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Cover image: Calcareous tufa deposits coating the roof, sides and floor of a small cave eroded into Pleistocene palaeosols (alternating soft soils and hardpan layers), Khowarib Valley, Kaokoland, Namibia (Photo: M. Pickford, 2023)

Revision of the timing of accumulation of the raised beach deposits of the central Sperrgebiet, Namibia

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Abstract :- The presence of Cainozoic marine sediments in the Sperrgebiet, Namibia, was noted as early as 1908 when diamonds were found at Kolmanskop. Because of the economic interest of these deposits, geological investigations were undertaken, which led to detailed mapping of their distribution, initially by Beetz (1926). In the Central Sperrgebiet early investigators correlated the 'highest' beach deposits (ca 160 metres above present-day mean sea-level) to the Eocene, referred to in the old literature as 'Höchster Stand der Eocänsee' or the 'Eocäne Marine Inundation' (Kaiser, 1926). Liddle (1971) extended this « ancient » strandline a few kilometres northwards to Elfert's Tafelberg. Dingle *et al.* (1983) dated it to the late Palaeocene – early Eocene. In contrast, along the Namaqualand coastal plain in South Africa, marine deposits attributed by Pether (1986, 1994) to the 90 metre package, the 50 metre package, and the 30 metre package were correlated to the Miocene.

Re-examination of the conglomerates at Eisenkieselklippenbake and Buntfeldschuh which crop out at ca 150-160 metres above sea level, reveals that some of the deposits are considerably younger than the Eocene, being instead of early Miocene (Aquitanian-Burdigalian) age. The beach conglomerates at both of these localities contain well-rounded and polished cobbles of densely ferruginised gravel and sand associated with cobbles of a great variety of other rock types (quartzite, silcrete, silicified freshwater limestone, vein quartz, agates, pebbles of banded ironstone formation (BIF), jasper etc.).

The conclusion about the Miocene age of the beaches follows from the observation that the ferruginisation of near-surface deposits in the sector of the Sperrgebiet between Kerbehuk in the south and Elisabethfeld-Grillental in the north occurred during the Oligocene (more precisely, the Chattian) the process petering out during the Early Miocene (Aquitanian-Burdigalian), and ceasing altogether with the establishment of hyper-aridity in the region (onset of fully desert conditions in the Namib) ca 17 Ma.

This means that cobbles derived from the break-up of the ferruginised deposits must be younger than the Chattian. Many of the cobbles of ferruginised sediment contain clasts of agate, BIF and jasper, vein quartz, silicified limestone etc. which were already present in the superficial deposits of the region prior to the Chattian, supporting the old conclusions concerning the presence of Eocene marine deposits in the Sperrgebiet. The revised age of the Eisenkieselklippenbake and Buntfeldschuh beach conglomerates means that the timing of the geomorphological development of the region, such as the back-cutting of the Buntfeldschuh Escarpment, requires revision, as do the correlations of near-surface deposits such as the fluvial Blaubok and Gemsboktal formations (Pickford, 2015) which are of Eo-Oligocene and Miocene age respectively.

Key words :- Raised beach, Miocene, Oligocene, Eocene, Ferruginisation

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Introduction

Ferruginised superficial deposits in the Sperrgebiet were originally correlated to the Late Cretaceous (Beetz, 1926; Kaiser, 1926; Liddle 1971) or younger periods (Kakaoberg – Pleistocene : Du Toit, 1954, cited by Hallam, 1964; Goethite Ring : Ward & Swart, 2018).

Pickford (2015) showed that the supposedly Cretaceous occurrences of 'ferricrete' near Pomona were considerably younger (Late Oligocene : Chattian) as were the outcrops in the Buntfeldschuh area. Further study has revealed that in the Sperrgebiet the processes of ferruginisation faded out during the Early Miocene, and did not extend into the Middle Miocene as postulated by Pickford (2015) nor was there any ferruginistion during the

Pleistocene as postulated by Ward & Swart (2018) the ferruginisation of the Goethite Ring outcrop having probably taken place during the same phase as the ferruginised deposits at Buntfeldschuh (Pickford, 2016). The youngest evidence of ferruginisation in the region occurs at Elisabethfeld and Grillental where patches of fossiliferous Early Miocene (Aquitanian-Burdigalian) sediments have been ferruginised (Pickford, 2016).

As now understood, ferruginisation of superficial deposits in the Sperrgebiet began when sea-levels dropped from the Rupelian high level to the extremely low sea stand that characterised the Chattian (Miller, 2009), and the process weakened and ceased altogether when sea-level rose again during the Aquitanian and Burdigalian. The process was driven by iron-rich groundwaters (Fe_2) flowing from the interior of the continent towards the Atlantic Ocean, that precipitated the iron as Fe_30_4, when encountering oxygen-rich near-surface deposits.

As a result, if derived or reworked blocks of ferruginised sediment are found in a deposit in this sector of the Sperrgebiet, then that deposit is likely to be younger than Chattian, which was the period during which ferruginisation occurred.

In 2023, detailed surveys of Buntfeldschuh and Eisenkieselklippenbake were undertaken in order to refine the age of accumulation of the agate- and BIF-bearing beach gravels exposed there at an altitude of ca 150 metres asl.

Buntfeldschuh

Ferruginised superficial rocks crop out widely but intermittently at Buntfeldschuh. Kakaoberg is an impressive mass of ferruginised aeolianite overlying altered bedrock and shallow marine sediments, and overlain by Namib I Calc-crust (Fig. 1). Elsewhere in the Buntfeldschuh area, ferruginised rocks comprise coarse angular gravel lag, marine sands, and ancient beach gravels (Fig. 4, 5). Ferruginisation post-dates shallow marine sediments that have yielded fossil teeth of the sand shark (*Isurus* sp.) and button-like teeth of 'parrot-fish' (Figs 2, 3). The fossils suggest that the deposits are younger than the Lutetian, not as old as the Palaeocene, the estimate published by Dingle *et al*. (1983).

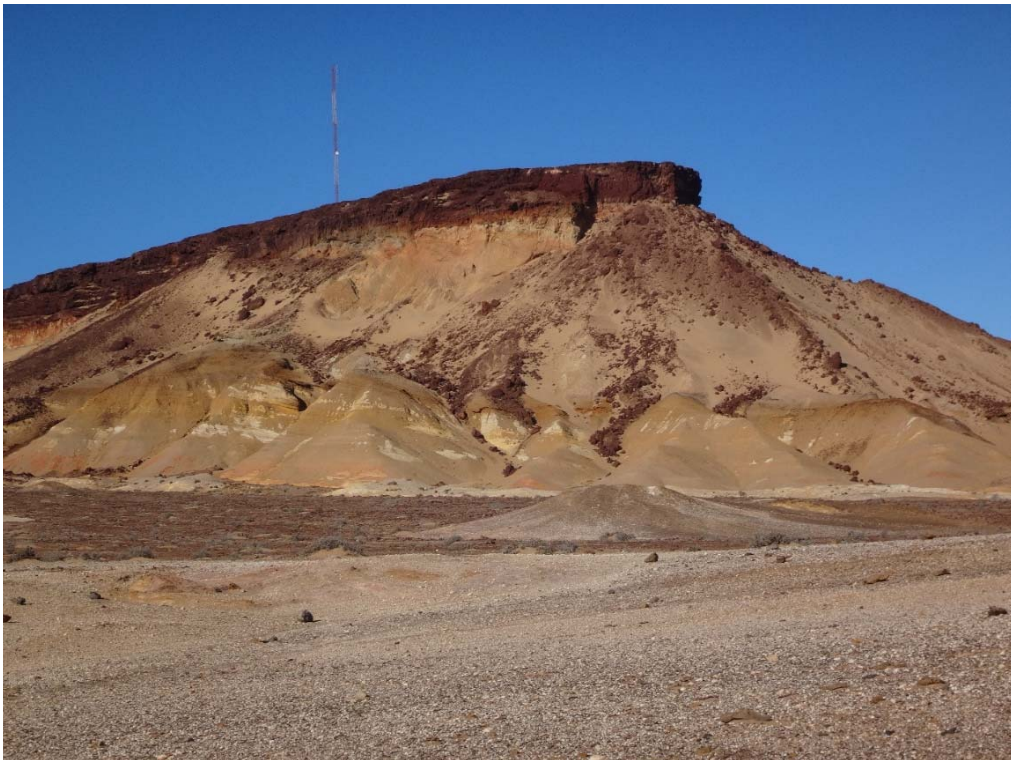

Figure 1. Stratigraphic succession at the northern nose of the Kakaoberg, alterite at the base, ferruginised aeolian sands at the top, with Eocene marine sand, gravels and conglomerates in between.

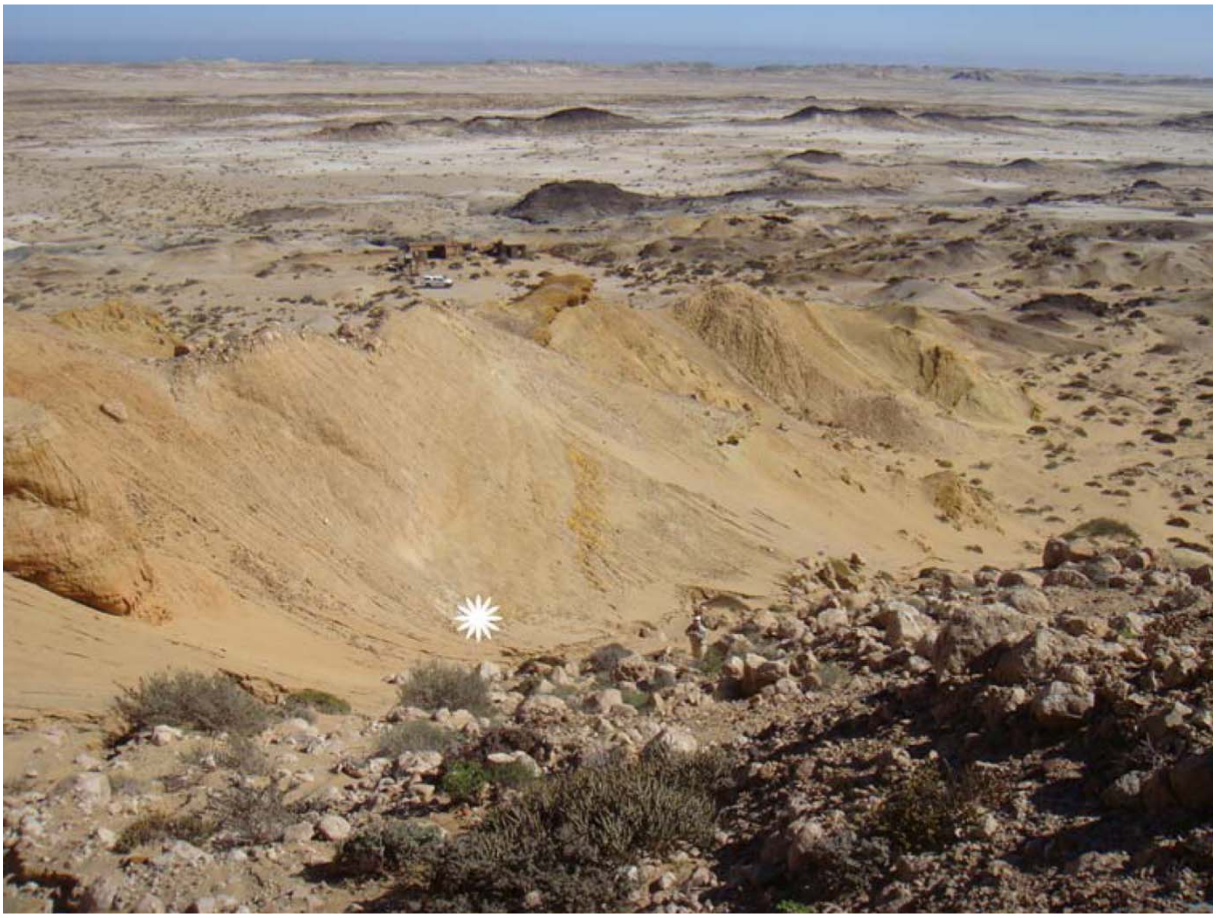

Figure 2. Shallow-water marine sands and gravels that crop out close to the Camel Camp at Buntfeldschuh, Namibia, yield fossilised teeth of sharks and fish (white star) (see Fig. 3). Note the vehicle parked close to the Camel Camp.

