Catoca kimberlite pipe: Diatreme/crater transition and dynamics of the crater sedimentation

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The kimberlite pipes with craters filled with sedimentary rocks are rarely preserved. The best studied and currently mined pipes are Orapa (Gernon et al. 2009) and Mwadui (Stiefenhofer and Farrow 2004). Gentle dip angles of rock stratifications are most typical there, while some steeper angles are considered to be controlled by an on-slope angle of repose (Gernon et al. 2009) or related to syn-eruption subsidence and faulting (Brown et al. 2008). Angola hosts many pipes of this type. For example, among 70 kimberlite bodies discovered within the concession of 350 km^2 in an area with the Catoca pipe in its center, 50% contain craters with volcanosedimentery infill. Owing to many post-emplacement deformations, the Catoca and some other pipes of the area can be studied to clarify the causes of possible syn-sedimentation subsidence within the crater.

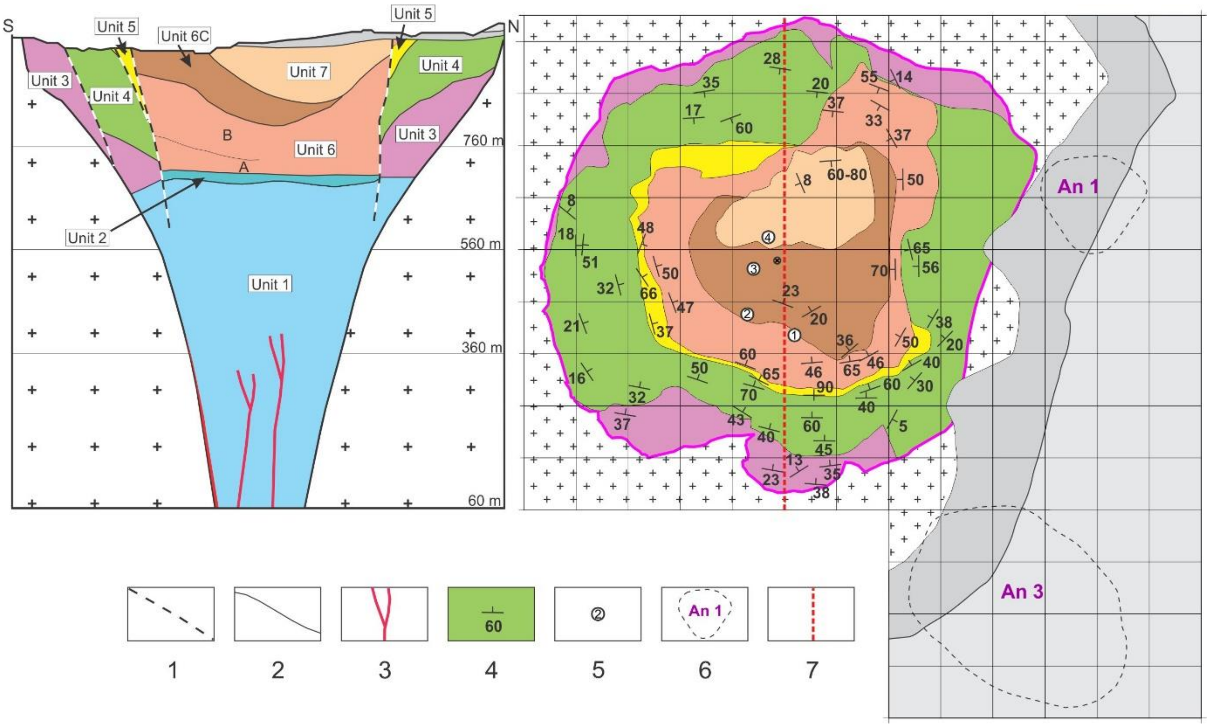

Figure 1: Schematic cross section (2002) and plan (Dec. 2009) of the Catoca kimberlite pipe (the vertical and horizontal scales are similar). See unit description in text. Overlying sediments are shown in grey. Projection of the pipe axis is marked by a crossed circle.
1 – Fault systems, 2 – conformable geological boundaries, 3 – kimberlite dykes, 4 – stratification strike and dip to horizon, 5 – location of boreholes 1 to 4 (see Fig. 2 for lithological columns), 6 – satellite kimberlite pipes, 7 – cross section line.

