Fossiliferous Plio-Pleistocene Cascade Tufas of Kaokoland, Namibia

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Abstract: Cascade tufas are common in Kaokoland, especially in the region north of Oruvandje, and there are impressive examples at Otjitamei and Ojtikondavirongo, yet they have not previously been reported in the literature. The Damaraland tufas further south at Ongongo, near Warmquelle, were described recently, and proved to be of interest on account of their fossil content (plants, gastropods, and a possible frog skeleton). The Kaokoland tufas are more numerous than those in Damaraland and are also highly fossiliferous, containing not only abundant plants and gastropods, but also vertebrates (fish, snakes, lizards, birds, mammals). The mammals are important because they indicate that some of the breccia infilling cavities in the tufas are probably of Late Pliocene and Early Pleistocene age, the first time that the age of Namibian tufas has been reasonably well determined. The geomorphological relationships of the tufa lobes reveal that they span a considerable period of time, some of the older eroded lobes probably being of Late Miocene age, overlain by Pliocene and Pleistocene tufas. Some of the breccias contain large mammal bones and teeth associated with primitive stone tools. The aims of this paper are to document the impressive tufa lobes in Kaokoland, to put on record the discovery of fossil invertebrates and vertebrates within them and to discuss the significance of the fossils for biochronology and palaeoecology.

Key Words: Tufa Lobes; Breccia; Plants; Gastropods; Mammals; Plio-Pleistocene; Namibia; Kaokoland.

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Introduction

Tufa deposits have long been known to occur in the vicinity of Sesfontein and Warmquelle in Damaraland, Namibia, although not a great deal has been published about them (Korn & Martin, 1937, 1955; Mocke, 2014). In April, 2013, MP was alerted to the presence of « peculiar » rocks near Oruvandje further north in Kaokoland, by Dr E. Freyer, Windhoek. A preliminary survey was carried out by MP and HM in November, 2013, which resulted in the identification of an abundance of cascade tufa deposits east and northwest of Oruvandje. All the deposits examined proved to be fossiliferous, notably containing plant remains and land snails, but at Okongwe, east of Okozonduno, vertebrate-bearing sandy limestone was found infilling a cavity in the tufa. Extraction of the fossils from 2 kg of breccia resulted in a crop of several dozen rodent teeth, as well as a few bat teeth, frog bones, snake vertebrae and bird bones. The rodents indicate a Late Pliocene age for the breccia, but it is clear from the field relations that tufa deposition took place over a considerable period of time, with many carbonate lobes being formed at various altitudes and at various times within each valley. Cavities within the waterfall tufas often contain speleothems as well as silty, sandy and pebbly breccia infillings of diverse ages. This find was sufficiently interesting to prompt a further survey.

This article reports the results obtained so far, but it is stressed that the quantity of tufa deposits is so vast that it will take many years of research to study them all in detail.

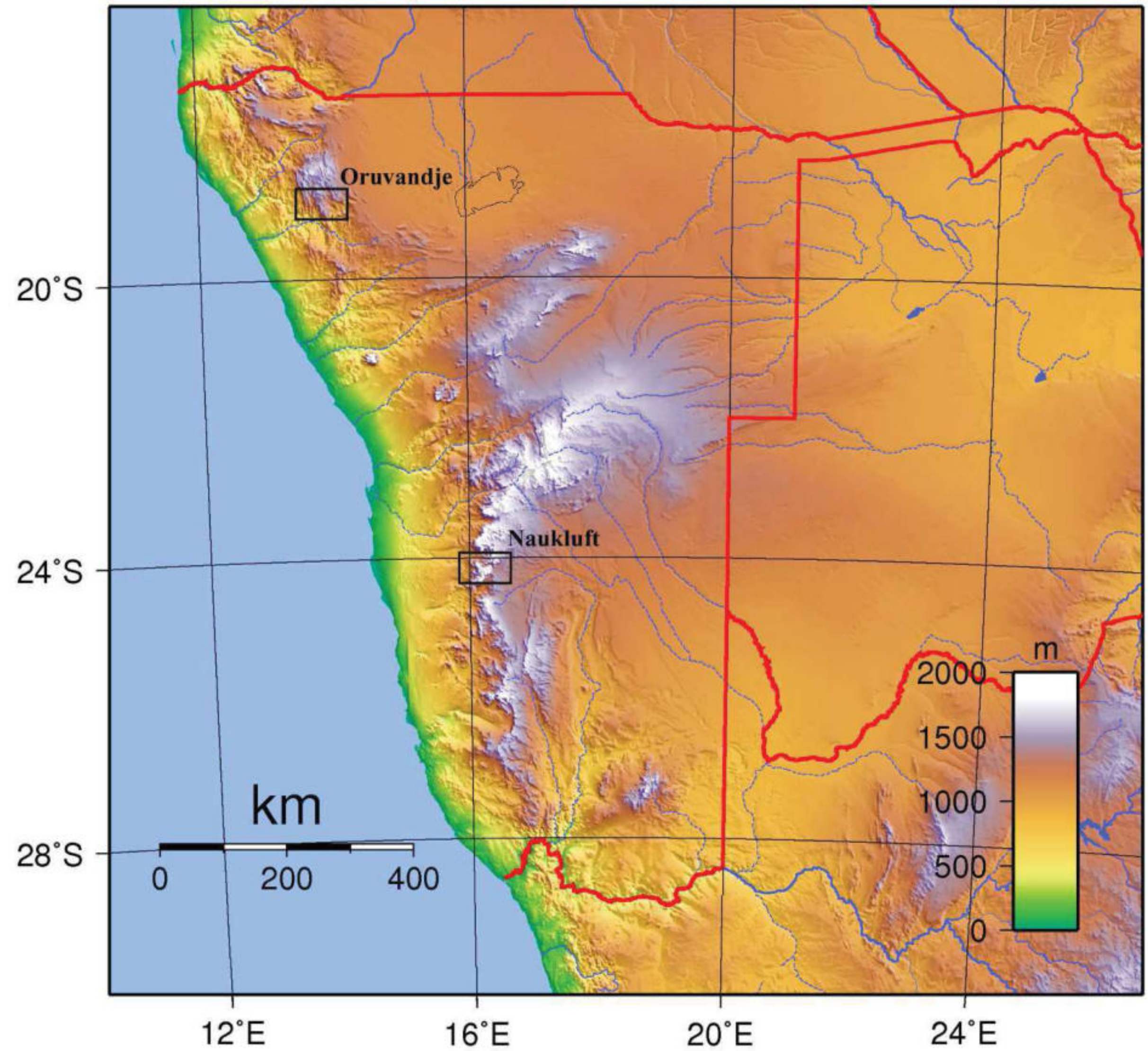

Figure 1. Relief map of Namibia showing the area of Kaokoland Tufa deposits (black rectangle at Oruvandje on the southern flanks of the Joubert Mountains) west of Etosha Pan (dotted ovoid outline) and in the Naukluft Mountains. Note the positions of the tufa deposits at high altitudes along the edge of the «Great Escarpment» which separates the deeply incised coastal strip, from the flatter interior of the continent.

Material and Methods

Prior to field survey, identification of tufa deposits in the Oruvandje area was carried out using Google Earth. The main tufa deposits are easily spotted using satellite imagery because of the clearly unconformable relationship that they have with the underlying, heavily folded Precambrian strata. By this means, the cliff-forming carbonate lobes at Omatapati, Okongwe, Okapika, Orutjene and Okovanatje were located at the mouths of streams flowing generally southwards from the Omatapati-Otjozongombe Carbonate Massif. Visits to Omatapati, Okongwe and Okapiku in 2013 confirmed their tufa nature. Further searches using Google Earth resulted in the identification of additional deposits at Otjitamei and Otjikondavirongo as well as near Ongongo, north of Warmquelle, all confirmed as tufa lobes by ground control.