Figure 3. Fossil teeth of the sand shark (*Isurus* sp.) and 'parrot-fish' from marine sandy gravels east of the Camel Camp at Buntfeldschuh (see Fig. 2) (scale : 10 mm). These fossils suggest a post-Lutetian age for the sediments from which they were collected.

Figure 4. Outcrop in the northern sector of the Buntfeldschuh exposures preserving a 25 cm thick layer of densely ferruginised coarse conglomerate and sand overlying altered basement rocks (visible beneath the overhang in shadow), and itself unconformably overlain by 2-3 metres of younger, unconsolidated, poorly sorted coarse-to-fine conglomerate and sand.

Figure 5. Wave-worn cobbles from ca 140-150 masl at Buntfeldschuh, Sperrgebiet, Namibia. The goethite that cemented the Eocene sandy-pebbly deposits was precipitated during the Chattian, a period of low sea-level. The ferruginised layers that resulted were broken up by wave action during the Aquitanian-Burdigalian, periods of high sea-level, leaving behind well-rounded and polished cobbles.

Eisenkieselklippenbake

Both of the outcrops of ancient beach deposits at Eisenkieselklippenbake (Fig. 6) yielded rounded and abraded pebbles of densely ferruginised sand in which there are diverse pebbles of quartz, BIF and agates (Fig. 7). The fact that the exotic clasts of agate and BIF are cemented by ferruginised sand (goethite) indicates that the accumulation of these clasts in the area was pre-Oligocene, because ferruginisation processes in this region of the Sperrgebiet occurred during the Oligocene (Chattian) and basalmost Miocene. The same beach gravels contain blocks of fossiliferous silicified freshwater limestones derived from local outcrops on both sides of the valley in which the beach deposits occur. There are also well rounded cobbles of silicified Plaquette Limestone. The fossils in the freshwater limestones are of Middle to Late Eocene age, as is the Plaquette Limestone which crops out sporadically but widely in the vicinity of the Klinghardt Mountains as well as at Chalcedon Tafelberg, Steffenkop and Black Crow. These agate-bearing gravels therefore accumulated after silicification of the freshwater limestones, but prior to ferruginisation, from which it is concluded that they must have been deposited at the very end of the Eocene or lowermost Oligocene, prior to the onset of the Oligocene (Chattian) low sea-stand.

The ferruginised cobbles in the Eisenkieselklippenbake beach gravels (Fig. 7) are well rounded with the pebbles embedded in them abraded level with the densely ferruginised matrix, indicating break-up of the ferruginised deposit into cobbles which were then rounded by wave action and water-borne sand abrasion.

On this basis this it is concluded that the Eisenkieselklippenbake beach gravels comprise a composite unit, with some clasts originally deposited during the terminal Eocene, followed by reworking at the onset of the Miocene, possibly with the input of additional agates and associated clasts. In between these two marine episodes there occurred the ferruginisation of parts of the marine gravels, as well as of the surrounding superficial outcrops on the flanks of the valley.

Overall therefore, it is concluded that the Eisenkieselklippenbake beach deposits have a rather similar history to those of the Buntfeldschuh area where initial deposition of agates occurred during the Eocene (teeth of the sand shark *Isurus* in the marine layers indicate a Lutetian or later age), followed by ferruginisation (Kakaoberg) then by cutting back of the Buntfeldschuh cliff during the first high sea-level of the Miocene (Aquitanian), during which similar beach gravels with ferruginised, agate-bearing cobbles accumulated about 10 metres above the foot of the escarpment at an altitude of ca 150 metres asl.

Figure 6. Miocene beach deposits at Eisenkieselklippenbake (the eastern outcrop) in a shallow valley incised into Priabonian-Bartonian silicified freshwater limestone deposits (brown ridges either side of the beach deposits).

Figure 7. Ferruginised sandy-pebbly cobbles containing agates and BIF collected from the two ancient beach remnants at Eisenkieselklippenbake, ca 150 masl. Top row, the two sides of a cobble from the westernmost outcrop; Bottom row, two views of a cobble from the easternmost outcrop.

Blaubok

A situation somewhat similar to that at Eisenkieselklippenbake, but on a smaller scale, occurs at the summit of the hill west of Blaubok Beacon, where ferrruginised masses of conglomerate have been broken up into cobbles up to 15 cm in diameter that have been abraded and rounded by wave action in an ancient beach or energetic shallow water marine setting (Fig. 8) (Pickford, 2016).

Figure 8. Wave-rounded cobbles of ferruginised Blaubok conglomerate cropping out near the summit of the hill west of Blaubok Beacon, at an altitude (GPS) of 141 masl.

Discussion and Conclusions

The new interpretation of the Buntfeldschuh, Eisenkieselklippenbake and Blaubok outcrops provides support for the stratigraphic relationships published by Pickford (2015) but the timing and duration of events requires minor revision. Silicification of fossiliferous freshwater limestones and the Plaquette Limestone occurred prior to or during the late Bartonian (ca 39-38 Ma), the first input of marine fossils (sharks) and gravels (agate, BIF, jasper etc.) occurred during the late Bartonian to Rupelian (some time between 33.9 and 28.1 Ma) and the ferruginisation of superficial deposits occurred during the Chattian to basal Miocene (ca 28.1-21.0 Ma), while the Aquitanian beach episode (ca 23-21 Ma) reworked the pre-existing marine deposits (some of which had been ferruginised) by breaking up the ferruginised gravels that had been cemented during the Late Oligocene.

Re-examination of the marine gravels in the Central Sperrgebiet which are currently ca 150 metres above sea-level, reveal that several outcrops (Buntfeldschuh, Eisenkieselklippenbake, Blaubok) contain wave-rounded cobbles of densely ferruginised sediment. The style of rounding of the cobbles indicate that ferruginisation occurred prior to the action of waves, which broke up layers of ferruginised sediments and then rounded and abraded the cobbles that resulted from this action.

Ferruginisation of superficial deposits in the Central Sperrgebiet was widespread but sporadic in distribution, with geothitic cement indurating a wide variety of deposits, ranging from angular reg to fine sand and silt. Such rocks occur from Elisabethfeld and Grillental in the north to Kerbehuk in the south, and from close to the present-day coastline in the west (possibly offshore as well) to as far inland as the edge of the Klinghardt Mountains (Pickford, 2016).

The superficial deposits of the Sperrgebiet where iron precipitation occurred were indurated by goethitic cement which in many places is extremely dense : to the extent that some of the deposits were originally mapped as silicified sediments (Kaiser, 1926).

Where information about the timing of the ferruginisation can be observed or inferred, it is concluded that there was but a single phase of this geochemical process that occurred over a period of several million years during the Chattian and basalmost Miocene.

The distribution and type of ferruginisation indicates that these deposits comprise groundwater 'ferricretes'. Reduced iron (Fe_2) was transported in solution by groundwaters flowing from the interior of the continent towards the coast, and upon encountering oxygen-rich environments close to the ancient land surface, the iron was precipitated as Fe_3O_4.

The existence of this long-lived groundwater process during the Chattian suggests that the palaeoclimate in the interior of the continent during this phase may well have been relatively humid, and that the arid to hyper-arid conditions that later prevailed in the Namib Desert didn't get established until the end of the Early Miocene, some 17 Ma.

It is likely that the drop in sea-level during the Chattian to ca 150 metres below present-day levels, resulted in an increase in the flow of groundwater westwards through the Sperrgebiet when compared to the periods of high sea-level prior to and after the Chattian when the coastal parts of what is now the Sperrgebiet were transgressed to an altitude of ca 150 metres above present-day sea-levels.

Ward & Swart (2018) considered that the iron in the Sperrgebiet 'ferricretes' resulted from hydrothermal processes related to the Klinghardt volcanic cluster, but the timing of the deposition renders this unlikely.

Silicification of the superficial deposits in the Sperrgebiet, in contrast, predated the phase of ferruginisation (Pickford, 2016) and the siliceous rocks could well be the result of hydrothermal processes related to the Klinghardt magma chamber.

Furthermore, the phase of travertine deposition in the Sperrgebiet (Pliocene to Pleistocene, Pickford, 2018; Senut *et al*. 2019) that was also linked to the long term flow of groundwater towards the Atlantic Ocean, was more related to the circulation of groundwaters enriched in Calcium ions than to hydrothermal activity at hot-springs.

The implications of this reinterpretation of the Sperrgebiet diamond-bearing raised beach deposits that contain cobbles of ferruginised sediment are far-reaching in that there are both economic and scientific issues to be resolved.

The Eisenkieselklippenbake and Buntfeldschuh beach gravels occur at an altitude of ca 150 metres above modern mean sea-level. South of the Orange River in Namaqualand, South Africa, the highest marine package is reported to be about 90 metres above sea-level (the so-called 90 metre package of Pether, 1986, 1994). Has there been down-warping or downfaulting of the region south of the Orange River relative to the Sperrgebiet, or uplift of the Sperrgebiet relative to Namaqualand, or both? (Pickford, 1998). Are the Namaqualand data reliable? Why are there no mapped equivalents of the 90 metre, 50 metre and 30 metre marine packages in the Central Sperrgebiet (Ward & Swart, 2018). Were such deposits present but then destroyed by erosion, leaving only a few remnants of their presence in sheltered locales such as Eisenkieselklippenbake and Buntfeldschuh? Further research is required.

