than throughout the rest of the rock. Despite the intense alteration, these coatings preserve a very different texture to that seen throughout the rest of the rock and is interpreted to be a thin coating of altered coherent kimberlite. Note, these coatings are described as very different to the previously described altered rims seen on the edges of many of the olivine crystals, where no obvious intra-rim crystals are visible. These coated clasts are interpreted as possible juvenile pyroclasts, and the rock is classified as volcaniclastic.

Breccia Formation

Numerous studies have shown that rock fragmentation can be characterized as a fractal process (Turcotte, 1986; Blenkinsop, 1991; Kaminsky and Jaupart, 1998). The fractal dimension (D) might be indicative of the fragmentation process (Jébrak, 1997) as well as the amount of energy that has gone into defining the final size distribution (Blenkinsop, 1991; Kaminsky and Jaupart, 1998). K08 breccia particle size distribution (PSD) was analyzed using drill hole measurements and photographs. Results from the two data sources agreed precisely, showing multi-fractal trends with 2 to 3 fractal ranges (Fig.3). A fractal dimension value of 3 is considered by Turcotte (1986) to be the absolute maximum value that a primary fragmentation process can achieve. The general trend of the PSDs in both the 1D and 2D analyzes approximates a value of 3. The coarser population in CRB_1 has a D only slightly greater than 3, indicating that the breccia is close in character to that formed by primary fragmentation. The coarse clast range in the CRB_2 breccia has greatly increased D values indicating further fragmentation significantly beyond primary fragmentation (Blenkinsop, 1991). D values of *circa* 2.6 are usually only observed in the finer particles sizes below 3-5 cm (down to microscopic scales; Barnett, 2004), and is often interpreted to represent constrained comminution (Biegle *et al.*, 1989; Blenkinsop, 1991), which occurs quickly and easily in fine particles as they are point-loaded by larger particles.

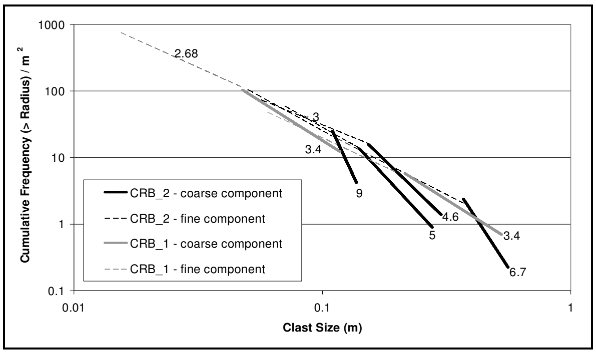

Fig.3: Fractal plot of breccia particle sizes determined from photographs.

Since CRB_2 is associated with increased clast alignment, smaller average clast size and zones of shearing, the secondary fragmentation is considered to have been due to applied shear stresses as parts of the breccia body adjusted to volume changes during different phases of intrusion and pipe formation. The nature of the primary fragmentation (D=3) is now explored. The surface area of the particles is considered to be directly proportional to the energy used to create the surface. The PSD for a mine production blast (*circa* 0.3 kg ANFO explosive/m^3) was compared to the PSD for CRB_1 and CRB_2. The PSD for each data set was converted to a 3D PSD using CSDCorrections 1.37

(Higgins, 2000). The energy for the CRB_1 breccia (similar to D=3) fragmentation is estimated at 72% (0.22 kg ANFO/m^3) that of the blast. The additional energy needed to go from CRB_1 to CRB_2 is 48% that of a blast. The structure and texture of the mega-breccia layering suggests that the pipe growth process was predominantly upwards by progressive collapse (caving) of the hangingwall of the volcanic excavation. However, such a process will form a PSD similar to that of the unbrecciated jointed rock, which is clearly very different. Hydraulic breccias are known to have a low D of *circa* 1 (Jébrak, 1997), so that process is certainly not dominant in K08. The calculated energy for primary fragmentation of the modeled volume of CRB (4.4 million m^3) is 656 Tons of TNT. Explosive fragmentation must have been involved.

