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Misconceptions in Kimberlite Pipe Emplacement Models

Volker Lorenz[1] and Stephan Kurszlaukis[2]

[1] Institut für Geologie, Universität Würzburg, Pleicherwall 1, D-97070 Würzburg, Germany;
[2] De Beers Canada Inc, Exploration Division, Suite 300, 65 Overlea Blvd, Toronto, Canada, M4H 1P1

The widely accepted predominantly magmatic kimberlite pipe emplacement model and its various sub-models contrast in a number of aspects with the phreatomagmatic model of basic, ultrabasic and ultramafic maar-diatreme volcanoes widely recognized in physical volcanology. Whereas in case of the non-kimberlitic maar-diatreme volcanoes the whole volcano can be studied by integrating a Quaternary maar crater and its tephra ring deposits with Quaternary and older subterranean diatremes and root zones, a big disadvantage for the analysis of kimberlite pipes is, however, that since the early Tertiary no kimberlite pipe erupted and, thus, Quaternary kimberlite maar tephra ring deposits cannot be studied. Unfortunately, all early Tertiary and earlier kimberlite maar tephra ring deposits required to deduce the evolution of the emplacement history of the kimberlite maar-diatreme volcano have been eroded. Therefore, only a specific portion of the kimberlite maar-diatreme volcano can be studied, i.e. the subterranean pipe, that consists of the diatreme and the root zone, and their respective fill. At least at the top end of a number of kimberlite pipes, as, e.g., at Orapa, Mwadui and Yubileinaya, posteruptive maar crater sediments are preserved which point to the hydrogeological environment effecting the deposition of finely bedded lacustrine sediments inside the kimberlite maar crater lake and sediments derived from the reworking of tephra ring deposits. It is, however, from the subterranean part (diatreme and root zone) of the kimberlite maar-diatreme volcano that volcanological process-oriented analyses in the field and in diamondiferous kimberlite mines have been elucidated so far. As a result many researchers proposed in the past and still propose today that copious amounts of volatile phases exsolved from the kimberlite magma are the only or the dominant cause for the pipes to have been cored into the uppermost 2-2.5 km of the crust either from the bottom upwards or the top downwards. It must be realized that until the intensive onset of physical volcanology in the 1960s this magmatic model was applied to most non-kimberlite maars and diatremes as well.

In contrast to kimberlite pipes, the non-kimberlite Quaternary maar-diatreme volcanoes have the big advantage that their tephra ring with its many rather thin beds is in part or even completely preserved. This allows deductive analysis of the eruptive style of the maar-diatreme volcanoes from the beginning of the eruptions to the end. And finally, historic maar-diatreme eruptions as, e.g., the Ukinrek Maars in Alaska which erupted in 1977, allow the study of the actual eruptions and the total length of the eruptive period. Since the 1960s the majority of maar-diatreme volcanoes and the respective historically formed volcanoes, like the Ukinrek Maars, were assumed to be phreatomagmatic in origin. Because of their age and erosion, both possibilities - the study of the tephra ring deposits and that of the historic eruptions - are lacking for kimberlite pipes. We therefore suggest that also researchers of kimberlite pipes should not neglect any longer the study of non-kimberlite phreatomagmatic maar-diatreme volcanoes. A comparative study of kimberlite pipes and non-kimberlite maar-diatreme volcanoes is required in order to understand the principles of the formation of the whole kimberlite maar-diatreme volcano. Such a comparison is not only of academic relevance but also of relevance in respect to the evaluation of the infill of diamondiferous kimberlite and lamproite pipes and the relationship of the pipes with their feeder dykes and tectonic structures in the neighboring country rocks.

The contrasting models resulted from different volcanological approaches and have led to a series of misconceptions.

1. “Kimberlite pipe excavation is exclusively magmatic or predominantly magmatic in origin. If all kimberlite pipes would be phreatomagmatic in origin this would imply that kimberlite magma reached the Earth's surface only where there happened to be groundwater.” This statement neglects that kimberlite pipes and kimberlite dykes occur in the same volcanic fields and both occur in the same level of erosion, i.e. in the uppermost 2-3 km below the Earth's surface. It is regularly neglected that the kimberlite dykes should have formed scoria cones and lava flows at the syneruptive surface as do basic to ultramafic dykes in volcanic fields elsewhere – as, e.g., in the West Eifel and in the French Massif Central. Thus we suggest that a large number of kimberlite volcanoes were scoria cones with associated lava flows whereas only where sufficient groundwater happened to occur dyke magma interacted in thermohydraulic explosions which resulted in coring the kimberlite pipes from near-surface levels downward. The occurrence of lacustrine post-eruptive sediments in kimberlite maar craters clearly indicates a high regional groundwater level. Experiments investigating the potential of a remelted magmatic Hanaus kimberlite interacting explosively with water were highly successful. Similar experiments showing that sufficient volatiles can be released from kimberlite melt at near-surface level and core a full-sized diatreme have not been performed yet and are also not numerically modeled.