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Small birds (Psittaculidae, Galliformes and Passeri) from the Early Miocene of Namibia

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Abstract :- Several post-cranial bones of small birds collected from Early Miocene deposits at Grillental in the Sperrgebiet, Namibia, are attributed to three groups, a small parrot-like species (Psittaculidae), a songbird (Passeriformes) and a gamebird (Galliformes). All three are among the earliest records of their respective groups in Africa. The lovebird specimens, in particular, greatly extend the fossil record of the family in the continent from the previous earliest record at Langebaanweg, South Africa (ca 6-5 Ma) to the Early Miocene (ca 20-19 Ma). The material is an interesting source of information about palaeoenvironments and palaeoclimate and, as an assemblage, it indicates that the locality was more humid than it is today, and that it lay within the summer rainfall belt, in contrast to the hyper-arid conditions with winter rainfall that prevail in this part of the continent at present.

Key Words :- Aves, Early Miocene, Namibia, Palaeoecology, Palaeoclimate

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Introduction

Fossilised bones of small birds collected from the Early Miocene (ca 19-20 Ma) green silts at Grillental VI, Sperrgebiet, Namibia, represent three different groups, Psittaculidae (lovebirds), Galliformes (gamebirds) and Passeriformes (song-birds). The lovebird from Grillental is by far the oldest known from Africa, the passerine from the site is one of the oldest known from the continent, the other record being from similar aged deposits at Napak, Uganda, (Riamon, pers. comm.) while the galliform is also one of the earliest records of the group in Africa, only a record from Elisabethfeld, Sperrgebiet, Namibia, being slightly older than it (ca 21-20 Ma) (Mourer-Chauviré, 2008).

For these reasons, it is interesting to describe the avian material from Grillental VI and to use it for throwing light on aspects of the Early Miocene palaeoenvironment and palaeo-climate of southern Namibia.

Material and Methods

The fossils described herein are curated at the Earth Science Museum, Geological Survey of Namibia, Windhoek. They are registered with the abbreviation GSN GT followed by a field number and the year of collection (e.g. GSN GT 39'23).

Images of the fossils were captured with a Sony Cybershot Digital Camera, and were treated with Photoshop Elements15 to increase contrast, reduce tremor and clean away unwanted background. Scale bars were added following measurements of the fossils with sliding calipers.

Locality and Age

The locality from which these bones were collected is a small knoll (26°58'10.04"S : 15°19'26.50"E) in the broad area of sediment exposures known as Grillental VI in the northern Sperrgebiet, Namibia (Pickford, 2008a) (Figs 1-2). The deposits have yielded mammalian fossils that indicate an Early Miocene correlation (Aquitanian-Burdigalian). The strata are considered to date from 20-19 Ma.

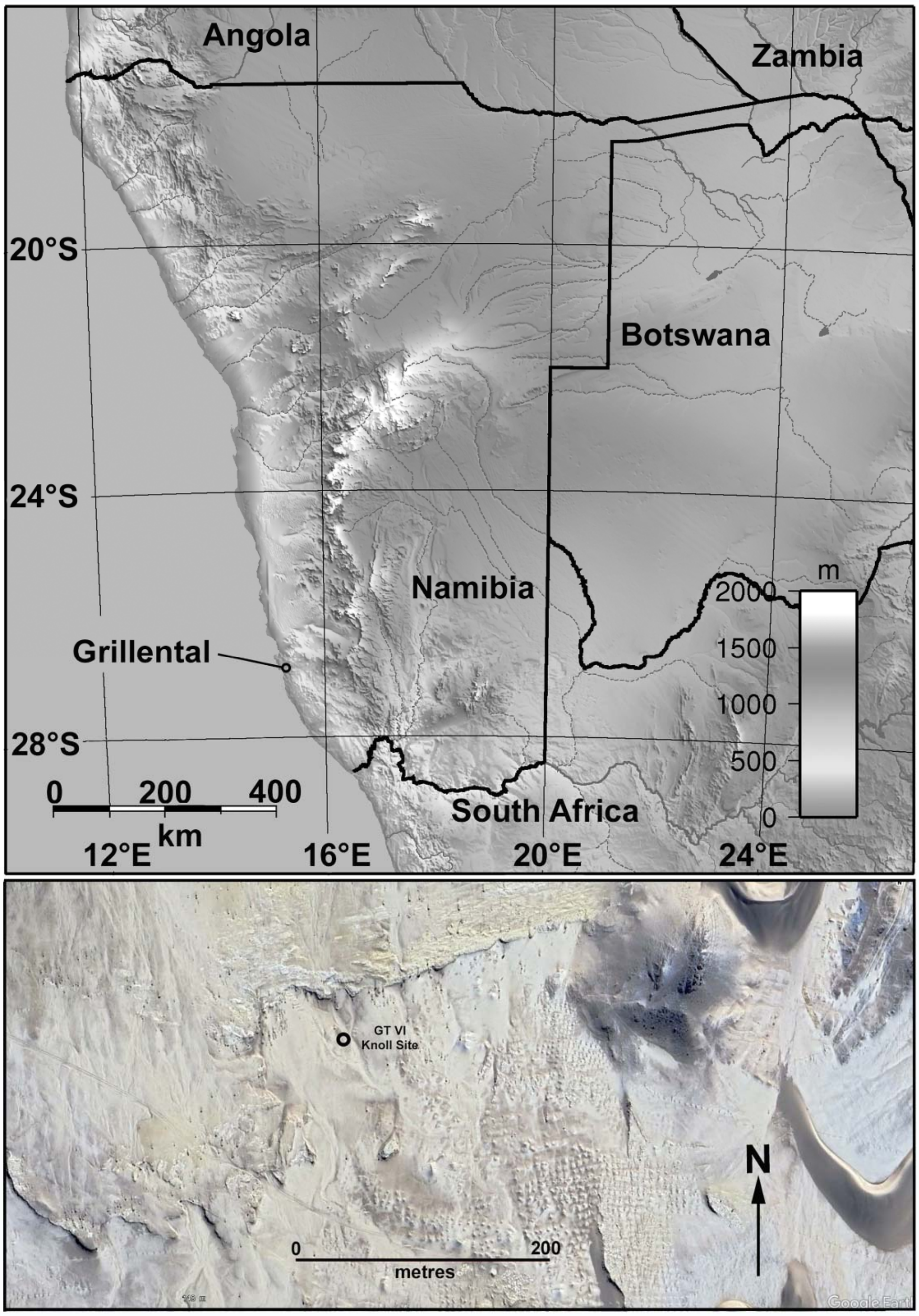

Figure 1. Digital elevation map of Namibia (upper frame) showing the location of Grillental in the Sperrgebiet. The Knoll Site is in the Grillental VI complex of fossiliferous deposits (lower frame: image modified from Google Earth). Note the regular pattern in the floor of the depression formed by trommel screen heaps resulting from diamond mining during the 1920's.

Figure 2. View of the Knoll Site at Grillental VI. In the foreground is a fossilised hive (*Namajenga mwichwa* Pickford, 2008b) a bioconstruction (fungus garden) made by a species of the termite, *Hodotermes*.

Systematic study

Order Psittaciformes Wagler 1830

Superfamily Psittacoidea Rafinesque-Schmaltz 1815 (sensu Joseph *et al.* 2012)

Family Psittaculidae Vigors 1825

Subfamily Agapornithinae Salvin 1882

Genus *Agapornis* Selby 1836

Type species :- *Agapornis swindernianus* Kuhl 1820

Species *Agapornis* incertae sedis

Locality :- Grillental VI, Sperrgebiet, Namibia.

Age :- Early Miocene, ca 20-19 Ma.

Material :- GSN GT 39'23, left humerus, distal part (Fig. 3), GSN GT 38'23, left carpometacarpus (Fig. 4).

Osteology

Humerus

Measurement :- distal width, 4.0 mm.

On the cranial side of the humerus, the *condylus ventralis* projects weakly and the *condylus dorsalis* is almost vertical. On the caudal side the *fossa olecrani* is wide and shallow, and the *epicondylus ventralis* projects strongly ventrally.

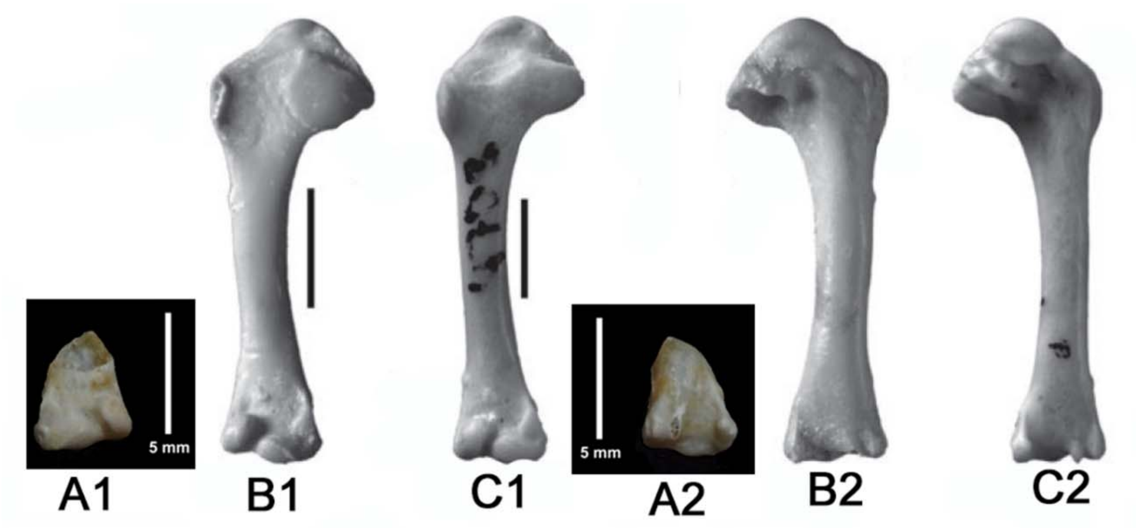

Figure 3. *Agapornis* sp. from Grillental VI (A - distal left humerus, GSN GT 39’23), *Agapornis attenboroughi* Langebaanweg (B - right humerus,) and extant *Agapornis roseicollis* (C - right humerus). Images B and C are modified from Manegold (2013) (A1-C1 : cranial views, A2-C2 : caudal views) (scale bars : 5 mm).

Carpometacarpus

Measurement :- total length, 14.4 mm.

On the carpometacarpus the *processus extensorius* and the *os metacarpale minus* are missing. The *processus pisiformis*, below the *trochlea carpalis*, on the medial side, is well developed .

