NEAR SURFACE EMPLACEMENT OF KIMBERLITES: CONTRASTING MODELS AND WHY

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The most complete kimberlite emplacement models result from detailed studies of specific localities. Investigations undertaken for economic reasons create extensive 3D exposure and permit thorough studies. The first such model outside Russia was developed for the main diamond mining areas of that time around Kimberley, South Africa (Clement and Reid, 1989 and previous work by Clement and Skinner). These studies showed that kimberlites are unusual, and require kimberlite-specific terminology (Field and Scott Smith, this volume), and emplacement models. The Cretaceous southern African kimberlite pipes were shown to comprise three zones: a complex root zone, a steep sided diatreme zone and an overlying crater zone which together can be up to 2km deep. Each zone is largely filled with texturally specific types of kimberlite (Fig. 2 of Field and Scott Smith, this volume), indicating that each zoned formed by a different process.

The model for these kimberlites shows that the near surface emplacement occurred in a closed system created by many barriers and cap rocks through which the kimberlite has to intrude (e.g. Karoo dolerites, basalts, earlier kimberlites). The kimberlite magma was clearly inhibited during its final ascent to surface resulted in complex and massive subsurface brecciation of the country rock as well as an immense build up of juvenile gases, volumetrically dominated by carbon dioxide. When breakthrough to surface was achieved, sudden and rapid degassing caused fluidization of the sub-surface magma. This in turn excavated the diatreme zone through the pre-brecciated country rock. This process was short lived and the fluidized, degassed magma rapidly condensed to form a very specific textural rock type (tuffisitic kimberlite breccia). This rock type contains in the order of 50% xenoliths derived from the adjacent pipe wall which are set in the products of the remaining condensed kimberlitic fluids. It is important to emphasize that the same process created both the diatreme and its infilling. The underlying root zone and overlying crater zone formed by more normal processes that are part of the same event. This model has been tested and validated by other workers. At Orapa, Botswana the same model can be extended up into the crater (Field et al., 1997). At the Orapa North pipe a single extremely powerful magmatic eruption caused the excavation of both the diatreme and crater. The crater was rapidly infilled with primary pyroclastic products, that are similar to, and derived from, the fluidized kimberlite that formed the diatreme below. It has been shown elsewhere in the world that this model has been repeated in space and time.

In contrast Lorenz (1985 and other papers) proposed a phreatomagmatic “maar-diatreme” model for the southern African kimberlite pipes. Maars are formed by two separate processes : (1) crater excavation and (2) subsequent infilling. The maar craters are excavated into the country rock by phreatomagmatic explosions that relate to an aquifer. The products of this process form mainly crater rim base surge type deposits. Subsequent infilling of the crater is mainly by re-sedimentation of crater rim or wall material, although there may be some infill derived from pyroclastic magmatic eruptions. The latter notably lack country rock xenoliths. Many recent maars are only partially infilled. The same maar-forming process is repeated in space and time. Notably, in many cases there seems to be scant evidence for the presence of steep sided pipes below maars. There is no geological evidence to support the suggestion that maar-like phreatomagmatic processes were important in the formation and infilling of the southern African kimberlite pipes.

Scott-Smith et al. (this volume) have developed a model for the Cretaceous kimberlites in Saskatchewan, Canada, which differs considerably from that of the southern African kimberlite diatreme model. No diatremes or root zones were developed in these pipes. The pipes formed by two separate processes : (1) crater excavation and (2) subsequent infilling. Empirically these saucer shaped craters are thought to have formed by maar-like phreatomagmatic processes relating to a well-known aquifer approximately 200m below the present surface, the point from which the craters flare. It is considered that the lack of barriers and cap rocks in the 600m of Phanerozoic sedimentary cover permitted the kimberlite magmas to reach surface easily. The kimberlite magma, therefore, erupted in an open system. This precluded the sub-surface build up of juvenile volatiles which is requisite for the formation of diatreme and root zones. Subsequent to crater formation, the craters were filled with primary pyroclastic kimberlite and re-sedimentation does not appear to have been an important process. In this respect, the Saskatchewan pipes differs from maars. In Saskatchewan much of the infill was derived from Hawaiian and Strombolian-style eruptions. In a few pipes a different kimberlite-specific eruption mechanism has been proposed. This more explosive style of eruption resulted from the massive degassing of juvenile volatiles close to surface and formed mega-graded beds up to at least 90m thick within the craters. This and other features highlight the fact that kimberlite magmas are very different from more common magma types.