Field surveys comprised clambering over the tufa lobes searching for micromammalian remains and gastropods. By this means several mammal-bearing breccia occurrences were discovered at Okongwe, Omatapati and

Otjitamei. Gastropods and plants remains are present at all the deposits surveyed. At Omatapati, some of the breccias are rich in large mammal remains associated with stone tools of various sorts.

Each fossil occurrence found was localised using GPS set to WGS 84. Sample blocks for palaeontological analysis were kept separate from each other in order to avoid mixing faunas.

Breccia was dissolved in formic acid at 7% concentration, buffered by calcium triphosphate. After extraction, the insoluble residues were examined under a binocular microsope, and fossils found were consolidated using a dilute solution of glyptol dissolved in acetone.

Images of fossils were captured using a digital camera with the lense positioned over the eyepieces of the microscope. Images were enhanced using Photoshop Elements 03.

Geological and Geomorphological Settings of the Cascade Tufas of Kaokoland

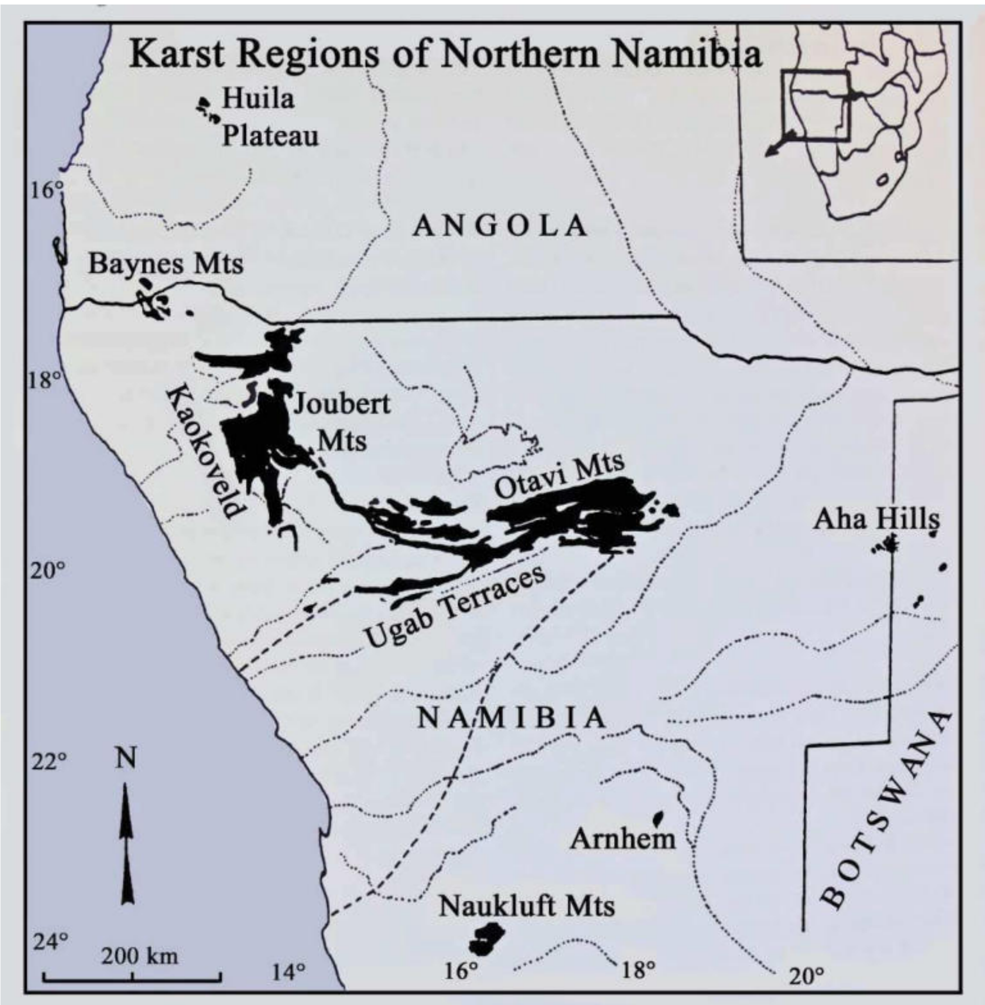

Figure 2. Distribution of the Otavi Dolomites and other Proterozoic carbonates (black areas) in Namibia and Angola. The southern flanks of the Joubert Mountains and the Naukluft Mountains were the sites of extensive tufa deposition during the Late Neogene and Quaternary.

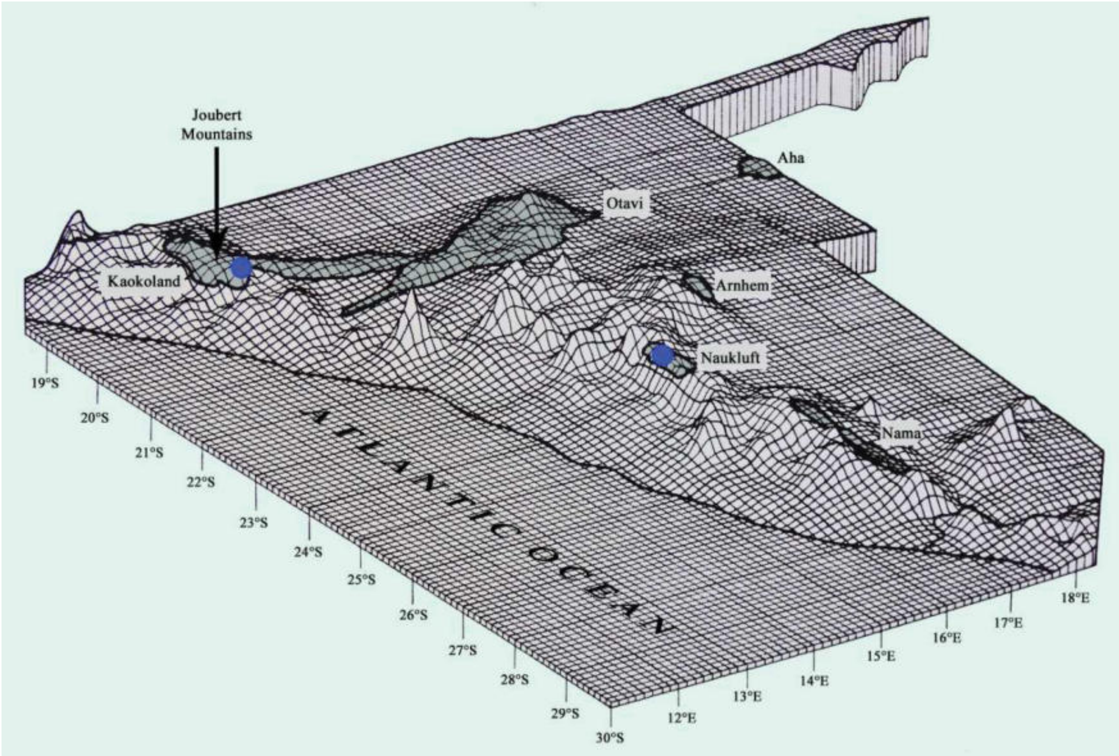

Figure 3. Oblique relief map of Namibia showing the distribution of dolomites (light blue) and extensive tufa deposits (dark blue). The tufa deposits formed preferentially at high altitudes along the edges of the Great Escarpment indicating the essential roles that climate and bedrock substrate played in their genesis.