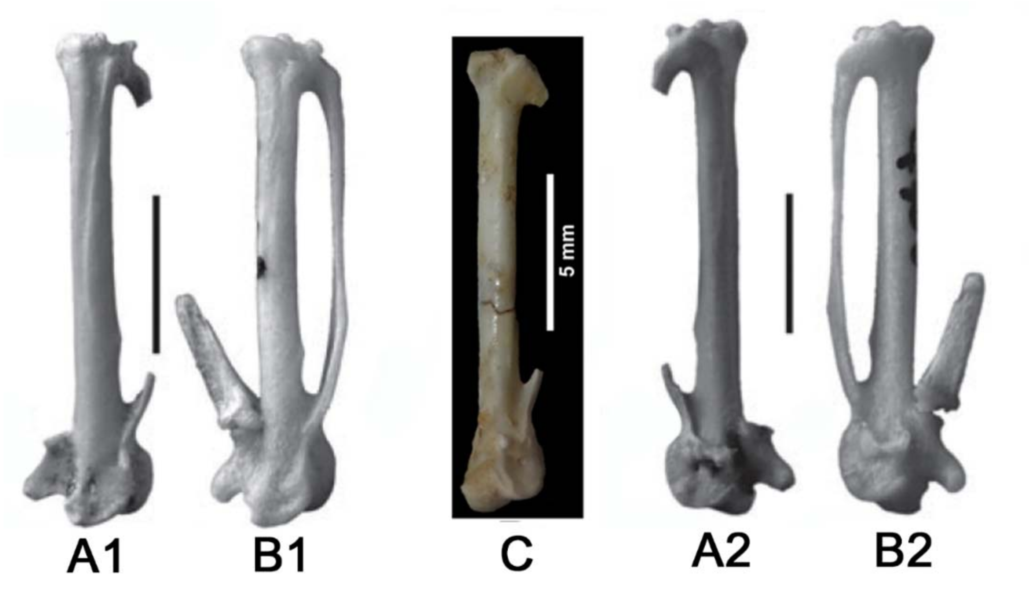

Figure 4. *Agapornis attenboroughi* from Langebaanweg (A - right carpometacarpus) extant *Agapornis roseicollis* (B - right carpometacarpus) and *Agapornis* sp. from Grillental (C - GSN GT 38’23, left carpometacarpus). Images A and B are modified from Manegold (2013) (A1-B1 : dorsal views, A2, B2 and C : ventral views) (scale bars : 5 mm).

The dimensions of these fossil bones from Grillental are comparable to those of the smallest extant species of the genus *Agapornis* (Manegold, 2013).

Fossil Record of *Agapornis*

Fossil remains of *Agapornis* have been reported from seven areas in Africa, most of which are far from the extant distribution of the genus (Fig. 5). The Moroccan occurrence (Mourer-Chauviré & Geraads, 2010) is close to the Mediterranean more than 2,500 km north of the present day range of the genus and the localities of Langebaanweg (Manegold, 2013; Stidham, 2006) and Gauteng (Pocock, 1969; Stidham, 2009) are well south of the closest extant occurrences.

Until the material from Grillental VI was found, the oldest record of the genus was from Langebaanweg, South Africa (ca 6-5 Ma) (Fig. 5, 6).

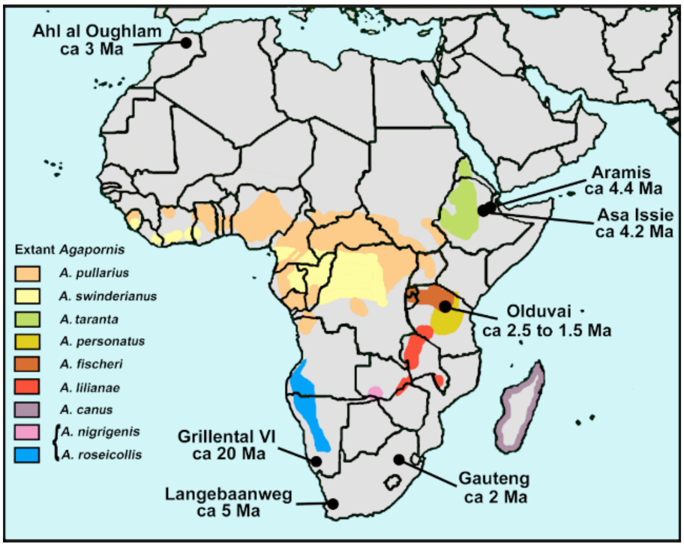

Figure 5. Distribution of fossil and extant species of *Agapornis*. Extant distribution is based on https://www.zoochat.com/community/media/lovebirds-distribution-maps.564221/, downloaded 28/10/2023. Note that only one of the palaeontological sites (Olduvai) that have yielded fossils of *Agapornis* falls within the present-day distribution range of the genus. Two extant species (bracketed) occur in Namibia.

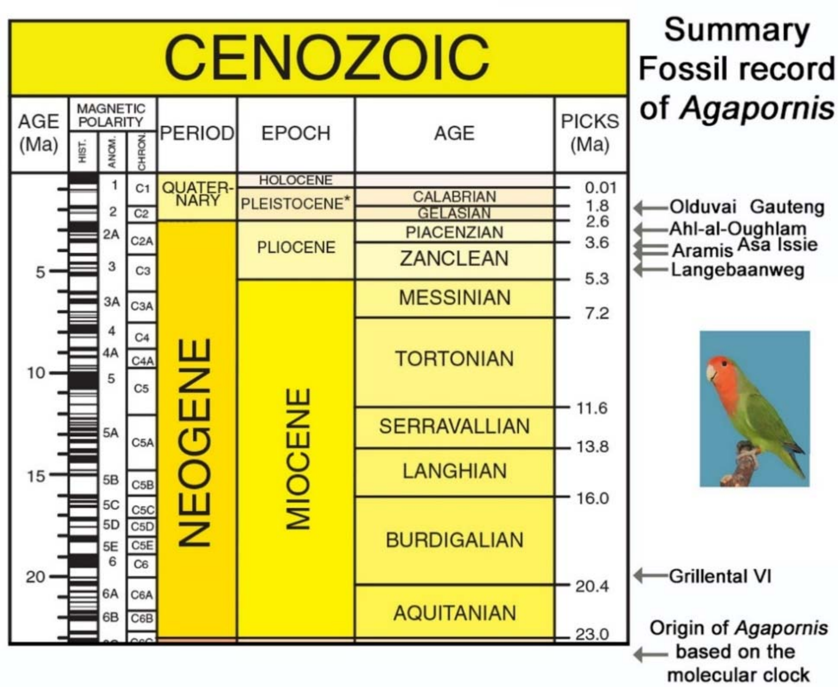

Figure 6. Stratigraphic position of fossils attributed to *Agapornis* species. Data from Manegold (2013), Louchart *et al*. (2009), White *et al*. (2006) and this paper.

Discussion

Interpretations of molecular data obtained from extant parrots suggest that *Agapornis* dispersed from Australia to Africa at the end of the Oligocene or the beginning of the Miocene (Manegold, 2013). If the timing of this trans-oceanic dispersal is correct, then it would imply that the Grillental VI fossils were preserved relatively soon after the arrival of the genus in Africa. This dispersal took place a long time after a previous dispersal of parrots to Africa during the Palaeogene, represented by *Namapsitta praeruptorum* from the Late Eocene of Eocliff, also in the Sperrgebiet (Mourer-Chauviré *et al*. 2014, 2017).

Palaeobiogeography

Lovebirds (*Agapornis*, Psittaculidae) currently occur in many parts of Namibia including Mopane Woodland and slightly more humid environments (Miombo Woodlands, Savannah) but are not often encountered in the Namib Desert or in winter rainfall areas of the country. Fossils of this family of small parrot-like birds, also known as parakeets, have been described from the late Miocene of South Africa (Langebaanweg, ca 5-6 Ma - Stidham, 2006; Manegold, 2013) and the Pliocene of Morocco (Ahl-al-Oughlam, ca 3 Ma - Mourer-Chauviré & Geraads, 2010) among other younger sites in Ethiopia (Louchart *et al*. 2009; White *et al*. 2006), South Africa (Pocock, 1969; Stidham, 2009) and Tanzania (Brodkorb, 1985; Prassack, 2010) (Fig. 5).

The distribution of fossils of *Agapornis*, even though limited to seven areas in the continent (Fig. 5, 6) is intriguing, in that six of the seven occurrences fall outside the distribution ranges of extant species of the genus. The locality of Ahl Al Oughlam, Morocco, is north of the Sahara, some 2,500 km from the nearest present-day occurrence of the genus. Two of the three fossiliferous areas in southern Africa that have yielded *Agapornis* (Fig. 7) are also far from the ranges of extant species, Gauteng (Plover's Lake, Kromdraai and Sterkfontein) being some 400 km south of the nearest occurrence, and Langebaanweg, ca 1,000 km south. Grillental VI falls outside the distribution range of extant *Agapornis*, but the distance is not great (ca 100 km) although its winter rainfall regime differs from the summer rainfall regime that today characterises the places where *Agapornis* survives.

Palaeoecology and Palaeoclimatology

Extant species of lovebirds nest in tall trees or crevices in high cliffs or in arboreal termite hives, and the staple diet of most species consists of grass seeds while only one species (forest-dwelling *Agapornis swinderianus*) feeds on figs (Manegold, 2013). The macrofaunal and microfaunal remains from Grillental VI include several vertebrate lineages (crocodiles, large tortoises, anthracotheres, rhinocerotids, proboscideans, hyracoids, ruminants, suids, carnivorans, rodents, macroscelideans, erinaceids, etc.) (Pickford, 2008c) which indicate that, during the Early Miocene, the region was relatively humid and well vegetated, with an important tree cover, radically different from the treeless hyper-arid conditions that prevail there today. The termites (hives of the polycalate genus *Hodotermes*) and the large species of the land snail genus *Dorcasia*, indicate that the area was probably within the summer rainfall zone, although the presence of the land snail *Trigonephrus* at Grillental VI suggests that the winter rainfall zone was not far away.

The presence of *Agapornis* in the Early Miocene sediments at Grillental reinforces these palaeoenvironmental and palaeoclimatic reconstructions. Considering all the evidence, it is concluded that the hyper-arid conditions that prevail in the Namib Desert today, were established sometime after the deposition of the Grillental green silts, hyper-aridity probably starting about 17 Ma.

The birds previously described from Grillental (Mourer-Chauviré, 2008) were not from the Knoll Site, but were found nearby. They comprise several waterbirds, *Megapaloelodus* (Family Palaelodidae, a primitive flamingo), and four Anseriformes, two in the subfamily Oxyurinae (stiff-tailed ducks) and two in the Anserinae (swans and geese). It is generally considered that Palaelodidae were fully aquatic. Taken together, the waterfowl from Grillental indicate the presence of significant bodies of water.

The fossil ostriches from Grillental (Mourer-Chauviré *et al*. 2023) suggest that there was open country in the region. The picture is emerging that during the Early Miocene, the Northern Sperrgebiet was considerably more humid than it is today, with savannah to woodland vegetation and substantial bodies of water in rivers and ponds.

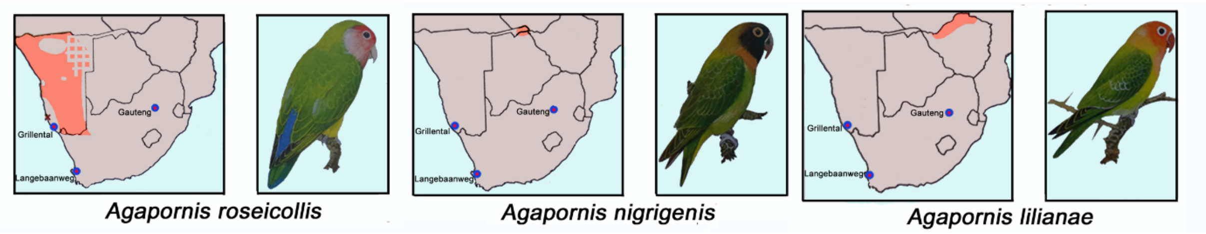

Figure 7. The distribution of extant lovebirds in Southern Africa and the position of three fossiliferous areas that have yielded specimens of these small parrot-like birds (blue circles with red centre). Distribution of extant species is from Sinclair & Hockey (2005).

