Emplacement Temperatures of Pyroclastic and Volcaniclastic Deposits in Kimberlite Pipes in SouthernAfrica

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The estimation of the emplacement temperatures of pyroclastic deposits, using palaeomagnetic techniques pioneered by Aramaki and Arimoto (1957), has been successfully carried out on many deposits worldwide. Several attempts have been made to estimate the emplacement temperatures of kimberlite deposits. The general absence of thermal metamorphic effects on entrained xenoliths and in adjacent country rock led some authors to propose emplacement temperatures of < 500°C for volcaniclastic kimberlite deposits (e.g. Watson, 1967; Mitchell, 1986; Skinner and Marsh, 2004). Sosman (1938) deduced intrusion temperatures of 340°C for North American kimberlites from thermal effects of coal inclusions (see Watson, 1967). Stasiuk et al. (1999) interpreted reflectance values in dispersed organic matter inclusions within Canadian kimberlites to deduce temperatures of 150-200°C for pipe-facies and < 100°C for crater-facies volcaniclastic kimberlites. Palaeomagnetic studies by McFadden (1977) on wall rock samples and accidental inclusions pipes suggested emplacement temperatures of ~300°C. Stability fields of alteration assemblages in kimberlite pyroclastic rocks give minimum temperatures of 300-340°C (Stripp et al., 2006).

Here we present the results of palaeomagnetic measurements of the emplacement temperatures of pyroclastic and volcaniclastic kimberlite deposits within three contrasting kimberlite pipes in southern Africa (Orapa A/K1, Venetia K1 and K2) for which the internal geology is well constrained by recent geological studies. We discuss the implications of the results in the context of the supporting geological evidence for the mode of formation of the kimberlite deposits and for the nature of kimberlite eruptions.

Sampling strategy

Eight tholeiitic Stormberg Formation basalt lithic clasts were sampled from the Orapa north pipe (NPK – pyroclastic kimberlite) and south pipe (SVK - volcaniclastic kimberlite - and basalt talus breccias). Eleven individual specimen cores were demagnetized from the eight sampled clasts. Thirty-five samples were collected from the K1 and K2 pipes, Venetia mine. Thirty-three samples, mainly of amphibolite, were collected from the two main lithofacies in K2 (matrix-supported volcaniclastic kimberlite breccias (mVKBr) massive volcaniclastic kimberlite deposits (MVK). Two samples were collected from MVK deposits in K1.

Results – Orapa

The eight samples are strongly magnetic displaying NRM (natural remanent magnetism) intensities ranging from 0.69 to 26.10 amperes/meter (A/m). The intensities of north pipe (NPK) samples (~ 14.5 to 26.0 A/m) are one or two orders of magnitude greater than samples from the south pipe (~ 0.69 to 6.0 A/m). Following demagnetization to a peak temperature of 590°C, five of the eight samples were demagnetized to less than 5% of the original NRM intensity; the remaining three samples (from the north pipe) retain intensities between 12 and 27%. These samples have not been remagnetized by the heating process which indicates the samples contain ferromagnetic grains with T_bs >590°C (e.g. haematite or titanohaematite grains; T_c of 680°C). Homogeneous thermal demagnetization behaviour is displayed between samples taken from the same clast. During thermal demagnetization, a low-

unblocking temperature (T_{ub}) component was removed in 5 cores by heating to 100 or 140°C. These components possessed no directional grouping and are interpreted as being a low-stability VRM (viscous remnanent magnetism) component acquired during storage of the samples. After removal of these VRM components, all samples displayed well-defined characteristic (chRM) single or two-component magnetizations.

Figure 1 displays T_e (emplacement temperatures) estimates determined from individual lithic clasts, using methods described above. All four NPK clasts provide minimum T_e estimates, interpreted as being emplaced >590°C. Maximum T_e estimates of 140°C are provided by two of the SVK clasts, and the one talus deposit clast. These are interpreted to have been emplaced at ambient temperatures, or <140°C, which is the minimum valid T_e estimate after removal of low-stability VRM components. A T_e estimate of 340-380°C is provided by the one SVK sample displaying a two-component magnetization.
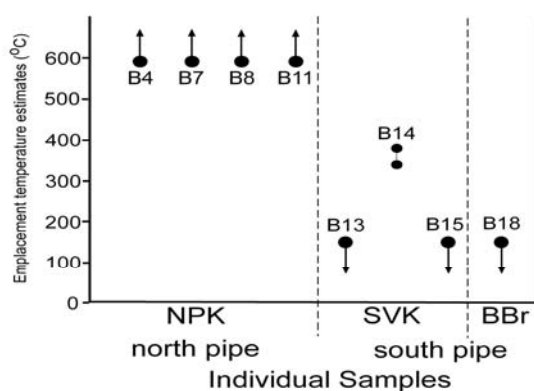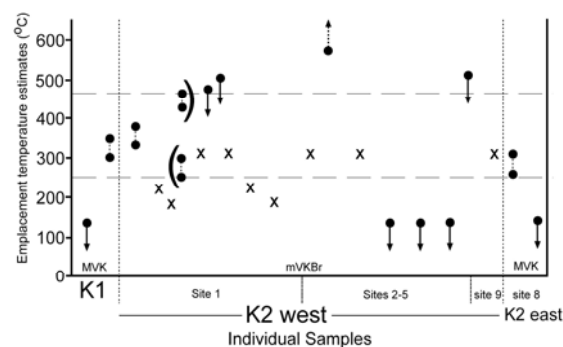

