Speleogenesis of the Mount Elgon 'Elephant Caves', Kenya

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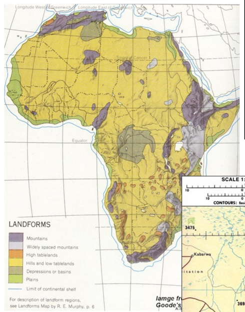
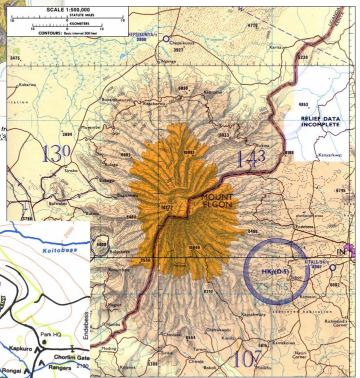


Introduction

Mount Elgon, Africa's fifth highest mountain, is a 4321m high extinct stratovolcano encompassing ~ 4000 km^2 straddling the Kenya-Uganda border. The lower flanks of the mountain are penetrated by a series of large caves of unusual geomorphology and spectacular aspect. These caves are up to 160 m long, 80 m wide, and 20 m high.

The caves of eastern (Kenyan) Mount Elgon have been internationally recognized since they were first described by Joseph Thompson in the late Nineteenth Century (Thompson, 1885), and were well known to local people for centuries before that. Thompson was unable to decide if the caves were of natural or human origin, and it was left to Hobley (1918) to develop a theory of natural (littoral) origin involving a postulated ancient lake. Oswald (1918) quickly dismissed Hobley's theory, preferring instead an origin by percolation solution.

Oswald's theory was taken up by Ollier and Harrop (1958), who provided additional observations supportive of a percolation-solution origin, and in 1961 a phreatic half-tube was reported (Wright,1961). Nevertheless, the matter has never been settled. Sutcliffe (1973) describes the evidence for mining by the El Kony people in some of the caves, but also notes at least one cave that channels an active stream. Beginning in the early 1980's, Redmond (1982; Redmond and Shoshani, 1987) pioneered a program of study focusing on the use of the Mount Elgon caves by elephants, concluding that at least Kitum cave was largely formed by elephants excavating the walls for their salt content (Redmond, 1992). A geochemical study provided additional useful data (Bowell et al. 1996), but left the issue of the quantitative contribution of elephant geophagy unresolved.



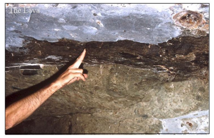
A. Geology and Hydrology

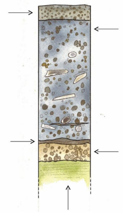
The main rock type is grey, soda-rich pyroclastic agglomerate. This is the unit exposed in most of the chamber walls and roofs. Minor unit below this is yellow-grey agglomerate, separated by lava unit, underlain by green clay.

- The caves are surprisingly dry inside, even during the wet season. Percolation is limited to the ~1-2 m green clay tuff, and to the ~0-30 cm lava layer; no drip points were observed that were not in association with the lava layer. In the dry season most of the undercuts marking chamber edges remain muddy; in the rainy season many parts are inundated with standing water.
- Although caves are almost invariably associated with *surface* water streams (they develop behind waterfalls under small surface stream valleys), no water flow was found in the caves, even after heavy rain. No evidence of resurgence water could be found in the surface valleys. Some caves have standing pools of clear water. All have isolated areas of muddy floor where the roof drips.
- No evidence was found of phreatic or vadose activity, although round tree-trunk moulds superficially resemble phreatic tubes, while elephant-worn pathways may resemble vadose channels.

Typical geological sequence

CAPROCK: well-indurated pyroclastic agglomerate; forms the topmost unit of cliff.

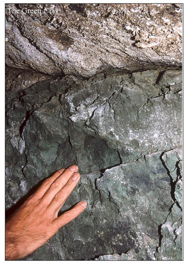




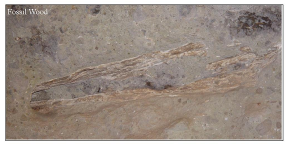
GREY AGGLOMERATE: pyroclastic tuff breccia; the principal unit, exposed in the main chambers.

BROWN LAVA
Distinctive dark coloured, brown-black lava; numerous spherical, silica-filled amygdules (up to 2 mm in diameter); up to 20% vesicular; bed ~10-20 cm thick, often discontinuous, or complex, of several separate layers, sometimes filling shallow swales. Exposed in walls and roofs. This unit carries water, is usually wet, and is the source of most of the cave drips.

YELLOW AGGLOMERATE: tuff breccia, phenocrysts 1.5-4 mm in length, inclusions of subrounded, glassy, vitrophyric basaltic lava; poorly indurated in places, sometimes friable and ashy; variable bed thickness ~2-4 m thick; exposed in lower walls. This unit is the focus of much of the geophagy.