Order Galliformes Linnaeus 1758

Family Phasianidae Vigors 1825

cf Genus *Palaeortyx* Milne-Edwards 1869

Material :- Left tarsometatarsus, distal part, GSN GT 104'19 (Fig. 8)

Osteology

Tarsometatarsus

Measurements :- distal width, 11.0 mm; distal depth, 7.5 mm.

On the tarsometatarsus the *trochleae met. II* and *IV* are relatively far apart from the *tr. met. III*. In distal view, the three trochleae are arranged along a slightly curved line. The *tr. met. II* extends a short way beyond the base of the *tr. met. III*, and it is weakly displaced plantarly. The *tr. met. IV* reaches the middle of the *tr. met. III*. The *foramen vasculare distale* is wide open and is followed by a broad groove between the *tr. met. III* and *IV*. The *incisura intertrochlearis lateralis* is wide.

Above the *incisura intertrochlearis medialis*, on the dorsal surface, there is a very small foramen. On the plantar surface this foramen opens by two very small orifices. This small foramen also exists in the genera *Pavo*, *Afropavo*, in some specimens of *Gallus*, and in several other phasianid genera (Mourer-Chauviré, 1989).

By the setting aside of the trochleae and the presence of a large *foramen vasculare distale*, this tarsometatarsus differs from those of the genera *Afropavo*, *Pavo*, *Gallus* and *Phasianus* and closely matches that of the genus *Palaeortyx* (Göhlich & Mourer-Chauviré, 2005).

Figure 8. Stereo images of GSN GT 104'19, distal left tarsometatarsus of cf *Palaeortyx* sp. A) dorsal views, B) distal views, C) plantar views.

Discussion

The genus *Palaeortyx* is known in Europe from the very beginning of the Late Oligocene to the Early Pliocene. It is wide-spread in France, Germany, Hungary, Spain and Italy (Mourer-Chauviré & Geraads, 2010). In Africa, a proximal carpometacarpus from the early Miocene of Elisabethfeld has been referred to *Palaeortyx* (Mourer-Chauviré, 2008) and two proximal parts of humeri from the basal Middle Miocene of Arrisdrift also show the morphological features of this genus (Mourer-Chauviré, 2003).

Order Passeriformes Linnaeus 1758

Suborder Passeri Sibley *et al.* 1988

Genus *incertae sedis*

Material :- GSN GT 54'23, left tarsometa-tarsus, distal part (Fig. 9).

Osteology

Tarsometatarsus
Measurement :- distal width 2.1 mm.

On the dorsal side of the tarsometa-tarsus the trochleae are slightly damaged. They are better preserved on the plantar side but the tip of the *tr. met. II* is broken. This tarsometa-tarsus shows the characteristic shape of the Passeriformes, Passeri. In distal view, the three trochleae are disposed in a straight line. The *tr. met. III* is larger and shows a groove, the *tr. met. II* and *IV* are narrow and ungrooved, the *tr. met. II* is directed slightly obliquely towards the medial side.

Figure 9. GSN GT 54'23, left tarsometatarsus of a small passerine bird from Grillental VI, Sperrgebiet, Namibia. A) dorsal view, B) plantar view.

Discussion

Apart from the Acanthisittidae of New Zealand, the Passeriformes are divided into two large groups, the Tyranni (or Suboscines), and the Passeri (or Oscines). The Tyranni are mainly present on the American continent and in the Old World tropics, while the Passeri are widespread over the entire globe, with the exceptions of South and Central America, and Antarctica.

The Tyranni were present in Europe from the Early Oligocene (Riamon *et al*. 2020), while the crown-group Passeri were present in Europe only from the Late Oligocene (Mayr, 2022). The Tyranni and the Passeri coexisted in Europe until the Early Miocene (Manegold, 2008). Passeriformes are unknown from the Palaeogene of Africa, Asia, North and South America. Passeriformes are present in the Early Miocene of Grillental and also of Napak in Uganda (Riamon, pers. comm). These two localities have yielded the earliest evidence of Passeriformes in Africa.

General Discussion and Conclusions

The green silts at Grillental VI Knoll Site have yielded a rich and diverse assemblage of small and medium-sized mammals, as well as remains of frogs, snakes, lizards and small birds. The mammalian fauna indicates correlation to the Early Miocene, ca 20-19 Ma (Pickford, 2008a, 2008c).

Three groups of small birds are now known from the deposit, Psittaculidae (lovebirds), Galliformes (gamebirds) and Passeri (songbirds). The staple diets of two of these groups comprise grass seeds, suggesting that, during the Early Miocene, the Northern Sperrgebiet was endowed with areas of grassland. Other fossils from the deposits such as termites, land snails and mammals, indicate a savannah to woodland environment, with annual rainfall of ca 750 mm which fell during the summer, contrasting with the hyper-arid conditions and winter rainfall that prevail in the region at present.

At 20-19 Ma, the Grillental representatives of the three avian groups described herein are among the earliest known from Africa. Previously, the oldest known lovebird from the continent was from Langebaanweg, South Africa (ca 6-5 Ma) (Manegold, 2013), the oldest known passerine was from Napak, Uganda (ca 20-19 Ma) (Riamon, pers. comm.) while the oldest known *Palaeortyx* was from Elisabethfeld (21-20 Ma) with slightly younger fossils of this genus known from Arrisdrift (ca 17.5 Ma) (Mourer-Chauviré, 2003, 2008).

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New remains of *Struthio coppensi*, Early Miocene, Namibia

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Abstract :- Field surveys over the past decade in the Sperrgebiet, Namibia, have led to the recovery of additional fossil remains of the Early Miocene ostrich, *Struthio coppensi* Mourer-Chauviré *et al*. 1996, including three fossils from a locality, Grillental VI, from which the species had not previously been recorded. Among the new material, there are two pedal phalanges and a cervical vertebra, as well as additional leg bones (tibiotarsus, tarsometatarsus). Descriptions and illustrations are provided of the material, which conform in dimensions and morphology with what would be expected for *Struthio coppensi*, which had ca 65% the dimensions of the extant ostrich, *Struthio camelus*.

Key Words :- Ostrich, Early Miocene, Osteology, Body size, Africa

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Introduction

The earliest known fossil ostriches, *sensu stricto* (Family Struthionidae) in the world were collected at Elisabethfeld, Namibia, from red silt-clay deposits correlated to the Aquitanian-Burdigalian (Early Miocene, ca 20-21 Ma) (Mourer-Chauviré *et al*. 1996a, 1996b; Senut *et al*. 1998; Mourer-Chauviré, 2008). The next youngest fossil bones of this family of large flightless bird (described herein) have been collected from green silts-clays at Grillental VI (ca 20-19 Ma), that are slightly younger than the red sediments at Elisabethfeld. Even younger fossil ostrich material (un-named species) is known from Kenya (Kadianga West, ca 14 Ma, Fort Ternan, ca 13.7 Ma, Ngorora ca 12.5 Ma; Leonard *et al*. 2006) and North African sites (Rich, 1974; Widrig & Field, 2022). In Eurasia, the oldest known representative of the *Struthio* group is from Çandir, Turkey (late Middle Miocene) (Sauer, 1979).

As currently understood, it is probable that the crown group ostriches, Struthionidae, originated in Southern Africa and were confined to the subcontinent until the base of the Middle Miocene, after which the family dispersed northwards throughout Africa, reaching Eurasia before the end of the Middle Miocene (Mayr & Zelenkov, 2021).

Stem group Struthioniformes occurred widely in Eurasia during the Palaeogene (Widrig & Field, 2022) and it is possible that one or other of these primitive Eurasian proto-ostrich lineages may have dispersed to Africa towards the end of the Eocene or Oligocene, where it gave rise to the 'true' ostriches. The apparent lack of fossil ostriches in African Palaeogene localities, could, however, be an artefact of the rather poor representation of sedimentary deposits of this period in the continent, with very little known from Sub-Saharan regions.

The palaeoenvironmental conditions at Elisabethfeld and Grillental 20 to 21 million years ago, based on the associated fauna (termites, pipid frogs, crocodiles, birds, rodents, macroscelidids, chrysochlorids, tenrecoids, erinaceids, creodonts, carnivores, lagomorphs, orycteropodids, hyracoids, proboscideans, suids, rhinocerotids, ruminants) are considered to have been somewhat more humid than they are today, probably savannah to open woodland, with at least 750 mm of rain per annum (Guérin, 2008; Mein & Pickford, 2008a-c; Morales &

Pickford, 2018; Morales *et al*. 1998, 2008a-b; Mourer-Chauviré, 2008; Mourer-Chauviré *et al*. 1996a-b, 2023; Pickford, 1997, 2006, 2008a-k, 2018; Pickford & Senut, 2008, 2018; Pickford *et al*. 2008a-b; Quiralte *et al*. 2008; Senut, 2000, 2008).

The fact that several of the small mammal taxa at Elisabethfeld and Grillental possessed hypsodont cheek teeth, indicates that grass was present, but possibly not in great enough quantities to support large mammals, most of which were brachyodont or bunodont.

The presence of the lovebird, *Agapornis* at Grillental VI (Mourer-Chauviré *et al*. 2023) supports this inference, because the staple diet of eight out of the nine extant species of this bird, comprises grass seeds that need to be available all the year round.

The termite hives (*Hodotermes*) and the molluscan fauna found at Grillental VI indicate that during the Early Miocene the region was under a summer rainfall regime, but with a winter rainfall zone not far away, because the land snail, *Trigonephrus*, that is today confined to regions experiencing winter rainfall, occurs at the site, alongside large species of *Dorcasia*, typical inhabitants of summer rainfall zones.

Systematics

Order Struthioniformes Latham, 1790

Genus *Struthio* Linnaeus, 1758

Species *Struthio coppensi* Mourer-Chauviré *et al*. 1996

Holotype :- GSN EF 3'94, distal end left tibio-tarsus.

Type locality and age :- Elisabethfeld, Sperr-gebiet, Namibia, Early Miocene, ca 21-20 Ma.

Other localities :- Grillental VI, Sperrgebiet, Namibia, ca 20-19 Ma.

New material
Grillental :- GSN GT 54'16, tibiotarsus, distal part (Fig. 2); GSN GT 41'18, first phalanx pedal digit III (Fig. 9); GSN GT 8'13, second phalanx pedal digit III (Fig. 10).
Elisabethfeld :- GSN EF 7'23, cervical vertebra (Fig. 1); GSN EF 4'23, right tibiotarsus distal part (Fig. 3); GSN EF 1'14, left tibiotarsus distal end (Fig. 4, 5); GSN EF 1'16, right tarsometa-tarsus, distal part and shaft (Fig. 6); GSN EF 18'16, left tarsometatarsus (Fig. 7, 8).