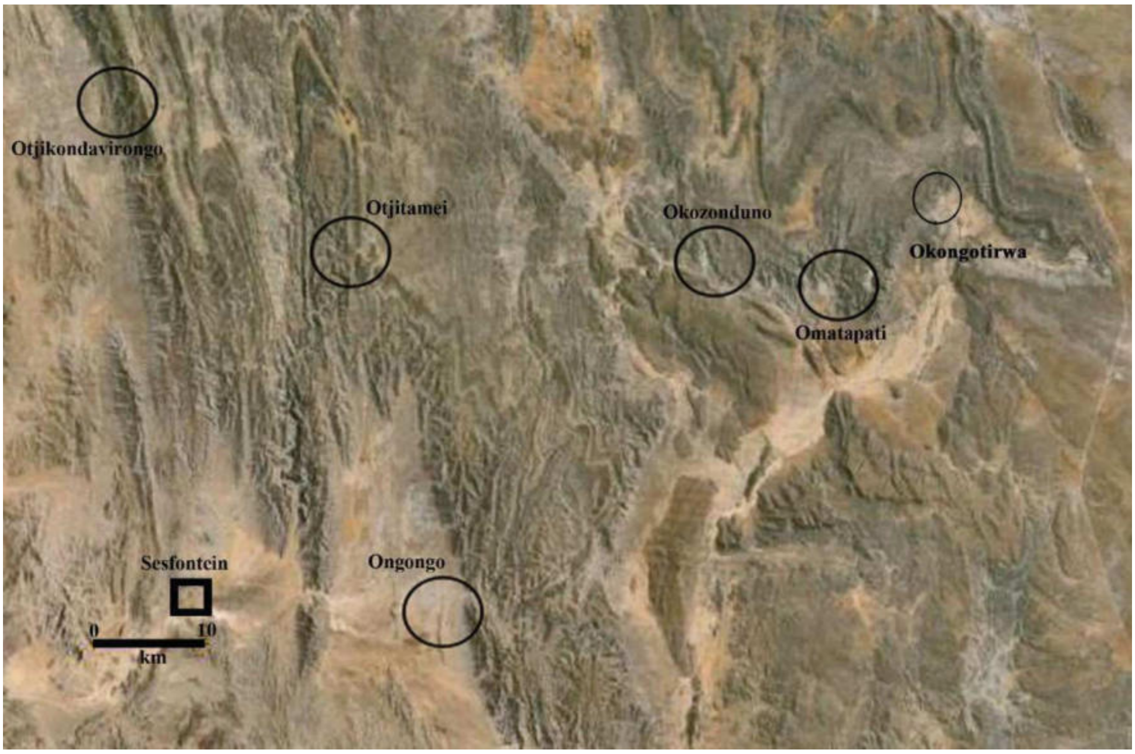

Figure 4. The main areas in Kaokoland, north and east of Sesfontein, at which cascade tufas have been mapped (Map modified from Google Earth).

The cascade tufas of Kaokoland are spatially associated with Precambrian dolomites and limestones of the Otavi Group. They generally occur at the mouths of streams that flow from the upland dolomitic areas to low-lying country beneath. Several of the occurrences show three or more tufa masses at different altitudes in the same valley, and most of them show that, at each level, two or more lobes of carbonate were built up as the lime-rich waters were diverted from one lobe to start building up another one nearby.

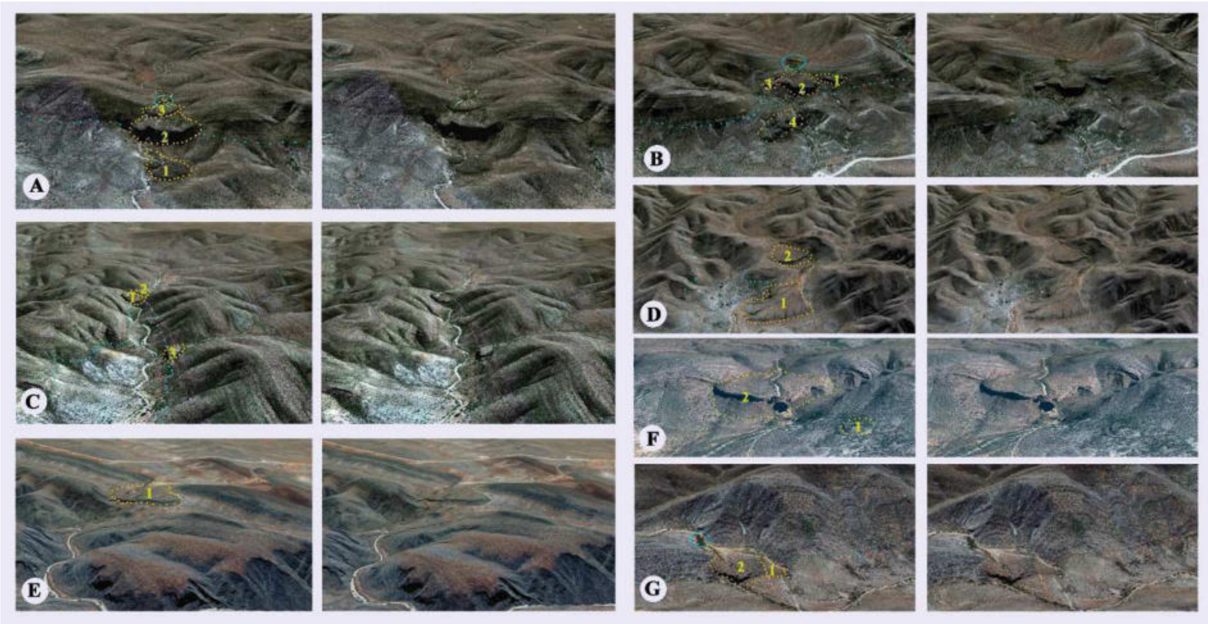

Figure 5. Stereo oblique views of cascade tufa lobes in Kaokoland showing the characteristic geomorphology that they produce. A) Okapiku (3 lobes), B) Okongwe (4 lobes), C) Orutjene (2 lobes) and Okovanatje (1 lobe), D) Omatapati (2 lobes of very different ages), E) Otjimatei (1 huge lobe), F) Okongotirwa (2 lobes), and G) Otjikondavirongo (2 lobes of different ages). The blue dots follow the contact between carbonate rocks above and relatively impervious sericitic rock below. The blue ovals encircle resurgences upstream from the tufa lobes. The dimensions, co-ordinates and altitudes of the lobes are provided in Table 1 (images modified from Google Earth).

A common theme of the Kaokoland tufa lobes is that they occur near the exposed contact between impervious rocks beneath (sericitic, fine-grained rocks at Omatapati, Okongwe and Okapika, for example, comprising the Swakop Schist) which are overlain by folded, well-bedded carbonate rocks (Otavi Dolomite) (van der Merwe, 1983). A further common theme is that a short distance upstream from several of the occurrences, there appears to be an ancient resurgence (sometimes still active) where lime-charged waters emerged to the surface. It is thus likely that the ancient water table at the time of lobe growth, was considerably higher than it is today, and that phreatic water was the main agent which dissolved the Proterozoic carbonate, transported it in solution, and then brought it to the ancient land surface where much of it was precipitated as a byproduct of aquatic plant photosynthesis (mainly mosses) and as a result of exposure to warm air. Under the present-day water table regime, the lobes are undergoing erosion, or only very slight growth compared to the intensity of activity that occurred when the water table was high. On the basis of the observation that there are two or three generations of extinct lobes at some of the sites (Okongwe, Okapiku, Omatapati) it is deduced that there occurred alternating phases of active lobe construction on the one hand and of lobe destruction, erosion or absence of growth, on the other. From this it is concluded that the ancient water table fluctuated in height depending on local to regional climatic change. The position of the tufa system at high altitudes along the edges of the «Great Escarpment» was probably crucial from the palaeoclimatic point of view, with alternating phases of lobe growth or lobe destruction being largely controlled by changes in rainfall and/or temperature.