The Catoca kimberlite pipe is a symmetrical flaring upward body of about 63.6 ha in area on the pipe surface (970 masl = metres above sea level) (Fig. 1). The open pit reached now 820 masl and exploration boreholes – 60 masl. The contact between crater and diatreme zones is sharp and nearly horizontal (705±10 masl). The diatreme zone is composed of massive-textured pyroclastic kimberlite with coherent kimberlite as minor dikes and local diatreme infill (*Unit 1*). The crater zone is more complicated and consists of earlier relict ring of resedimented volcaniclastic kimberlite and banded pyroclastic kimberlite (*Units 3 and 4*) and later central depression of epiclastic kimberlite (*Units 6 and 7*). The ring is separated from the central depression by a circular zone of extensive steeply dipping dislocations with boudinage and numerous bedding-plane and stepped dip-slip faults.

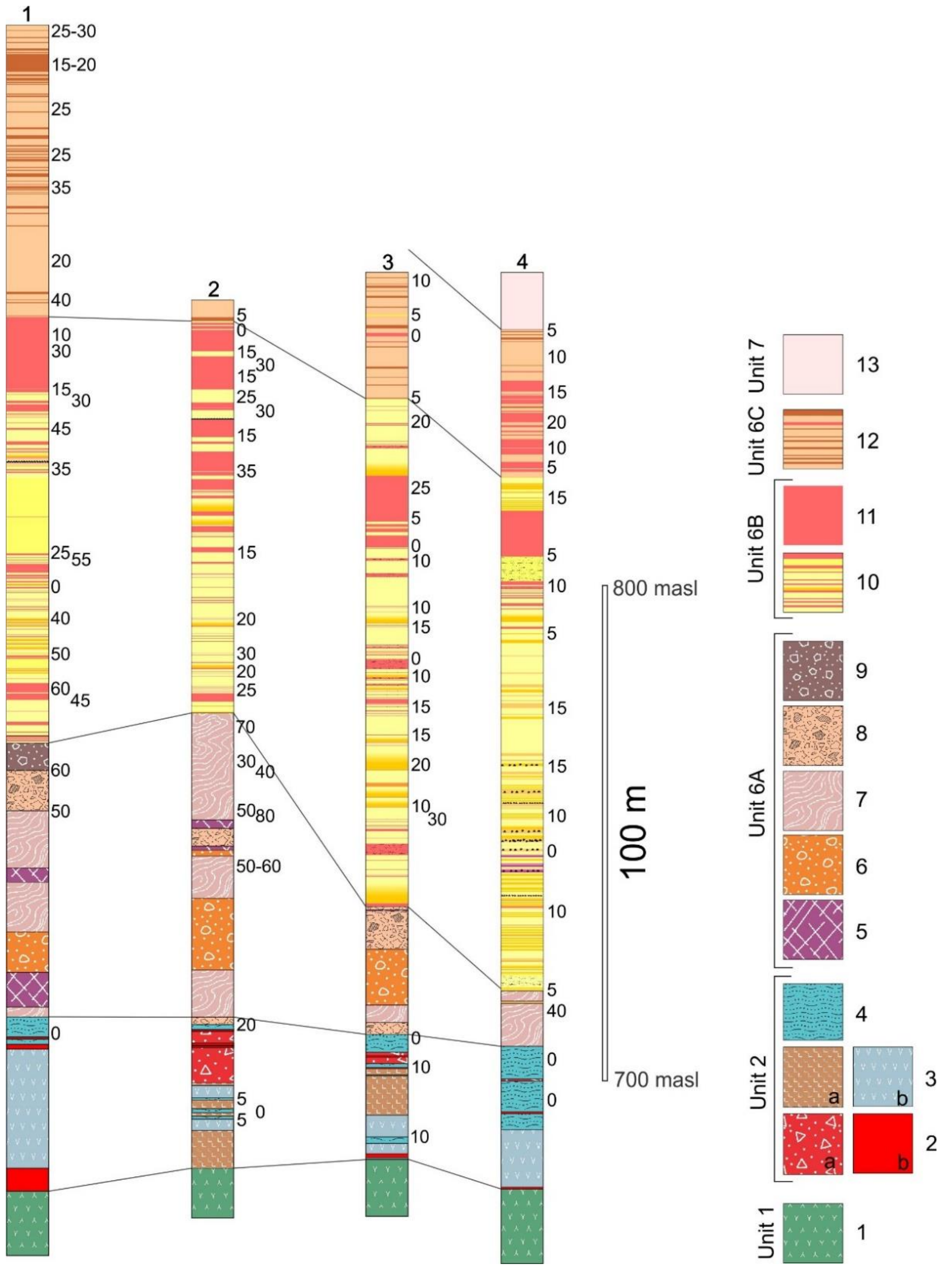

Figure 2: Correlation of borehole profiles (see Fig. 1 for borehole location). Figures at the right hand side of the columns indicate dip angles of stratification to horizon.