Anatomical Descriptions

Cervical vertebra GSN EF 7'23

In comparison with neck vertebrae of the extant ostrich, *Struthio camelus*, this specimen can be considered to correspond to cervical vertebra 5 or 6. It is damaged and slightly crushed in the dorso-ventral direction. On the dorsal surface, the left transverse process is missing and the one on the right is incompletely preserved, but the *facies articularis*, which is oval in outline, is visible. On the ventral surface the two costal processes are broken but the ventral part of the *arcus vertebrae* shows a swelling at the level of the base of these processes. The two *foramina transversaria* are followed by lateral gutters which extend beyond the midpoint of the vertebral body. The *facies articularis cranialis* is elongated laterally and flattened in the dorso-ventral direction. The 'wings' of the *facies articularis caudalis* are broken but the centre of this facies corresponds closely to the form observed in the extant ostrich.

The total length of this vertebra is close to that of the extant species, but the dorso-ventral height is appreciably less, probably because of the crushing that the specimen underwent during fossilisation. The main difference concerns the diameter of the vertebral foramen which, in the fossil, is considerably smaller than that of the extant ostrich.

Table 1. Measurements (in mm) of the cervical vertebrae of *Struthio coppensi* from Elisabethfeld and extant *Struthio camelus*.

Measurement	GSN EF 7'23	*S. camelus* VC 5	*S. camelus* VC 6
Total length of the *facies articularis cranialis* to the *facies articularis caudalis*	ca 51.1	50.4	55.4
Minimum breadth	16.0	17.5	16.0
Height at the same point	15.4	22.5	24.0
Dorso-ventral height of the *facies articularis caudalis*	ca 6.2	6.4	6.6
Breadth of the vertebral foramen	7.0	12.0	12.7
Dorso-ventral diameter of the vertebral foramen	6.0	11.5	11.7

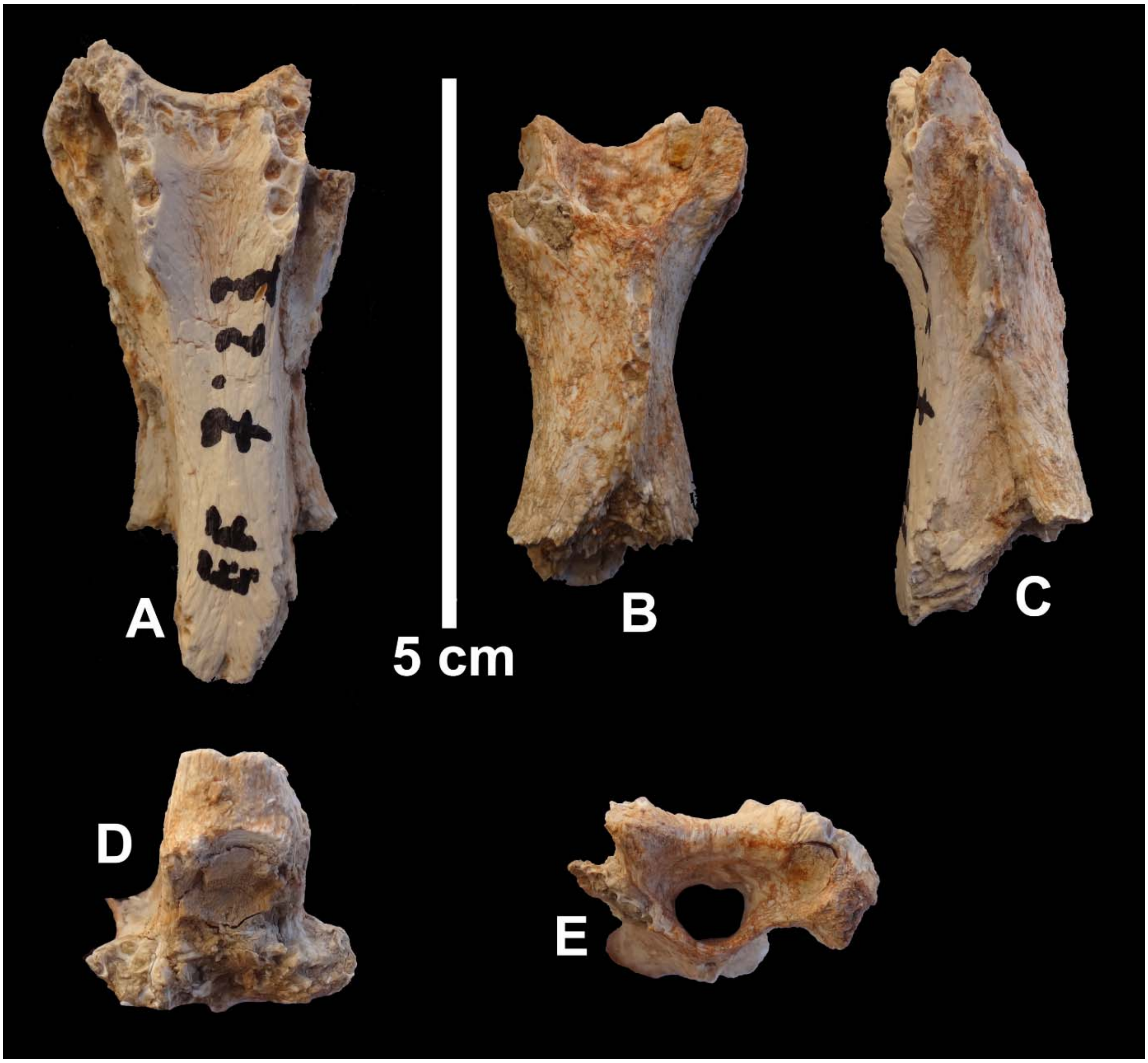

Figure 1. GSN EF 7'23 cervical vertebra 5 or 6. A) ventral view, B) dorsal view, C) right lateral view, D) caudal view, E) cranial view.

Right tibiotarsus, GSN GT 54'16

GSN GT 54'16 is a poorly preserved distal tibiotarsus. Part of the shaft is preserved along with much of the distal articulation, the width of which is 44 mm on the caudal side. What remains of the specimen closely resembles the holotype of *Struthio coppensi*.

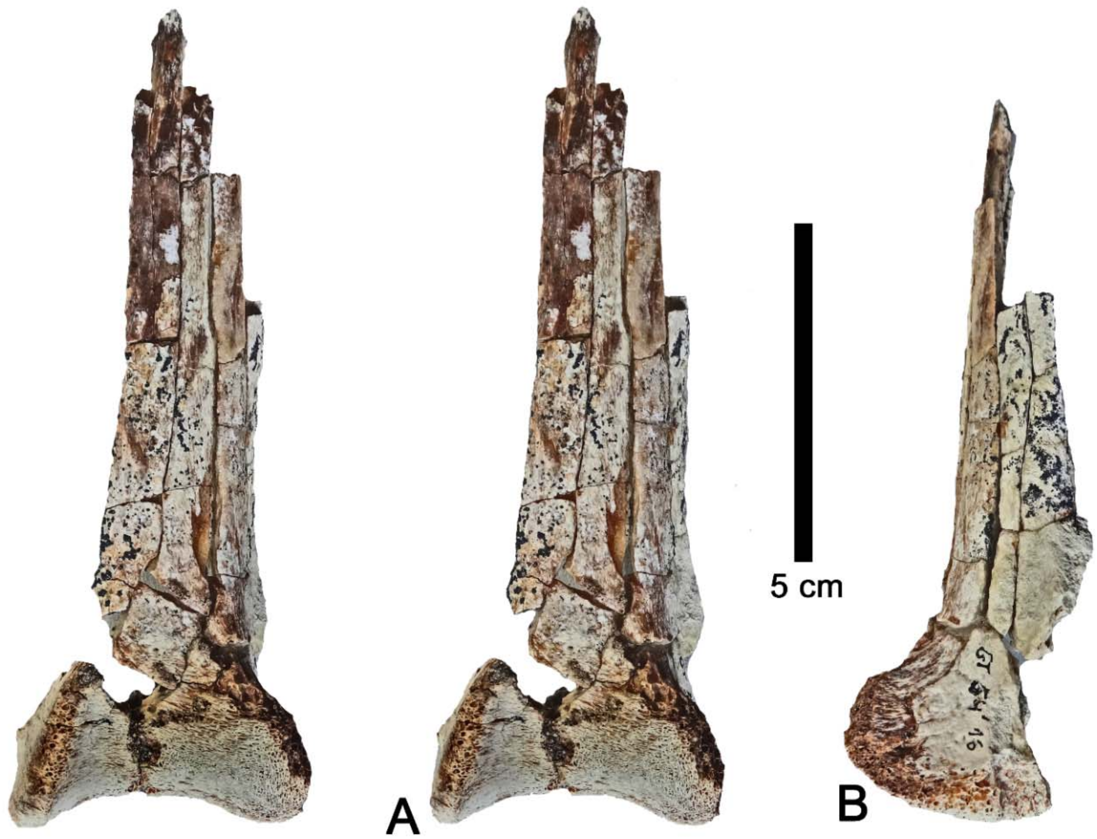

Figure 2. GSN GT 54'16, distal right tibiotarsus of *Struthio coppensi* from Grillental VI, Sperrgebiet, Namibia. A) stereo caudal view, B) medial view.

Right tibiotarsus GSN EF 4'23

The distal end of the right tibiotarsus is poorly preserved but shows the same characteristics as GSN EF 3'94, the holotype of the species *Struthio coppensi* Mourer-Chauviré *et al*. 1996 (Fig. 3). Its dimensions, where they can be measured, are slightly lower, but that is probably due to its poor state of preservation. The minimum diameter of the distal articulation is 26 mm which is the same as that of the holotype of *S. coppensi* (Mourer-Chauviré *et al*. 1996).

On the lateral side (Fig 3 B) and on the medial side (Fig. 3 D) all the cranial parts of the medial and lateral condyle are missing. On the medial side (Fig. 3 D) one can see the *fovea lig. collateralis*, which is circular in outline.

On the caudal side the shape of *the trochlea cartilaginis tibialis* is craniocaudally elongate while in *S. camelus* it is rectilinear and almost perpendicular to the axis of the shaft. The two condyles are similar and clearly less projecting than in *S. camelus*. In *S. camelus,* still on the caudal side, the medial condyle is rounded, while the lateral condyle is blade-like.

Table 2. Measurements (in mm) of GSN EF 4'23, distal right tibiotarsus from Elisabethfeld, Namibia.