2. “In kimberlite pipes groundwater may have participated in the eruptions, as groundwater exists only in the uppermost few hundred meters of the crust.” This statement accepts participation of groundwater in the kimberlite eruptions but nowhere has it been outlined in detail how the groundwater is envisaged to have participated in its physical details: was the consequence of its participation an explosion or just furthering the eruptions via its evaporation? In addition this statement neglects the depth of diatremes underneath accepted phreatomagmatic maar craters. These maar craters and their underlying diatremes have the same size range both in respect to diameter and depth as kimberlite maar craters (with posteruptive sediments) and kimberlite pipes. The depth of the basic to ultramafic phreatomagmatic diatremes is established by gravimetric and magnetic studies and studies on the origin of country rock xenoliths in the tephra ring ejecta beds or in the diatreme tephra. The phreatomagmatic growth model of maar-diatreme volcanoes requires that only limited amounts of groundwater need to be available in hydraulically active fracture zones. If too much water has access to the rising magma tuff-rings or tuff-cone volcanoes form. The latter case occurred in the kimberlitic Fort à la Corne Volcanic Field where kimberlite magma erupted frequently in the shallow sea. If there would be not sufficient groundwater in hydraulically active fracture zones beneath the valley system in the otherwise groundwater-poor West Eifel, down to a depth of about two km, no large maars with large and deep diatremes underneath could have formed.

3. “Kimberlite scoria cones and lava flows do not exist.” In contrast to this statement the Igwisi Hills represent accepted Quaternary kimberlite volcanoes, 3 cones and one lava flow. Unfortunately they have not been studied applying modern physical volcanology.

4. “Thin-bedded tephra in uppermost kimberlite pipe levels and interbedded thick-bedded beds are all representing reworked material deposited in post-eruptive times in a deep open crater or they represent tephra deposited in a deep open steeply-walled crater in a waning phase after an initial Plinian eruption.” These statements neglect that phreatomagmatic volcanoes in their tephra rings typically show such thin-bedded tephra beds the characteristics of which are accretionary lapilli, vesiculated tuffs, plastering of ash against obstacles, impact sags, base surge deposits, and mud flows. These features point to moist or wet deposits in the maar tephra ring. Not all of these features must exist at any single maar volcano or at any volcanic field containing maar-diatreme volcanoes. In a number of kimberlite pipes some of these features occur in upper diatreme levels and thus have to be considered indicators of phreatomagmatic eruptions. The growth model for kimberlite pipes also explains the occurrence of thick-bedded debris flows by repeated collapse of tephra ring segments. If such deep steep-walled craters reaching almost to the depth of the whole diatreme would really have existed they should rather have been filled by a lot of debris from the rock-mechanically unstable diatreme walls.

5. "Kimberlite pipes were formed by an initial Plinian phase and only in the waning phase did the deep crater which is almost equal in depth to the depth of the diatreme get filled with tephra." This statement is based on the assumption that the relatively finely bedded tephra in the kimberlite pipe does not explain the size and shape of the impressive whole pipe. Thus a first high energy eruptive phase has been postulated which fragments and excavates the pipe in its entire depth. In contrast the phreatomagmatic maar-diatreme volcanoes of basic to ultramafic magma chemistry show in the tephra ring deposits that the typical maar tephra are thin-bedded from the beginning onwards right to the end of the eruptions. The phreatomagmatic growth model for maar-diatreme volcanoes – supported by the formation of the two 1977 Ukinrek Maars – is clearly sufficient for the formation of both the maar crater and the large underlying diatreme. Maar-diatreme volcanoes grow as do all other volcanoes and they grow in small increments which equates with the small thickness (on average 1 m) of their feeder dykes. It is furthermore difficult to explain, how a Plinian eruption is achieved from a dyke without a shallow underlying magma reservoir. The active length of a feeder dyke underneath a root zone is – even in large pipes - 100 to 200 m. With a dyke thickness of one to two meters at eruption, the magma ascend rate would have to exceed the speed of sound to reach Plinian production rates, which is not realistic. In addition, no such fallout deposits from Plinian eruptions, which should be documented somewhere in the geological record, are present.

6. "Kimberlite pipes are different from maar-diatreme volcanoes related to magmas of other chemistry." Kimberlite pipes are different to other pipes in that they contain upper mantle xenoliths derived from a deep lithospheric root and they may contain diamonds. Otherwise, however, they are very similar to non-kimberlitic maar-diatreme volcanoes in a number of important aspects like the high content of highly comminuted country rock clasts which require high fragmentation energy and that their juvenile clasts contain no vesicles or are poor in tiny vesicles. In addition kimberlite maar craters and their respective underlying pipes are of the same size range of their crater and pipe. The latter aspects are the ones relevant for formulating a model for the origin of the pipes and these aspects are the same as the ones typical for phreatomagmatic maar-diatreme volcanoes.

7. "The association of kimberlite fragmental rocks with hypabyssal coherent kimberlite is typical for magmatically emplaced kimberlite pipes." This statement neglects that many non-kimberlite maar-diatreme volcanoes because of lack of further groundwater influx were intruded in a second non-phreatomagmatic phase by magma forming dykes, sills or plugs in the diatreme and scoria cones or lava lakes in the maar crater. Recent logging of Tuzo kimberlite pipe also shows that coherent kimberlite intrudes earlier fragmented kimberlite in a large scale, non-fragmental way.

We suggest that kimberlite magma like any other magma can erupt phreatomagmatically when interacting with groundwater and forms maar-diatreme volcanoes. Without interaction with groundwater kimberlite magma rises in dykes and can erupt magmatically forming scoria cones and lava flows as, e.g., in the Quaternary Igwisi Hills in Tanzania.