Table 1. Surface dimensions of cascade tufa lobes in Kaokoland, Damaraland and the Naukluft Mountains, Namibia (+ means that the lobe is partly covered by a later lobe or has been eroded) (Thicknesses are not provided but most lobes are 15 – 30 metres thick along the cliff exposures, sometimes well over 50 metres, thinning upstream and laterally. Latitude, Longitude and Altitude are from Google Earth).

Local name	Lobe N°	Latitude S	Longitude E	Altitude (m)	Width across (m)	Length (m)
Okapiku	1	18°53'30.8''	14°03'18.6''	1218	220	140
----------	2	18°53'21.6''	14°03'23.6''	1317	320	250
----------	3	18°53'17.0''	14°03'25.5''	1359	490	370
Okongwe	1	18°53'43.0''	14°04'32.1''	1350	200	50
-----------	2	18°53'40.5''	14°04'23.6''	1338	320	180
-----------	3	18°53'35.9''	14°04'17.1''	1321	120	80
-----------	4	18°53'51.6''	14°04'16.1''	1221	330	160
Orutjene	1	18°51'38.6''	14°02'27.6''	1346	230	170+
----------	2	18°51'34.2''	14°02'29.1''	1363	190	180
Okovanatje	1	18°52'15.5''	14°02'43.5''	1319	220	130
Omatapati	1	18°54'01.8''	14°08'50.2''	1137	700	670
-------------	2	18°53'35.3''	14°08'53.7''	1220	400	340
Otjitamei	1	18°51'53.9''	13°44'56.9''	1306	810	600
Okongotirwa	1	18°49'31.1''	14°14'48.8''	1190	110	60
----------------	2	18°49'27.5''	14°14'31.9''	1220	460	300
Otjikondavirongo	1	18°44'43.8''	13°33'10.5''	1141	130+	190+
---------------------	2	18°44'37.1''	13°33'08.0''	1165	310	370
Ongongo SW	1	19°09'14.0''	13°49'04.1''	772	230	150
Ongongo SE	1	19°09'15.4''	13°49'22.9''	797	350	120
Bleskranz	1	24°08'01.5''	16°14'00.0''	1443	300	300

Under the current water table conditions, there is only very minor active tufa deposition at some sites (Okovanatje, Okapiku, Otjikondavirongo) which is related more to surface waters (following the rains) locally redistributing carbonates derived from the lobes or upstream Neogene carbonate-rich valley infillings, than to recharge from subterranean waters flowing through Proterozoic country rock. A result of this superficial activity is the development of epikarst features on the surface of the lobes (rillenkarren, clints, grikes) (Pickford & Senut, 2010).

The tufa masses that resulted from the build-up of carbonate lobes are not homogeneous, but are full of cavities of various dimensions. Occasionally, masses of tufa (bryophyte curtains, for example) broke off from the lobe fronts under their own weight and would accumulate at the base of the lobe, adding to the complexity of the depositional succession. Vadose water seeping underground through the lobes resulted in their thorough cementation by calcite and the deposition of speleothems in cavities. By this means huge volumes of densely cemented tufa were formed.

Cavities in the tufa acted like caves, and frequently show classic speleothem deposition of stalagmites, stalactites, flowstone and cave pearls in gour pools. If the cavities were open to the surface, then they provided roosting places for bats and owls, and if accessible were (and still are) used as lairs by carnivores, baboons, klipspringers, dassies and other animals (land gastropods, agama lizards, snakes).

The carbonate lobes were vegetated, as shown by the quantities of leaves, stems and root systems that they preserve. Most of the tufas show that mosses were the dominant plants associated with their growth, producing phytoherms (cushions, curtains) with layered structures, each layer of which has a cellular fabric (Pedley *et al.* 2003). Other plants associated with the tufas are sedges, reeds and trees of various sorts, including Figs (*Ficus sycomo-*

rus) and Mopane (*Colophospermum mopane*) (Mocke, 2014).

The tufa lobes tended to block the streams in which they were growing, and upstream from the resulting «dams» or «barrages» there are masses of calcified conglomerates, sands and silts forming lobe-top terraces and valley infillings. This gives rise to a characteristic geomorphological signature, in which the tufa lobe front is a cliff facing downstream, behind which is a flat or gently sloping, roughly triangular terrace-like area, broad at the downstream end and narrowing upstream.

The presence of cobbles and pebbles in the lobe front, often caught up in tufa, attests to the fact that from time to time particularly energetic surface water flow occurred, which transported cobbles and boulders over the lobes and into the downstream sectors of the systems where they were often calcified, on occasion forming impressive deposits of cemented colluvial and fluvial gravels. There is evidence of phases of active cut and fill upstream and downstream from the cascade tufa lobes as well as within the lobes themselves.

The tufa lobes are always accompanied upstream and downstream by calcified fluvial deposits in the valley bottoms, sometimes extending right across the valleys, sometimes eroded to form terrace-like cliffs through which the present day streams flow for a few days after rain. Fans often formed at the ends of valleys where the streams debouch onto plains and these are generally calcified into cohesive aprons, sometimes incised by subsequent stream activity. Further downstream, paludal tufas have been deposited, for example, near the Camel Camp at Sesfontein. At Otjomatemba, on the terrace upstream from the Otjitamei Tufa Lobe there is an extensive cover of paludal tufa half a metre thick, underlain by poorly consolidated silt. At both sites the paludal tufas are porous and rich in plant remains, and are intercalated in soft marls and silts. In general though, the paludal tufas close to the cascade lobes were intensively calcified and are thus densely cemented.