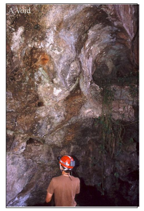


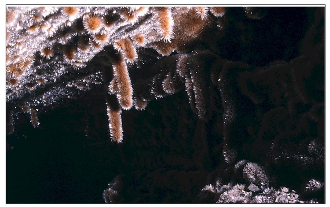
GREEN CLAY: tuff formed by settling of a pyroclastic density current; incorporated bits of country rock; non-indurated; at least 2 m thick, (lower contact never observed); top surface often undulating; focus of some geophagy eg, by smaller animals; clay normally very wet, dries and cracks on exposure to cave air, mechanically weak, cracks under weight of overburden.

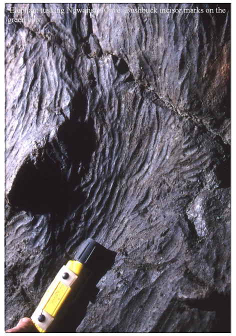


FEATURES OF THE AGGLOMERATES:

- Pyroclastic tuff breccias, containing sub-rounded clasts of mafic alkalic lava or hypabyssal basalt; vesicular in zones, irregular, subrounded, and lined with zeolites.
- Bedding surfaces often undulating; beds typically ~1 m thick, often lenticular 1-1.5 m thick, 20-30 m wide. In several places slickensiding between units is apparent, giving flat to gently curved smoothed/polished separation surfaces, now apparent as a particularly flat, smooth cave roof.
- Many fossil trees trunks, some root systems, some twigs, and occasional mammal bones; may be oriented parallel to each other at bedding planes, but more often at random orientations. The wood is often replaced by zeolites (eg, natrolite) or calcite but the wood form is retained.
- Many tree trunk moulds where decayed trees left voids; the moulds are often lined with sharp needles of zeolite crystals, sometimes acquiring stalactitic forms. The open moulds are strongly reminiscent of phreatic tubes until closer examination reveals the zeolite lining and the absence of continuation (they are usually only a few metres long and end in a complex of root remnants).
- Secondary minerals form readily: evaporation from the agglomerate ground mass causes efflorescence of sodium sulphate salts, mirabalite. These grow rapidly and, if not eaten by animals, fall to the ground.







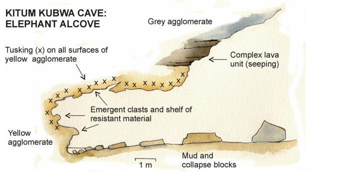
B. Geophagy

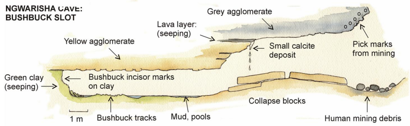
Three types: a) Elephants, b) Bushbucks (and possibly other small animals), c) Human Mining (indirect geophagy, for cattle)

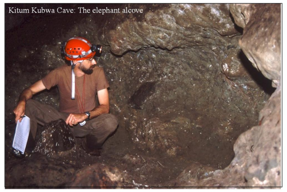
Elephants show distinct preference for yellow agglomerate, and for ground mass of agglomerate; rock units with few, separated, large clasts and thus lots of matrix are well tusked. Lava clasts are gouged around and out, leaving emergent clast surface morphology and debris on floor. Tusked notches are up to ~4.5 m high (where lithology permits), generally ~ 3 m deep, floor not particularly flat; wall and ceiling of notch show emergent clasts surrounded by tusk marks. Several examples exist where access to tusking sites has been blocked by large-scale collapse; new collapse blocks provide access to higher parts of walls; thus locus of tusking thus moves in tandem with collapse. Elephant (and buffalo) trails are well marked inside caves, lined with soft layer of degraded dung, eroded out into channel-like form by centuries of feet.

Bushbuck mine the clay unit rather than the agglomerate. The deeply incised, very muddy, slot is only ~1.5 m high and too small for elephants.

- There is a long history of human mining for salts to supplement cattle feed, recorded on the cave walls by round pick-axe marks and complex rounded alcoves, which are ~1.5 m high (but can reach 2.5 m); often quite deep into rock face, eg, ~6 m. These old mines can be recognised by the flat floors and unique mining debris of rounded clasts from the agglomerate, cleaned of all ground mass.