1 – Pyroclastic kimberlite, 2a – gneiss breccia with volcaniclastic matrix, 2b – gneiss blocks, 3 – psammitic (a) and psephytic (b) volcaniclastic kimberlite, 4 – pelitic to psammitic volcaniclastic kimberlite, 5 – strongly altered and deformed kimberlite, 6 – complex mixture (conglomerate) of pebble of various kimberlitic rocks (tuffaceous sand- to mudstone to altered pyroclastic kimberlite) and similarly variable matrix, 7 – sand- to mudstone with complicated wrinkled texture and multiple creep microdeformations, 8 – contorted and brecciated sandstone–tuffaceous sandstone–silt- to mudstone locally with kimberlite inclusions, 9 – strongly deformed kimberlite breccia with gneiss clasts, 10 – sandstone and tuffaceous sandstone (yellow and dark yellow, respectively) with bedsets of normally graded 1–2-cm silt-to-mudstone laminae (rose), 11 – thick bedsets of normally graded 1–2-cm silt-to-mudstone laminae, 12 – sandstone with beds of altered resedimented kimberlite (dark brown) and mudstone (rose), 13 – sandstone poorly cemented.

The diatreme to crater transition displays abrupt changes in lithology and rock attitude. The upper diatreme *Unit 2* is 4 to 44 m thick. It consists of frequent intercalation of quartz-free kimberlitic tuffs with variable particle sizes (granule, sand, silt to mud; normally graded beds are characteristic) – 80%, as well as breccias (30–60% xenoliths) and gneiss blocks – totally 20% by thickness (Fig. 2). Analysis of thickness and lithology of Unit 2 based on 23 boreholes showed no distinct centroclinal regularities. The finer grained rock attitude is very gentle to horizontal. We interpret the Unit 2 as a product of waning pyroclastic eruptions with variable intensity intermittently transporting very fine to coarser grains to the surface. Vertical fluid escape channels (probable ways of fines transportation to the surface) were encountered in the upper zone of the underlying pyroclastic kimberlite. Random debris flows provided gneiss clasts and blocks, however, their proportion in the Unit 2 does not exceed the average gneiss content in various rocks of the pipe (<15–20 vol %).

In contrast, volcanosedimentary sequence of the central depression begins with *Unit 6A* of complex structure and composition (Fig. 2). Its thickness is larger in the outer (particularly southern) part of the depression (30–100 m) and significantly decreases (2–15 m) towards the pipe center. This unit probably corresponds to the stage of most intense and rapid downwarping in the central depression with avalanche, slumping, and vast mud–sand flows, with extra-crater sand material generally transported from the south. The Unit 6A passes upward into *Unit 6B* with multiple intercalation of 0.3–1-m-thick beds of tuffaceous sandstone to sandstone and sets of several rhythmic laminae of silt- to mudstone. A 9–15-m-thick mudstone-rich layer occurs in the upper part of the unit. The rocks normally show abundant sedimentary structures (normal grading, parallel and cross-bedding, symmetrical ripple marks, mud cracks, load cast, current marks) indicating their fluvial and shallow lacustrine origin. These rocks deposited when the subsidence became slower. The *Unit 6C*, the uppermost unit of the volcanosedimentary sequence, comprises intercalation of sandstone with tuffaceous gravelstone enriched in strongly altered coarse pseudomorphs after olivine. It may have formed by reworking of the Unit 4 rocks locally exposed at the surface at that time. The *Unit 7* sandstone is devoid of kimberlitic components. It fills the uppermost part of the crater depression and is 105 m thick in its center. Significant deformations in this unit resulting in steep angles and several angular discordances indicate rather active subsidence within the crater even at this late stage of the pipe evolution. All other younger sediments are considered to be overlying and correlated with the *Calonda and Kalahari* deposits.

The Catoca pipe is unique in the abundance and intensity of post-emplacement deformations. The rocks of all crater-filling units (3 to 7) dipping now at high angles show evidence of their primary horizontal deposition. For example, the banded pyroclastic kimberlite of Unit 4 now dipping at about 40°–60° gradually and conformably passes upward into a sequence containing sand- to mudstone layers with equally steep dip angles. Figure 1 demonstrates broad centroclinal dipping at angles particularly high near the circular fault zone. This may indicate significant subsidence of the depression base during sedimentation. However, the formation of the 240-m-deep depression entirely by the gradual sinking from the pipe surface is now hardly explicable. Possibility and causes of significant compaction of pyroclastic material in the diatreme, which is necessary for such a process, should be a subject of comprehensive consideration. We could suggest a specific physical state of the diatreme infill – an olivine-rich low-density aqueous silicate suspension capable of significant compaction. Future studies may prompt the solution to this problem.

References

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