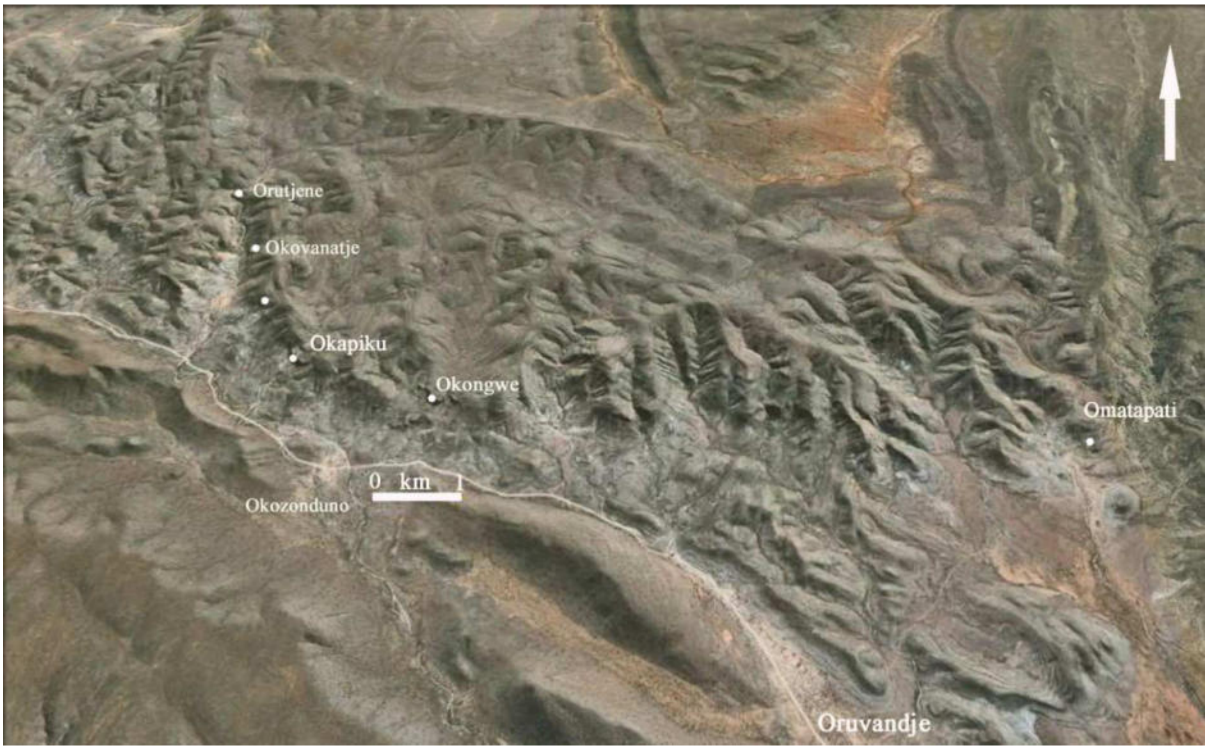

Figure 6. Locations of the main tufa lobes along the southern flanks of the dolomite massive exposed between Omatapati and Orutjene (image modified from Google Earth).

Close examination of the carbonate massif north of Oruvandje, between Omatapati and Otjozongombe, reveals that there are many small occurrences of tufa in almost all the valleys. These could represent remnants of ancient tufa lobes that have been eroded, or may have been lobes that for one reason or another (climatic change, not enough carbonate-rich water, their confined position within the valley) stopped growing while they were still small. They are comparable to the « Barrage Tufas » recorded in the Naukluft Mountains (Stone *et al.* 2010; Viles *et al.* 2007; Goudie & Viles, 2015). Each of these occurrences, of which there are many dozens, need to be investigated to determine their content and origins.

There are karstic features such as caves, dolines, sink holes and rillenkarren in the Precambrian dolomites and limestones of the area, but the larger karst features are not numerous, nor very obvious, apart from a cave near Robbie's Pass, 9 km north of Otjikondavirongo (18°40'05.6''S : 13°32'13.4''E, altitude : 1562 m). The Plio-Pleistocene tufa lobes, in contrast, show an abundance of localised epikarst activity such as klints, grikes and rillenkarren, and where they are eroded or incised, subterranean karst features such as speleothem deposition (stalagmites, flowstone) and cave pearls which formed in gour pools, can be observed.

The Kaokoland Tufa Lobes

The Okozonduno-Oruvandje area

Figure 7. The Okongwe Tufa Lobe Cluster viewed from the northwest, showing the development of lobes at different altitudes. Lobe N° 1 is associated with a small spring to the south of the main valley in which the other three lobes formed. Fossil mammals were found in breccia infilling former cavities in lobe N° 4 (the base of which is obscured from view by the trees).

Figure 8. The lowermost tufa lobe (N° 4) in the Okongwe cluster, with the collapsed cave, viewed from the southwest. Fossil mammals occur in breccia inside the collapsed cave as well as in subsidiary infillings of other caves on the north flank of the lobe (left in the image).

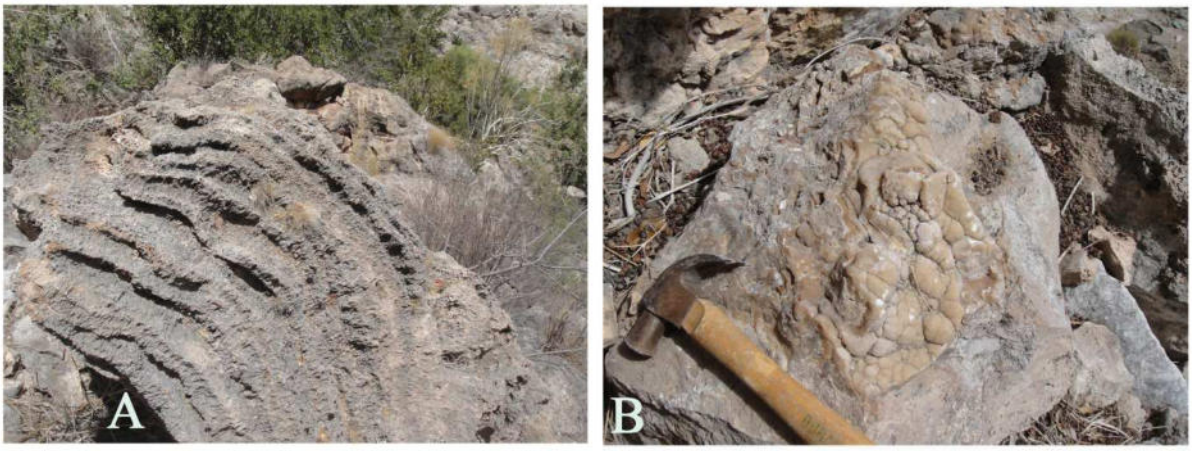

Figure 9. A) A large fragment of bryophyte curtain tufa at the foot of Okongwe Lobe 4, near the cave. Note the alternating layers of structured and massive tufa (2-5 cm thick) and the cellular structure within the layers that are most resistant to erosion. B) Speleothem covering a block of intensely calcified tufa at the Okongwe 4 cave site.

Figure 10. The Okapiku Tufa Lobe viewed from the west.

Figure 11. The Okovanatje Tufa Lobe with its intermittently active bryophyte curtains, viewed from the west.

Figure 12. Okovanatje Tufa Lobe viewed from the north. The stream feeding the system divides into two chutes, each of which is the site of moss growth and tufa deposition from the top of the cliffs to their base. The main growth trajectory is thus sideways out into the neighbouring valley but there is also a minor vertical growth trajectory which maintains the height of the structure.

Figure 12. Okovanatje Tufa Lobe, showing well developed but currently inactive bryophyte curtains (arrows) growing out over hollows in the tufa lobe front.

Omatapati

Figure 13. Cave and canyon eroded into the older of the two tufa lobes at Omatapati. This lobe could well be of Late Miocene or Early Pliocene age judging from its stage of erosion.

Figure 14. Rillenkarren developed in densely cemented tufa exposed on the surface of the eroded lower tufa lobe at Omatapati.

Figure 15. Eroded speleothems and cave breccias in the lower tufa lobe at Omatapati.

Figure 16. Brown tufa overlying pale, densely cemented fluvial gravels and sands at the Omatapati Lower Tufa Lobe.

Figure 17. The upper tufa lobe at Omatapati. This lobe has advanced more than 100 metres over a pre-existing flat boulder-covered river terrace, part of which is exposed in the foreground.

Otjitamei

Figure 18. Otjitamei Tufa Lobe showing the cliff front and the pool at its base (in shadow), at present fed by underground seepage of vadose water. Mammal fossils occur in breccia exposed at the top of the cliff.

Otjikondavirongo

Figure 19. Otjikondavirongo Tufa Lobes, comprising an older, somewhat eroded lobe (the sloping ground to the right of the image), and a younger, still active lobe forming the steep cliffs with vegetated waterfall to its left. The latter lobe has grown out from its parent valley, forming a huge bluff in the topography (vehicles in trees at left for scale).