Other examples of the Saskatchewan model may occur in Zaire (Scott Smith et al., this volume) and in Alberta at Mountain Lake (Wood et al., this volume) and Buffalo Hills (Carlson et al., this volume). In this area of Alberta 1-2km of Phanerozoic sediments overlie the basement. No diatreme-facies kimberlite has been identified at these localities but the Cretaceous pipes are infilled with xenolith-poor volcaniclastic kimberlite. It is therefore presumed that these pipes were excavated by maar-like processes. In contrast to Saskatchewan, some of the Alberta pipes appear to be steeper sided and/or deeper (up to 350m). The different shape may reflect the variable nature of the sediments. In Saskatchewan the saucer-like shapes reflect the shallow location of the aquifer as well as the poorly consolidated and fine grain size of the uppermost Cretaceous sediments. In Alberta the uppermost Cretaceous sediments are sandier and so can support steeper crater walls. The fact that these pipes penetrate further than in Saskatchewan implies that a deeper aquifer must have been involved in their formation. These localities together appear to comprise a Canadian Prairies (+/- Zaire) kimberlite emplacement model where thick piles of poorly consolidated sediments containing no barrier-forming igneous rocks offer an easy route to surface for kimberlite magmas.

Recently many new kimberlites have been discovered on the Slave craton in the NWT, Canada. These kimberlites can be grouped in terms of age and geographic distribution. The youngest group (Cretaceous to Tertiary) occur in the Lac de Gras area of the central Slave. Many of these kimberlite pipes appear to be steep sided bodies with shapes superficially similar to the southern African diatremes. Relative to the southern African pipes, those at Lac de Gras appear to be small and infilled mainly with xenolith-poor volcaniclastic kimberlite (primary pyroclastic and resedimented). These Lac de Gras pipes appear to have formed by two process : pipe excavation and pipe infilling. It seems unlikely that such deep pipes (up to +/-600m) represent explosion craters formed within the Archaean basement, irrespective of the process. The similarity in pipe shape to the southern African diatremes makes it tempting to suggest that a similar fluidisation process occurred. However, no comparable diatreme-facies infill (tuffisitic kimberlite breccia) is present. It seems to be significant that the Lac de Gras pipes are at least an order of magnitude smaller than many of those in southern

Africa. This suggests that, if the Lac de Gras pipes formed by the same processes as the southern African diatremes, they resulted from less powerful eruptions. The Archaean basement could impose a difficult route to surface for the kimberlite magma. This would allow sub-surface build up of juvenile volatiles that possibly could form a diatreme. The country rock at the time of emplacement included poorly consolidated clay-rich sediments (probably <100m) directly overlying the Archaean basement. The cover sediments would have allowed an easy breakthrough to surface and may even have contained an aquifer to aid crater formation. This contrasts with the southern African Cretaceous situation where the uppermost country rocks at the time of emplacement were competent basalts lavas. These basalts formed a major final barrier for the kimberlite magmas to penetrate. The lack of such a cap rock at Lac de Gras would have limited the amount of sub-surface volatile build up and would result in the formation of overall smaller diatremes. Some pipes in the Lac de Gras area contain only hypabyssal kimberlite. It is interesting to speculate why these kimberlite magmas did not excavate pipes similar to the volcaniclastic-infilled bodies.

Elsewhere in the Slave the known kimberlites appear are older (~172-538 Ma.) and so pre-date the Cretaceous sediments that formed the cover in the Lac de Gras area. In contrast it appears that in the other areas of the Slave the cover sediments were dominated by Palaeozoic carbonates. Although volcaniclastic and hypabyssal kimberlites are also present, there has also been development of southern African-style diatremes infilled with the diagnostic tuffisitic kimberlite breccias.

Conclusions : Kimberlites are unique carbon dioxide-rich magmas, whose near surface emplacement is controlled by the abundance juvenile volatiles and country rock geology. Two extreme emplacement models have been identified: (1) the southern African model and (2) the Canadian Prairies model. In some near surface environments, such as in southern African, barrier and cap rocks retard the upward movement of the magma. This produces closed magmatic systems from which kimberlite-specific magmatic processes generate pipes with distinctive root, diatreme and crater zones, each filled with different textural variants of kimberlite. In contrast, where the country rocks are easily penetrated by the upward moving magma, such as in the Prairies, the resulting open system precludes the build up of juvenile volatiles. Phreatomagmatic processes dominate to form maar-like craters with no diatreme or root zones. The shape of the crater depends on the nature of the country rocks and the depth of the aquifer. The infilling can be either primary pyroclastic deposits with their own kimberlite-specific characteristics and/or re-sedimented volcaniclastics. Obviously intermediate types of pipes must result from combinations of these two end member processes and the newly discovered pipes of the Lac de Gras area of the Slave may be such an example.

References

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