Distal width cranial part	41.6
Distal width caudal part	34.7
Minimum trochlear diameter	26.0
Depth of medial condyle (as preserved	34
Depth of lateral condyle (as preserved)	38

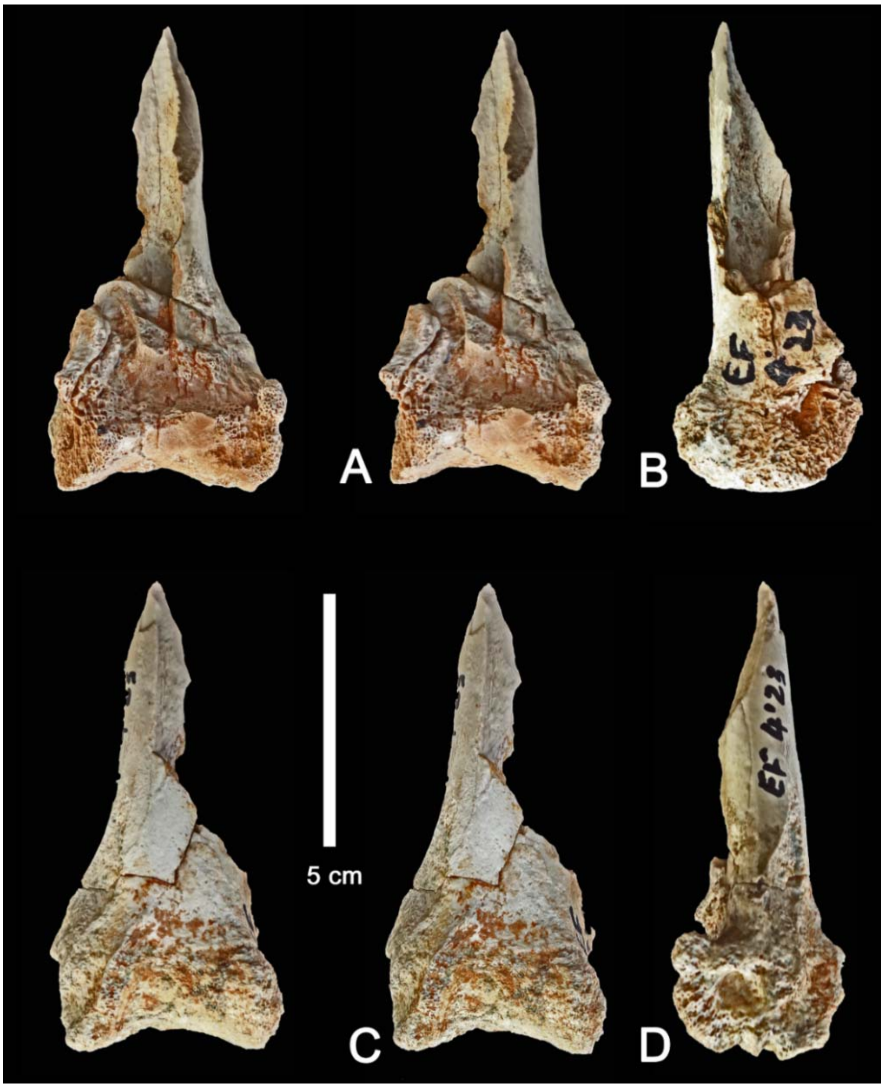

Figure 3. GSN EF 4’23, distal end of the right tibiotarsus. A) stereo cranial view, B) lateral view, C) stereo caudal view, D) medial view.

Left tibiotarsus GSN EF 1’14

GSN EF 1’14 preserves much of the shaft and the distal end of a left tibiotarsus (Fig. 4, 5). Its morphology is similar to that of the holotype of *Struthio coppensi* Mourer-Chauviré *et al*. 1996, but it is larger. Unlike the holotype, the shaft has not been crushed but there are several cracks in the bone, but with little or no displacement of the fragments.

The distal part is not as flattened as in the holotype, GSN EF 3’94. It is probable that the holotype has been squashed somewhat during fossilisation. On the cranial side the two condyles are linked by a wide open indentation. In the supracondylar fossa a flattened tubercle which is the supra articular tubercle (TSA) can be seen (Fig. 5).

As in *S. camelus*, on the cranial side, the medial condyle projects strongly cranially and the lateral condyle is more developed in the proximal direction. On the medial side the *depressio epicondylaris medialis* has the shape of a semilunate fossa, and above the *epicondylus medialis* there is a distinct attachment scar for the *ligamentum collaterale longum*. Both of these characters are present in the recent genus, *Struthio*, and in the extinct genus, *Palaeotis* (Mayr & Zelenkov, 2021). On the caudal side, as on the specimen EF 4’23, the two condyles do not project strongly caudally.

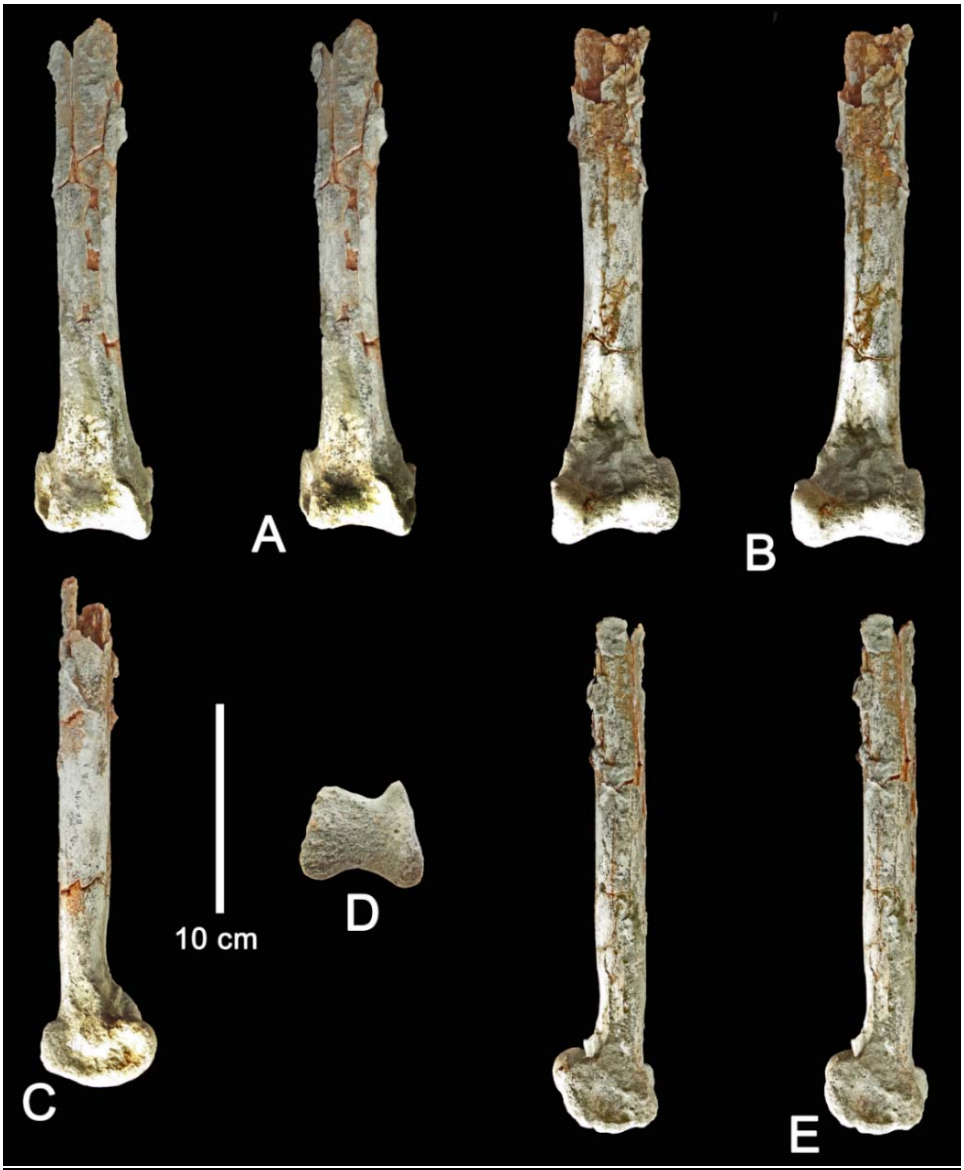

Figure 4. GSN EF 1’14, left tibiotarsus of *Struthio coppensi* from Elisabethfeld, Namibia. A) stereo caudal view, B) stereo cranial view, C) medial view, D) distal view, E) stereo lateral view.

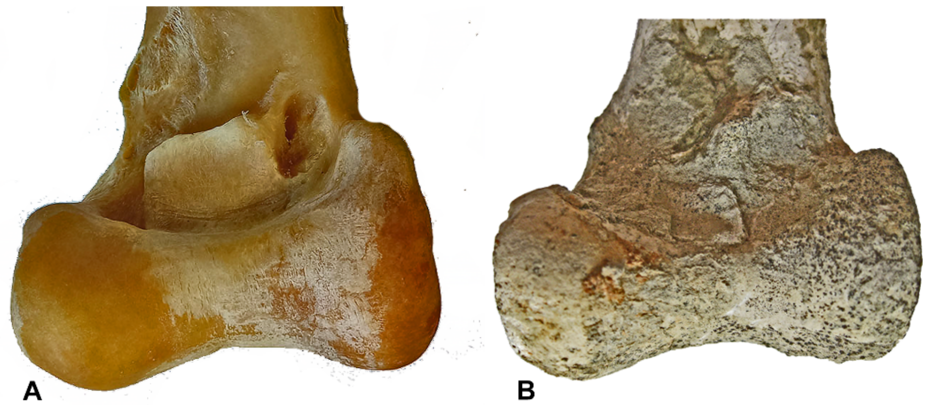

Figure 5. Comparison of the supra articular tubercle (TSA) of the distal left tibiotarsus in A) *Struthio camelus* (specimen Sh1 in the Musée des Confluences, Lyon) and B) *Struthio coppensi* (GSN EF 1’14). The images are produced at the same size to facilitate comparisons.

Right tarsometatarsus GSN EF 1’16

The right tarsometatarsus, GSN EF 1’16, is crushed cranio-caudally, and the distal articulations are damaged (Fig. 6). However, the overall length of the specimen is impressive, much of the diaphysis being preserved. The shaft is curved, being slightly outbowed, but this appearance could be enhanced by the crushing that the bone has undergone. The trochleae for the pedal phalanges are damaged and slightly distorted, but their dimensions indicate that they were somewhat larger than in the holotype of the species.

On the dorsal side the *foramen vasculare distale* is situated at the end of a short groove and at some distance from the *incisura intertrochlearis lateralis* while in *S. camelus* the foramen opens just above the *incisura* and the groove is absent. The vestigial *trochlea metatarsi II* was present on the tarsometatarsus GSN EF 1’94 paratype of the species (Mourer-Chauviré, 2008, fig. 1, B3) but is not visible on this specimen.

Table 3. Measurements (in mm) of GSN EF 1’16, distal right tarsometatarsus from Elisabethfeld, Namibia.

Preserved length	300
Width of trochlea III	ca 29
Width of trochlea IV	18.7

Figure 6. GSN EF 1’16, distal right tarsometatarsus of *Struthio coppensi* from Elisabethfeld, Namibia. A) stereo caudal view, B) stereo cranial view.

Left tarsometatarsus GSN EF 18'16

GSN EF 18'16 is a left tarsometatarsus lacking the proximal extremity and parts of the distal end. In addition it is broken and slightly crushed but parts of the distal end are reasonably well preserved (Fig. 7, 8). The trochlea of digit IV is well preserved and diverges at an angle of ca 30° from the axis of the condyle of digit III. Its extremity curves medially and caudally. Parts of the groove of the trochlea of digit III are missing, but the medial and lateral margins are reasonably well preserved, allowing the overall morphology to be observed. The width of the trochlea III is 26.5 mm which is slightly greater than in the holotype of *Struthio coppensi*.