Figure 20. At the foot of the old eroded tufa lobe at Otjikondavirongo, tufa is intercalated with fluvial conglomerate and sand which has been densely cemented. The sands contain land snails (*Sculptaria*).

Figure 21. The base of the actively growing part of the Otjikondavirongo Tufa Lobe. Note the abundance of moss and other plants growing on the cliffside and on exposed boulders at the foot of the cliff, and the algae proliferating in the pool. Note in particular the carbonate precipitating onto the bryophyte curtain, behind which there is a substantial cave.

Ongongo

The riverside tufas at Ongongo were described by Mocke (2014). The tufas are well exposed in a canyon which has cut through the carbonate deposits, revealing the interior of a large tufa system, rich in plant remains, freshwater gastropods and land snails.

South of Ongongo there are two further occurrences of tufa at a higher altitude than the riverside tufas. Called the Ongongo South Tufa Lobes, they crop out either side of a north-south trending ridge of Basement quartzite. Judging from their topographic position, they must have been emplaced prior to the downcutting of the present day valleys either side of the ridge.

Figure 22. Ongongo South Tufa Lobes positioned either side of a Basement quartzite ridge south of Ongongo Valley, viewed from the north. These tufa lobes, perched high above the plains, attest to the former presence of a radically different drainage network from that of today, because, as they stand, there is no obvious source for the carbonate of which they are built, nor is there a water supply to carry the carbonate in solution.

Figure 23. Paludal tufa overlying marls near the Camel Camp at Sesfontein. The tufas cover a large area, but are thin.

Palaeontology

Plants

Figure 24. Porous paludal tufa at the Camel camp, Sesfontein, is rich in natural molds of sedges and other plants and also contains land snails (*Achatina*). These tufas are probably Late Pleistocene or Holocene.

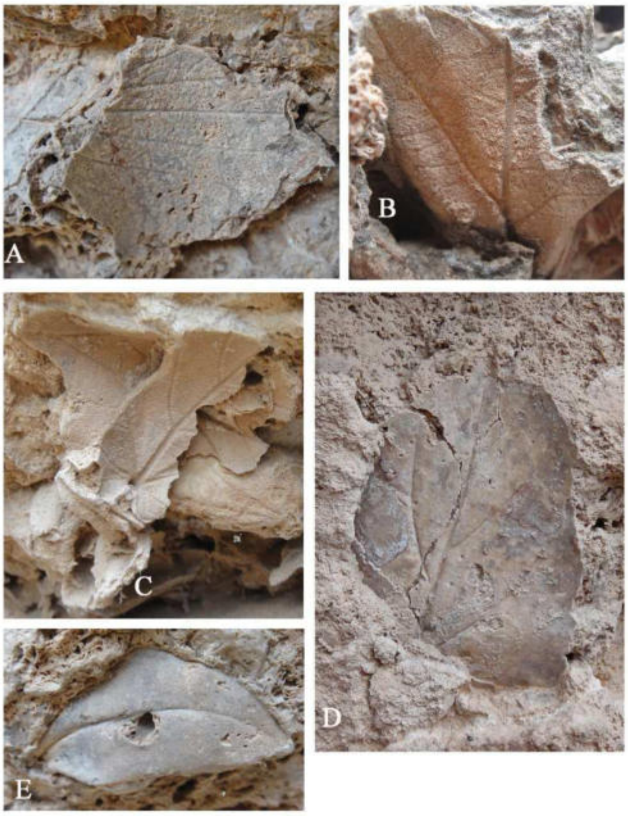

Figure 25. Examples of leaf imprints in tufa at Ongongo Gorge. A) *Colophospermum* (?), B-D) *Ficus*, E) *Salvadora*.

Invertebrates

Freshwater snails and land snails have been preserved in most of the Kaokoland tufas. Mocke (2014) illustrated an imprint of *Sculptaria*, a land snail, at Ongongo. This paper records the presence of *Bulinus* and a planorbid at Omatapati Lower Tufa Lobe, in association with the land snail *Succinea*, *Sculptaria* at Otjomatemba (near Otjitamei) and Otjikondavirongo, where *Achatina* also occurs, and *Xerocerastus* at Okongwe. Finally, the Omatapati Upper Tufa Lobe yielded an elongated Subulinidae, probably *Opeas*.

All these taxa occur in the region today, and they attest to a Summer rainfall regime, in strong contrast to the gastropod fauna of the Winter rainfall zone in southwestern Namibia (Pickford, 2008).