Emplacement Model

The primary stage of fragmentation is interpreted to have been completed by upward-moving collapse of the pre-conditioned hangingwall of a subterranean volcanic excavation. The pre-conditioning would have been caused by explosions, either phreatic or phreatomagmatic in nature. This seems the only way to explain the mega-scale layering across the width of the breccia pipe, and the explosive signature in the PSD. The explosions are likely to have been centered on magmatic dykes, or dykes of preceding volatile-fluid phases (Brown *et al.*, 2007). The explosions were inadequate in strength (76% of a production blast) to eject material from the pipe, and the pipe may not have breached surface.

It must be questioned whether the preserved K08 architecture represents early pipe development in general, or a possible late pipe geometry modification process. Previous literature describes sidewall and hangingwall caving processes elsewhere in the Venetia cluster (Kurszlaukis and Barnett, 2003; Barnett, 2004) and other kimberlites world wide. A requirement for emplacement models that include upward pipe growth processes is the availability of space (mass deficit at depth) into which the caving and/or dilating breccia can expand. It is possible that K08 must be connected to K02 at a depth somewhere below 400m (Fig.1), which has a significant impact on current resource estimates and mine plans. Such a model means that K08 is an ancillary sideward development to K02, and would help explain the presence of volcaniclastic kimberlite at depth within the K08 pipe. Alternatively, K08 may be an example of incomplete pipe development. It could be argued that the K08 pipe pre-dated the large K01 and K02 edifices, since the gas and magma supply would preferentially intrude the larger pathways to surface. Either way, the model suggests that upward growth processes should still be considered as viable for kimberlite pipe development, either early during proto-pipe emplacement towards the surface, or as late stage modification of established pipes.

The second stage of brecciation is interpreted to be due to complex adjustments in volume in the pipe causing shearing and re-fragmentation of the breccia. The numerous late intrusions must cause significant internal dynamics. The fractal analysis supports fragmentation models that increase D with increased energy input. As re-fragmentation continues, the signature of primary fragmentation (D=3) is replaced by higher D values as well as a component of constrained comminution (D=2.6) in smaller particles sizes.

Acknowledgements

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References

Barnett, W.P., 2004. Subsidence breccias in kimberlite pipes – an application of fractal analysis. Lithos, 76, 299-316.

Biegel, R.L., Sammis, C.G., Dieterich, J.H., 1989. The frictional properties of a simulated gouge having a fractal particle distribution. Journal of Structural Geology, 11, 827–846.

Blenkinsop, T.G. (1991). Cataclasis and Processes of Particle Size Reduction. Pure Applied Geophysics, 136 (1), 59-86.

Brown, R.J., Kavanagh, J., Sparks, R.S.J., Tait, M. and Field, M., 2007. Mechanically disrupted and chemically weakened zones in segmented dikes systems cause vent localization: Evidence from kimberlite volcanic systems. The Geological Society of America, 35, 9, 815-818.

Jébrak, M., 1997. Hydrothermal breccias in vein-type ore deposits: a review of mechanisms, morphology and size distribution. Ore Geology Reviews, 12, 111 –134.

Kaminsky E. and Jaupart C. 1998. The size distribution of pyroclasts and the fragmentation sequence in explosive volcanic eruptions. Journal of Geophysical Research, 103, B12, 19759-29779.

Kurszlaukis, S. and Barnett, W.P., 2003. Volcanological and Structural Aspects of the Venetia Kimberlite Cluster – a case study of South African kimberlite maar-diatreme volcanoes. South African Journal of Geology, 106 (2): 165-192.

Lorenz, V. (1975). Formation of phreatomagmatic maar-diatreme volcanoes and its relevance to the formation of kimberlite diatremes. In: Ahrens, L.H., Dawson, J.B., Duncan, A.R., Erlank, A.J. (Eds.), *Proceedings of the 1st International Kimberlite Conference*, Cape Town, South Africa, 1973. Physics and Chemistry of the Earth, 9, 17-27.

Michael D. Higgins, 2000. Measurement of Crystal Size Distributions. American Mineralogist, 85, 1105-1116.

Sparks, R.S.J., Baker, L., Brown, R., Field, M., Schumacher, J., Stripp, G. and Walters, A.L., 2006. Dynamic constraints on kimberlite volcanism. Journal of Volcanology and Geothermal Research, 155: 18-48.

Turcotte, D.L., 1986. Fractals and fragmentation. Journal of Geophysical Research, 91, 1921-1926.