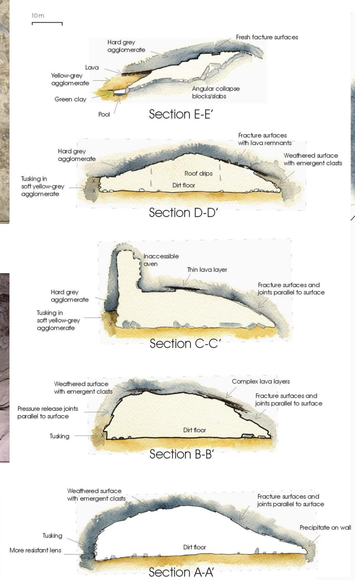


C. Collapse

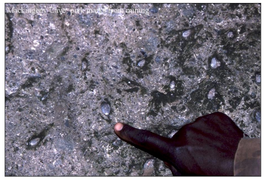
Collapse is obvious, recent and ongoing. The large caves have abundant fresh surfaces on ceilings, and large blocks on floor, some of which have scarcely broken in their fall and can be matched to the roof from which they fell.

- Failure is along sedimentary structures such as bedding planes, contacts (eg, of yellow agglomerate and clay, and of grey agglomerate and lava).
- Some may be caused by pressure release jointing

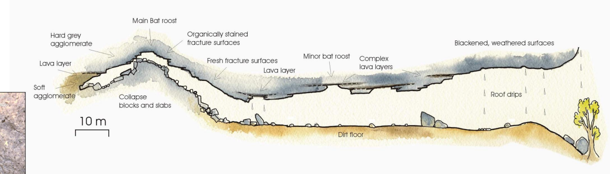
Mackingeny Cave cross sections

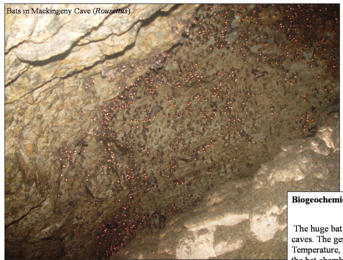


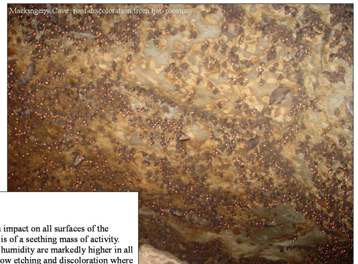
Mackingeny Cave plan



Mackingeny Cave: extended long section

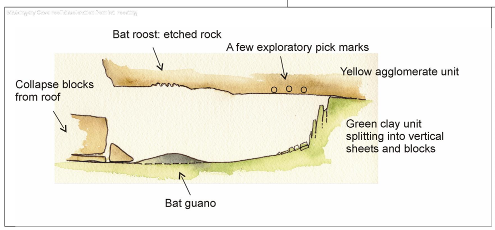






Biogeochemical activity

The huge bat colonies have an impact on all surfaces of the caves. The general impression is of a seething mass of activity. Temperature, CO_2 levels, and humidity are markedly higher in all the bat chambers. The roofs show etching and discoloration where bats roost. The floors of the bat chambers are completely obscured with wet, black, organic-rich guano.



Corrosion, Efflorescence, Flaking, Pressure release

These processes may be minor compared to collapse and geophagy, but they are ubiquitous. Every surface that has not recently fractured shows some evidence of chemical alteration, some type of flaking. Efflorescence appears to be somewhat more common close to cave entrances where evaporation may be significant. Chemical weathering (or biochemical) is dominant in the regions of high humidity (perhaps related to condensation processes). This corrosion is likely to result from a complex of dissolution, replacement, oxidation, salt weathering, etc.

Typically the clasts are not affected while the ground mass becomes decayed. The ground mass may then fall away leaving a surface morphology of emergent clasts. In turn these may fall out leaving a circular cavity.

A cycle develops of fresh fracture, weathering, renewed fracture. Fracture surfaces are usually planar in form, pale grey in colour, the clasts sheared off. They are modified to become differentially etched, dark in colour, with emergent clasts.

Larger scale flaking appears to be caused by pressure release. Joints develop parallel to the cave wall and the resultant slab tilts inward, eventually breaking off to leave a fresh surface.

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F. Proposed Speleogenesis:

- The association with surface streams explains the locus of cave initiation. The cavities begin by groundwater sapping behind the waterfall, usually of the highly incompetent clay. This is followed by collapse of overlying agglomerate layers.
- Collapse of the agglomerate layers exposes the attractive sodium-calcium-rich salts and stimulates geophagous enlargment of the underhang.
- Caves develop laterally by groundwater sapping of clay layer, and geophagy: edges of chambers are always undercut alcoves.
- Caves develop vertically by collapse: dominant passage shape for large caves is wide collapse dome. Collapse produces much of the wall and roof surface morphologies of fresh fracture planes. Failure occurs at "bedding" planes and partings
- The smaller caves are dominated by complex alveolar animal and human-mined alcoves with minor roof collapse features.
- The volume of breakdown material under the collapse domes does not account for the size of breakdown. Removal of material is both by geophagy and by transport on feet and skin.
- The ongoing removal of material allows continued collapse, while lateral extension continues as the clay unit fails.

Complex weathering (chemical, biological, physical) modifies all surfaces.

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