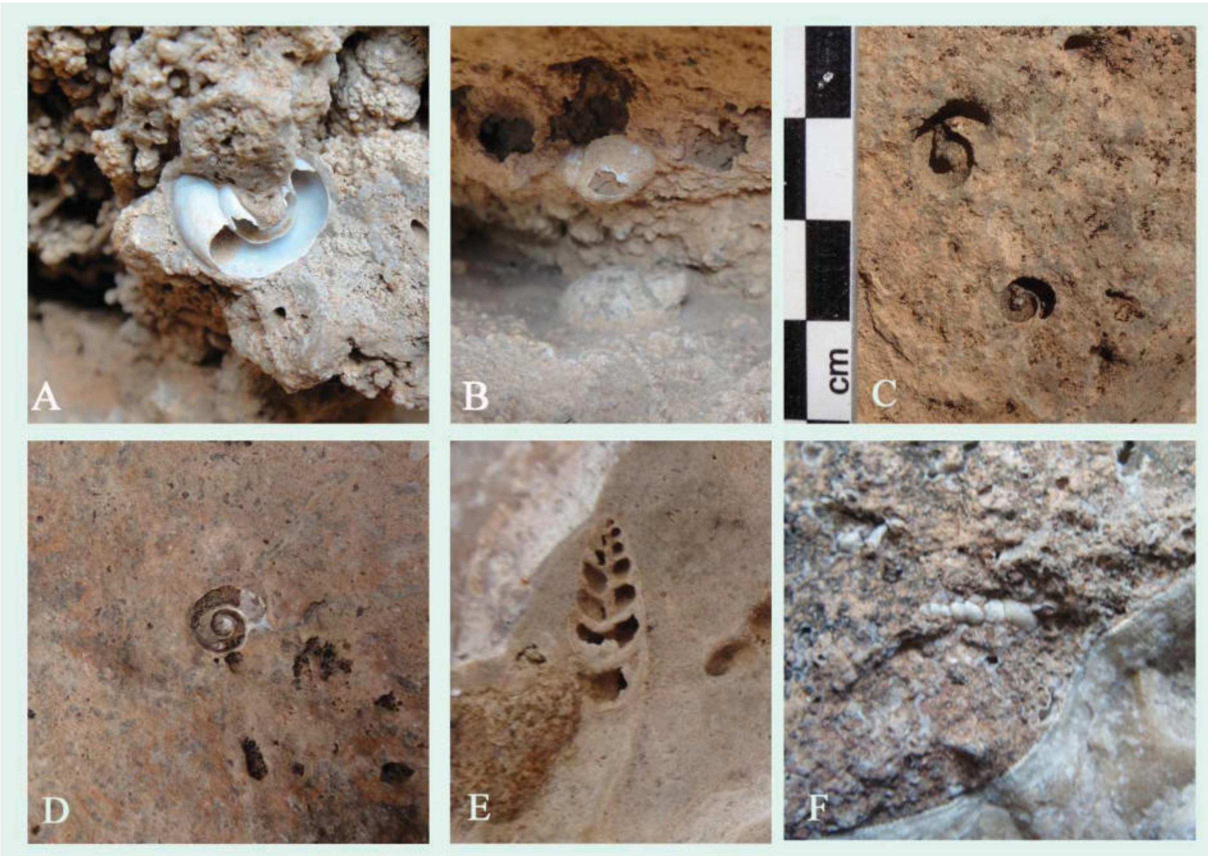

Figure 26. Freshwater and land snails in Kaokoland tufas and breccias. A-B) Omatapati Lower Tufa Lobe, A) damaged shell of a planorbid, B) complete sinistral shell of *Bulinus* (top) and dextral shell of *Succinea* (below); C) Impressions of *Sculptaria* shells in densely cemented fine sands at Otjomatemba, upstream from Otjitamei; D) *Sculptaria*, preserved in pink sandy breccia associated with the old tufa lobe at Otjikondavirongo. The snail is ca 15 mm in diameter; E) A sectioned shell of *Xerocerastus*, a dry country land snail common today in Kaokoland and Otavi, fossilised in pink, sandy breccia at Okongwe Tufa Lobe 4. The shell is ca 2 cm tall; F) Subulinidae shell in pink, sandy breccia associated with speleothems (bottom right corner of image) at Omatapati Upper Tufa Lobe. The shell is ca 20 mm tall.

Vertebrates

Figure 27. Micromammalian remains *in situ* in grey sandy breccia at the top of the Otjitamei Tufa Lobe.

Figure 28. Fossil bat jaw (possibly rhinolophid identified by V. Rossina) in breccia at the top of the cliffs at Otjitamei Tufa Lobe.

Figure 29. Fossiliferous Late Pliocene breccia *in situ* in the northern flank of the Okongwe Tufa Lobe N° 4, rich in the remains of rodents and other micromammals as well as fish, frogs and snakes.

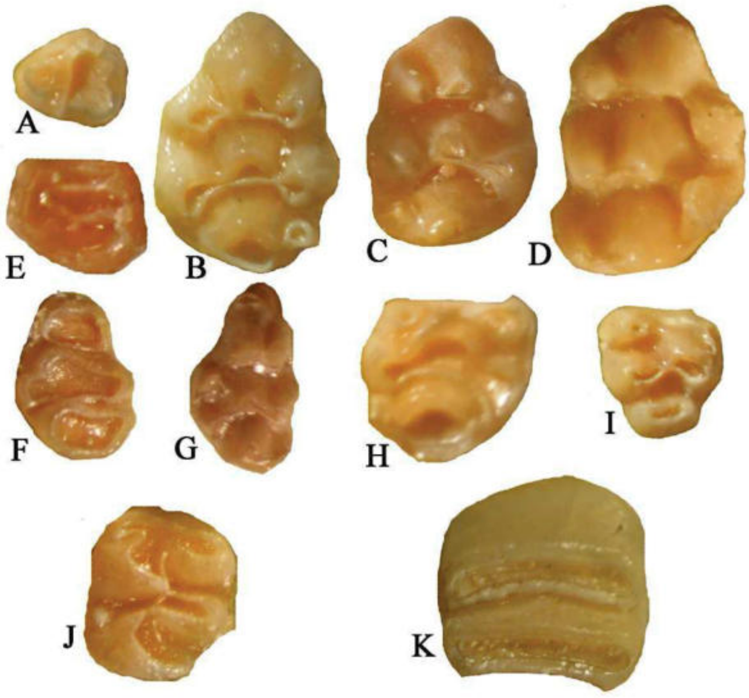

Figure 30. A small sample of the rodent fauna from sandy breccia associated with the palaeocave in Okongwe Tufa Lobe N° 4, to show part of the diversity (length x breadth measurements (in mm) in brackets). A) *Zelotomys woosnami*, right M3/ (0.99 x 0.97); B) *Aethomys chrysophilus* left M1/ (2.56 x 1.83); C) *Aethomys namaquensis* right M1/ (2.49 x 1.70); D) *Aethomys sp.* broken right M1/ (ca 2.47 x 1.75); E) *Graphiurus murinus*, right upper molar (0.85 x 1.23); F) *Steatomys krebsi* ? left M1/ (1.77 x 1.20); G) *Acomys spinosissimus* right M1/ (1.78 x 1.09); H) *Zelotomys woosnami* right M2/ (1.0 x 1.77); I) *Aethomys namaquensis* right M3/ (1.28 x 1.30); J) *Stenodontomys darti* left m/2 (1.27 x 1.06); K) *Parotomys littledalei* right m/2 (2.22 x 2.23).

Figure 31. *Pedetes* (Springhaas) mandible *in situ* in pinkish-grey sandy breccia at Omatapati Upper Tufa Lobe.

Figure 32. Small ruminant mandible and isolated teeth (probably klipspringer, *Oreotragus*) *in situ* in grey-pink sandy breccia at the top of Otjitamei tufa cliff.

Archaeology

All the Kaokoland tufa lobes examined show evidence of ancient and not so old human activity in the vicinity. Most of the stone artefacts observed were lying on the present day surface, or were partly buried in loose sediment, and are thus of little interest for dating the tufas. However, at Omatapati Upper Tufa Lobe, there are important masses of well-cemented breccia rich in the remains of large mammals (jaws, teeth, post-cranial bones) associated with stone tools of what looks like a primitive flake technology. The age of this breccia is unknown, but the mammal remains, when extracted and studied, may yield information of biochronological significance.

Figure 33. Stone tools and mammalian bones and teeth in breccia at Omatapati Upper Tufa Lobe.

Taphonomy

The micromammal concentrations at Okongwe and Otjitamei occur in discrete layers and masses suggesting that they represent accumulations of owl pellets on the floors of cavities in the tufa lobes. Some specimens represent the remains of animals that lived (and died) on the lobes. The Omatapati Upper Tufa Lobe is of interest on account of the association of large mammal remains with stone tools found there, indicative of early human habitation in the area.

Biochronology of the Kaokoland Tufa Lobes

The only fossils found so far in Kaokoland tufas that yield biochronological data are the micromammals. The small assemblage recovered from Okongwe Lobe 4 comprises micromammals, mostly rodents, but also macroscelidids and bats. Most of the rodent species are extant, but there is one genus, *Stenodontomys* Pocock, 1987, which is extinct. The type locality of this genus is Makapansgat, South Africa, dated ca 3 Ma (3.0-2.7 Ma, Pickford, 2006; or 3.03-2.58 Ma, Herries *et al*. 2013). The Omatapati Upper Tufa Lobe contains *Pedetes* (Springhaas) and other microfauna and macrofauna, but it has not yet been studied in detail. This means that the Okongwe Tufa Lobe breccias could be about the same age as the Thabaseek Tufas near Taung, South Africa, which are 1,500 km to the southeast and which yielded the type specimen of the early hominid *Australopithecus africanus* Dart, 1925 (Peabody, 1954; Butzer *et al*. 1978). A similar Late Pliocene age has been inferred for the travertine domes at Kaukausib in the Sperrgebiet (Pickford, 2000), so it would appear that the genesis of the Kaokoland Tufas could well be related to the same palaeoclimatic events that led to superficial carbonate accumulations over much of the sub-continent.

Table 2. Mammal fauna from Okongwe Tufa Lobe 4, Kaokoland, Namibia.