Figure 1. Emplacement temperatures for lithofacies in Orapa A/K1 pipe.

The results from NPK samples (T_e>590°C) implies that NPK is a primary pyroclastic deposit emplaced at significantly elevated temperatures, as proposed by Field at al. (1997) based on field and petrographic evidence. T_e estimates for SVK samples of <140°C and 340-380°C implies that clasts were emplaced in SVK at both ambient and elevated temperatures. This indicates both epiclastic and pyroclastic depositional processes occured in the south pipe. The result from talus deposits of <140°C is

consistent with emplacement by epiclastic processes.

Results – Venetia

Using data from dolerite clasts, upper bounds on T_e for VKBr deposits is placed at 460-500°C (depicted by the upper horizontal dashed line, Figure 2).

Figure 2. Emplacement temperatures for pyroclastic deposits in Venetia K1 and K2 pipes.

These clasts were exclusive to site 1 (Fig. 1B) and are unlikely to be wholly representative of K2 VKBr deposits. Two samples obtained from a single lithic clast in mVKBr deposits at site 1 give conflicting T_e estimates of 260-300°C and 420-460°C (parentheses in Fig. 1). This is more likely to be representative of magnetic inhomogeneity within the clast (i.e. alteration), rather than any indication of a thermal gradient developed within the clast. The evidence of VRM overprinting in some clasts implies T_e estimates below 260°C are unlikely to be valid, which is indicated by the lower dashed horizontal line. Scatter in the T_e estimates is most likely a result of variable amounts of CRM (chemical remanent magnetism) or VRM overprinting which has occurred since emplacement, and to some extent actual variation in the T_e of individual clasts.

Implications

Thermoremanent magnetism studies of lithic inclusions have successfully differentiated the emplacement temperatures of a variety of volcaniclastic lithofacies preserved within the Orapa and Venetia kimberlite pipes (Fig. 3). Obtained T_{dep} values are consistent with the field evidence of the various deposits. T_{dep}

estimates for pyroclastic deposits are consistent with previous estimates of kimberlite emplacement temperatures (≤340°C; see Sosman 1938; Watson 1967; McFadden, 1977; Stasiuk et al., 1999).
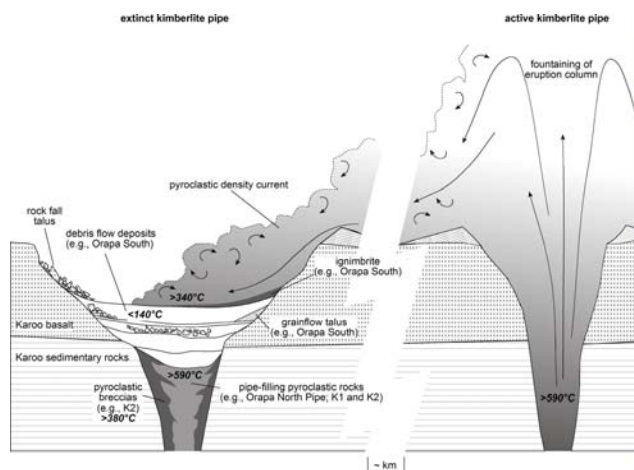

Figure 3. Cartoon illustrating emplacement temperatures for various pyroclastic and epiclastic lithofacies in southern African kimberlite pipes.

The T_{dep} values obtained for pipe-filling pyroclastic deposits (260-300°C - >590°C) are similar to the emplacement temperatures of extrusive pyroclastic rocks erupted from more silicic volcanic systems Pyroclastic deposits can become welded at the upper end of this temperature range and this is particularly common in pyroclastic deposits of low-viscosity magmas (Sumner 1998). Welding textures have recently been recognised in some rocks in Venetia K2 pipe (Brown et al., in press, a, b). Low T_{dep} estimates for clasts in the SVK and talus breccias (<140°C), which show a single-component magnetization, are consistent with emplacement at ambient temperatures by epiclastic processes (rock fall and debris flow).

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