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Floating reefs and their relevance for the emplacement of maar-diatreme volcanoes

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Volcanoes grow in size as do subvolcanic intrusions (e.g., dykes, sills, laccoliths), as long as magma is fed into these volcanoes and intrusions. This also holds true for maar-diatreme volcanoes that likewise grow in their crater size and the size of their subsurface diatreme.

"Floating reefs" (Clement 1982), also called "mega blocks" (e.g., Delpit et al. 2014), occur inside kimberlite and non-kimberlite maar-diatreme volcanoes. They have been observed since the early diamond mining in the Kimberley area in South Africa (Wagner 1914). Floating reefs consist in their majority of large accidental blocks derived from the host substrate, whereas some other floating reefs consist of blocks of solidified cognate material filling a diatreme. Floating reefs occur mostly along or near the diatreme wall where they subsided inside the diatremes from higher, nowadays eroded or still preserved stratigraphic levels from the host substrate surrounding the diatreme and even from the maar crater collar (Delpit et al. 2024). Despite their subsidence, they may be intact or more or less fragmented. They can be found in all structural levels of a maar-diatreme volcano.

Examples of floating reefs occur in many kimberlite pipes of South Africa, especially in the Kimberley and surrounding areas where they had been investigated by Clement (1982). Judging from the floating reefs in the Kimberley area, much of the full Karoo sediment sequence and volcanics were still present when the Cretaceous maar-diatremes erupted and were emplaced (Hanson et al. 2009).

Examples of accidental and cognate floating reefs in Canadian kimberlite diatremes occur in the Attawapiskat kimberlite field (in Delta, Tango Extension, and Victor) in northern Ontario and also in Tuzo, a kimberlite body from the Gahcho Kué cluster in the Northwest Territories. In some of these kimberlites, it is evident that large floating reefs even diverted tephra jets piercing through the diatreme, controlling the facies distribution of volcaniclastic units and thus the diamond distribution in the diatreme.

Floating reefs also occur in many ultramafic diatremes in the Missouri River Breaks volcanic field, Montana/USA (Hearn 1968). The diatremes were investigated in further detail by Delpit et al. (2004) and a phreatomagmatic emplacement was deduced. At the present erosion level, about 1000m below the syn-eruptive surface, bedded tephra and cross-cutting tephra jet conduits occur together with floating reefs of non-indurated host sediments along or near the diatreme walls. The presence of floating reefs/mega blocks points to growth processes that are similar in both kimberlite and non-kimberlite diatremes.

Cloos (1941) studied the maar-diatremes of the Swabian Alb volcanic field in Germany quite intensively. In the following decades, his publication had been cited in many publications on kimberlite diatremes. The emplacement of the ca. 360 Miocene maar-diatreme volcanoes in the Swabian Alb area had been the result of phreatomagmatic eruptions of olivine melilitite magma (Lorenz 1978; Lorenz and Lange 2022). In the large Jusi diatreme, which is cut by erosion along the escarpment of the present-day northern margin of the Swabian Alb, a floating reef at its northern diatreme margin has an arcuate shape, up to

50m wide that follows the curved, concave diatreme wall for 300 m at an elevation of 560 to 590m a.s.l. This megablock consists of bedded Upper Jurassic limestone and dips with 35° to 45° toward the diatreme center. From the original top level of the bedded limestone on the Swabian Alb, located today at about 700m a.s.l., the megablock subsided for about 110 to 140m and simultaneously tilted about 40°.

In the late Hercynian/Variscan Permocarboniferous Saar-Nahe-Graben in SW Germany, there occur about 20 diatremes where the best-known ones are exposed at a depth of up to 600 m below the syn-eruptive surface and contain juvenile clasts and some intrusives of basaltic andesite and dacite composition (Lorenz 1971a, b). The upper parts of many large diatremes consist of bedded tephra (Francis 1970) that subsided at the time of the eruptive activity as a consequence of the mass transfer of erupting tephra from the root zone onto the crater floor and the tephra ring as well as to distal areas. In many diatremes eroded to the level of their upper bedded tephra fill, the marginal bedded tuffs show a steep, up to almost vertical dip of the bedded tephra. This is due to the decrease in diameter of the cone-shaped diatreme towards its root zone and the higher degree of subsidence in the central area of a diatreme compared to its margins. Therefore, while bedded tephra in the central part of a diatreme has typically subsided further, it often shows much lower dip angles. During the eruptions of the diatremes in the Saar-Nahe-Graben, the host substrate had not been indurated in the uppermost ca. 2000m. Nevertheless, megablocks of non-indurated sediments and volcanic rocks (lavas and sills) subsided within the diatremes. High-temperature diagenesis and low-temperature metamorphism affected only later the sediments with its organic matter, forming even black coal seams, and volcanic rocks (Teichmüller et al. 1983; Lorenz 2008).

In our view, all diatremes grow toward depth, but, due to a more or less constant pipe wall angle (Hawthorne 1975) they also grow laterally in diameter (Lorenz and Kurszlaukis 2007; Lorenz et al. 2017). This lateral growth process “erodes“ the pipe wall and, therefore, produces floating reefs (Kurszlaukis and Barnett 2003; Barnett 2006a, b; Barnett and Lorig 2007). Some floating reefs are the product of the collapse of host substrate segments of the maar crater wall onto the crater floor and their subsequent subsidence into the diatreme. However, the majority of accidental floating reefs originate from the side wall of the upper and lower diatreme above the deepening root zone (Barnett 2006a). The lower part of large diatremes consists in several cases - as, e.g., in South Africa – of unbedded tuffs, which also contain accidental floating reefs close to the deep diatreme walls. Some of these megablocks have subsided for several hundred to more than a thousand meters from higher stratigraphic levels (Karoo). The significant subsidence of floating reefs towards the lower diatreme levels was only possible if the bedded tephra from the upper diatreme levels was still not lithified and also subsided more or less jointly with the floating reefs, but lost their bedding inside the deep diatreme levels. This loss of bedding can be attributed to shock waves of the thermohydraulic explosions in the underlying root zone and the tephra jet conduits penetrating from the root zone upwards.

Another interesting aspect is that cognate bedded tuff blocks have been reported from deep levels of southern African kimberlite mines (Clement 1982). While these tuff blocks testify to lithification phases and their subsequent re-brecciation in the emplacement history of a large kimberlite diatreme, they can also only subside if their hosting kimberlite tephra is not consolidated yet. Lithification of kimberlite tephra occurs due to serpentinization of the matrix of the volcaniclastic deposit at 500-550°C (Mevel 2003; Stripp et al. 2006). Therefore, the subsidence of both accidental and cognate floating reefs and the emplacement of the tephra in deep diatreme levels must have happened before intensive serpentinization solidified the pyroclastic deposit.

It is important to recognize these cognate and accidental floating reefs since they give important clues on the growth process of diatremes and can also have a controlling effect on the facies architecture and thus diamond distribution in a mine.

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