Vespertilionidae (Vesper Bat)
Rodentia
- *Acomys spinosissimus* (spiny mouse)
- *Zelotomys woosnami* (broad-headed stink mouse)
- *Stenodontomys darti* (extinct rodent)
- *Gerbilliscus winkleri* (bushveld gerbil)
- *Parotomys littledalei* (whistling rat)
- *Graphiurus murinus* (dormouse)
- *Aethomys namaquensis* (rock rat)
- Several other murids (mice)

Macroscelididae (Sengis)

The geomorphological settings of the various subaerial carbonate units in the Oruvandje, Warmquelle and Sesfontein regions indicate that they span a considerable period of geological time. Because the Okongwe cave fill has yielded a diverse rodent fauna including the extinct genus *Stenodontomys* originally described from Makapansgat (Middle Pliocene) and Langebaanweg (Early Pliocene) the deposits are likely to be Pliocene or older, whereas the valley bottom Swampland Tufas at Sesfontein and hard pans (indurated marls) are Late Pleistocene to Holocene, on the basis of the presence in them of planorbids and *Bulinus*. Some of the tufa at Omatapati Upper Tufa Lobe contains the remains of large mammals associated with stone tools which suggest an Early Pleistocene age, but further research is required to confirm this estimate.

Palaeoclimatic implications of the Kaokoland carbonate deposits

The Cascade Tufas at Oruvandje and north of Warmquelle attest to the existence of a more humid palaeoclimate than the present day arid to hyper-arid regime that typifies the region. The travertine masses are vast, they occur in most of the valleys in the region, they are located high above the extant valley floors and in cases such as Otjikondavirongo, their fronts have grown significant distances outwards over the neighbouring low country. In the Oruvandje area, there are three main levels at which the travertine masses formed. Today, the tufa masses at Oruvandje and Warmquelle are perched well above the valleys into which their respective drainages flow. The travertine cliffs at Ongongo South are located at the upper edges of a long North-South ridge of quartzite, and they could not have formed where they are under the present day topographic conditions. They attest to a considerable amount of erosion on both sides of the Quartzite Ridge since the period of growth, which, at the time of accumulation of the travertine, was traversed by a river.

The land snail fauna (*Succinea*, *Sculptaria*, *Xerocerastus*, *Opeas* (?) and *Achatina*) indicate that, at the time of tufa growth, Kaokoland lay within the Summer rainfall zone.

Palaeoecology

The micromammals from Okongwe Lobe 4 comprise taxa that today occur preferentially in semi-arid to sub-humid areas. Based on the ecological requirements of extant rodents of Southern Africa (De Graaf, 1981) the fauna from the Okongwe Lobe 4 deposit and Omatapati indicate a somewhat more humid and probably cooler Pliocene palaeoclimate than the present day arid regime that characterises the region, which supports Mopane woodland. The Pliocene vegetation at Okongwe may have been equivalent to wooded savannah, such as Miombo woodland. The land snails from the Kaokoland tufas are like those that occur in the region today, but they also resemble those of the more humid Otavi Mountains, for example.

Discussion

Preliminary palaeontological survey of parts of Kaokoland during the 1990's resulted in the discovery of a few unidentified gastropod specimens in epikarst deposits at Otjomatemba (Pickford & Senut, 2010), Robbie's Pass Cave and Erova, and some rodents and dassies from internal karst deposits at Ondera, Rocky and Tim's Cave. These occurrences were rather poor in fossils, but they already revealed that most of the sites were Pleistocene in age, and that the sediments accumulated under a Summer rainfall climatic regime (Pickford & Senut, 2010).

The new findings are much more comprehensive, and they indicate the existence of a vast archive of fossiliferous breccia at several loci in Kaokoland, preserving plants, invertebrates and vertebrates. Most of the fossils observed comprise the remains of microvertebrates that were brought into caves and fissures in the growing tufa lobes by owls and other raptors, but there are also the remains of small birds, snakes, frogs and the occasional fish that represent animals that lived in the vicinity of, or even on the lobes. There are also rare specimens of larger mammals such as small bovids and dassies, which, like the extant Klipspringer (*Oreotragus*) and hyraxes (*Procavia*), also probably lived on or near the tufa lobes.

Finally, at one of the sites, Omatapati Upper Tufa Lobe, there are well-indurated breccias rich in the remains of large mammals associated with stone tools. All this translates into a major palaeontological resource in Kaokoland which will take many years of concerted effort to prospect and study.

There have been previous attempts to date the main periods of tufa growth in the Naukluft Mountains, Namibia (Viles *et al.* 2007; Stone *et al.* 2010; Goudie & Viles, 2015) but without a great deal of success, due to the open geochemical nature of the depositional systems typical of porous tufa deposits (Rich *et al*. 2003).

Preliminary assessment of the rodent fauna from Okongwe Tufa Lobe N° 4, indicates a Late Pliocene age for tufa deposition there, but it is clear from the field relations of the various tufa lobes examined, their state of preservation and their degree of erosion, that there are older and younger occurrences in the region. The lower lobe at Omatapati could well be Early Pliocene or Late Miocene in age, as could the older of the two lobes at Otjikondavirongo. In contrast, the discovery of early stone tools in the Omatapati Upper Tufa Lobe suggests an Early Pleistocene age for some of the activity there. Finally, the paludal tufa fields at Sesfontein Camel Camp and on top of the Otjitamei Tufa Lobe at Otjomatemba, are probably Late Pleistocene to Recent.

Conclusions

The discovery of richly fossiliferous Late Neogene to Pleistocene and Holocene tufa deposits in Kaokoland is of great interest for African Neogene and Quaternary palaeontology. The tufa lobes occur in a part of Africa that has previously yielded very little palaeontological information. The nearest richly fossiliferous areas are at Etosha and Ekuma (Late Miocene to Late Pliocene) on the northwestern edge of Etosha Pan (Pickford *et al.* 2014, 2016) over 200 km to the east, in the Otavi Mountains 470 km to the east (Middle Miocene to Recent) (Pickford & Senut, 2010) and the Humpata Plateau in Angola, 440 km to the north (Plio-Pleistocene) (Pickford *et al.* 1990, 1992, 1994).

Preliminary studies of the Kaokoland fossils indicate that during phases of active tufa growth, the region was somewhat more humid and probably slightly cooler than it is today, probably comprising Miombo woodland, or the transition between Miombo and Mopane vegetation types, in contrast to the very arid climate with Mopane Woodland that currently characterises the area.

The cascade and paludal tufas of both Kaokoland and the Naukluft Mountains formed at the high edge of the Great Escarpment, in the vicinity of dolomite and limestone outcrops of the Otavi Group in the case of Kaokoland, and of the carbonate-rich Naukluft nappes in the case of the latter occurrences.

Mosses and other plants played a significant role in the tufa formation, as shown by the quantity of phytoherms and bryophyte curtains and cushions preserved. The tufas are associated with densely cemented gravels, sands and silts in the bottoms of the valleys both upstream and downstream from the tufa lobes, attesting to the presence of important quantities of carbonate in the groundwaters of the region. There are frequent plant remains (leaves, root imprints), gastropods and vertebrates preserved in sandy to pebbly breccias associated with the lobes.

The micromammalian remains in the tufa lobes appear to result from the activity of owls and other raptors that roosted in crannies and caves in the tufa lobes, regurgitating bone-rich pellets which accumulated on the floors of the cavities which then became cemented by calcite. Bats also lived in these cavities, as shown by the presence of jaws and teeth in the breccias. The fossils of other vertebrates such as lizards and snakes (colubrids (Rage, pers. comm.)), dassies and small bovids, may well represent the remains of animals that lived on the tufa lobes. Finally, there is evidence of early human activity preserved in some of the lobes, where well-cemented breccia contains large mammal remains associated with primitive stone tools.

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