Table 4. Measurements (in mm) of GSN EF 18'16, distal left tarsometatarsus from Elisabethfeld, Namibia.

Depth of trochlea III	ca 25
Width of trochlea III	26.5
Depth of trochlea IV	ca 18.2
Width of trochlea IV	11.0

Figure 7. GSN EF 18'16, left tarsometatarsus of *Struthio coppensi*, at the moment of discovery. Aeolian deflation of the red silts exposes the fossils, but the boisterous winds also break them into fragments. This fossil was not visible in 2015, and its condition when found explains why surveys in the Sperrgebiet are necessary every year. Had it not been collected in 2016, within a few months it would have been an unrecognisable assemblage of small bone flakes.

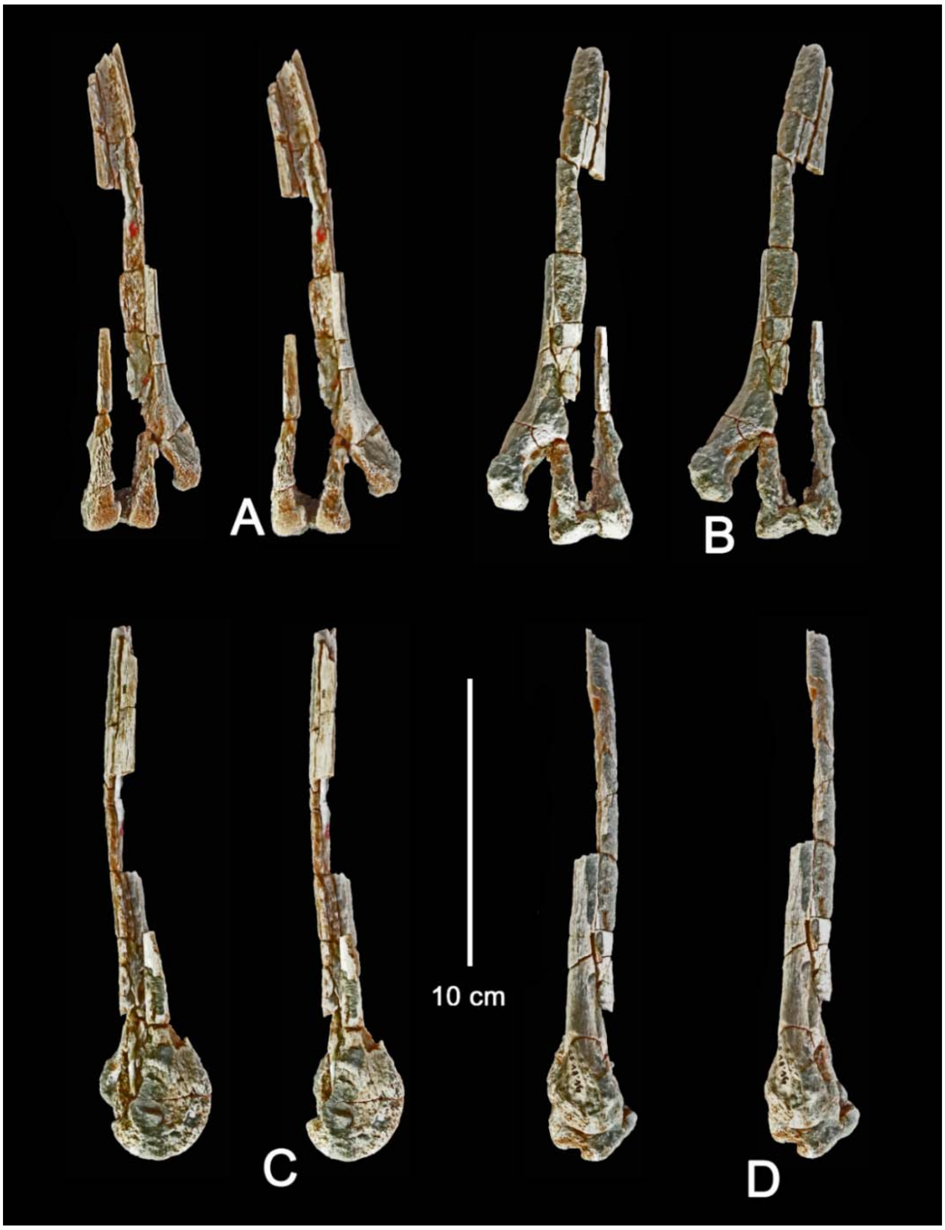

Figure 8. Stereo images of GSN EF 18'16, distal left tarsometatarsus of *Struthio coppensi* from Elisabethfeld, Namibia, after reconstruction. A) cranial view, B) caudal view, C) medial view, D) lateral view.

On this tarsometatarsus the *trochlea met. IV* diverges strongly laterally, as in the paratype tarsometatarsus GSN EF 1'94, while on the specimen GSN EF 1'16, the two trochleae are compressed together, probably due to crushing during fossilisation. On other tarsometatarsi from Elisabethfeld, the *trochlea metatarsi II* is very close to the trochlea III in GSN EF 172'01 and widely diverging from it in GSN EF 35'96 (Mourer-Chauviré, 2008, fig. 3, B and C).

Pedal first phalanx digit III GSN GT 41'18

GSN GT 41'18, the first pedal phalanx, digit III, from Grillental VI, is damaged, but its length and the morphology of one side can be reasonably well estimated (Fig. 9). With a length of 60 mm, it is 142% of the length of the second phalanx, digit III (see below). The fossa for the distal ligamentar insertion is deep and occupies about half the height of the distal end.

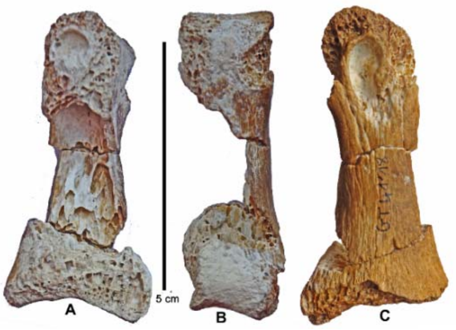

Figure 9. GSN GT 41’18, pedal first phalanx digit III. A) side view, B) plantar view, C) side view.

Pedal second phalanx digit III GSN GT 8’13

GSN GT 8’13 is a pedal second phalanx of digit III (Fig. 10). This phalanx differs strongly from that of *S. camelus* where the *corpus phalangis* is constricted both dorsoplantarly and mediolaterally. A similar, juvenile, phalanx has already been found in Elisabethfeld, (GSN EF 240’01, Mourer-Chauviré, 2008, fig. 3 E).

Its length is 42.2 mm. In extant *S. camelus* the mean length of this phalanx is 60 mm in females and 57.6 mm in males (Elzanowski & Louchart, 2021). The ratio between the length of the Grillental specimen and those of extant ostriches is thus ca 70 %, which corresponds closely with what was found at Elisabethfeld, where *S. coppensi* was shown to be about 65% of the dimensions of *S. camelus*.

Table 5. Measurements (in mm) of GT 8’13, pedal second phalanx, digit III, from Grillental VI, Namibia.

Total length	42.2
Proximal breadth	37.8
Proximal height	21.3
Distal breadth	22.0
Distal height	13.0
Mid-shaft breadth	20.2
Mid-shaft height	13.0

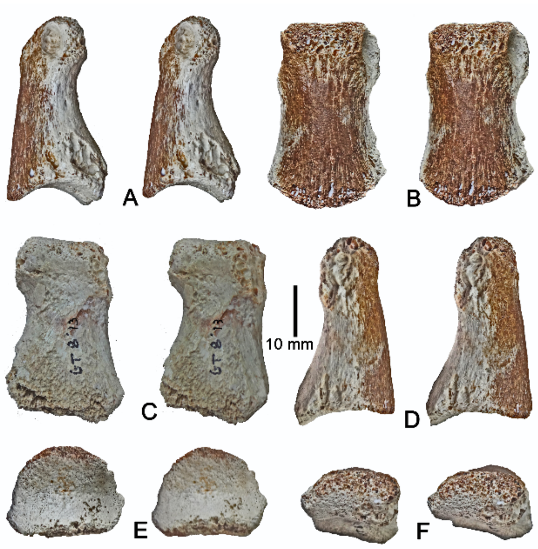

Figure 10. Stereo images of GSN GT 8’13, pedal second phalanx, digit III of *Struthio coppensi* from Grillental VI, Namibia. A) side view, B) dorsal view, C) ventral view, D) side view, E) proximal view, F) distal view.

Discussion and Conclusions

The fossil remains of *Struthio. coppensi* differ from those attributed to *Struthio* sp. from the middle Miocene of Kenya (Leonard *et al*. 2006). On a left tibiotarsus from Kadianga West, the medial condyle is not preserved on the cranial side but on the caudal side it is blade-like, as in *S. camelus*. On the cranial side the lateral condyle is very projecting, rounded, and the proximal border of the *incisura intercotylaris* is rectilinear, while it is incurved in *S. coppensi*. In contrast, in the distal tarsometatarsus from Fort Ternan, *the trochlea met. III* is wide and the *trochlea met. IV* is thin and much shorter than *the trochlea met. III*. In these characters, the Fort Ternan form seems to be more advanced than *S. camelus* in the process of reduction of the pedal digits.

The discovery of additional postcranial elements of struthioniform birds at Elisabethfeld and Grillental, Sperrgebiet, Namibia, confirms the presence of a primitive ostrich in the Early Miocene of Southern Africa, that was about 2/3 the dimensions of the extant ostrich *Struthio camelus*. The new collections include a cervical vertebra and two pedal phalanges, elements that were not represented in the original material described by Mourer-Chauviré *et al*. (1996) and subsequently by Mourer-Chauviré (2008) and not surprisingly, they also recall their counterparts in the extant species, apart from their smaller dimensions. There are however, some morphological differences between the two species, but these are not considered to be of sufficient weight to warrant separation of the species at the genus level.

The fossil struthious eggshells from the same localities in the Sperrgebiet, however, are rather different from those of extant ostriches, being more akin to those of aepyornithoids (Senut *et al*. 1998; Senut, 2000). The eggshells were formally named by Pickford (2014) as *Tsondabornis minor*, with a known distribution at Elisabethfeld, Fiskus, Grillental and Langental, all sites in the Sperrgebiet.

There is debate about the continent in which the family Struthionidae originated. Mikhailov & Zelenkov (2020) wrote that "*The first appearance of ostriches in the fossil record in the early Miocene of Namibia supports the South African origin of at least the crown representatives of the group*". In contrast, Widrig & Field (2022) wrote: "*With the reassignment of Eogruidae, there is now a clear record of stem Struthionidae in Eurasia well before the first crown struthionids appear in the Miocene of Africa. It now appears likely that this iconic clade of extant African birds first arose outside the continent….With Palaeotids interpreted as stem struthionids the case for an Eurasian origin of Struthioniformes is strengthened even further*". The latter hypothesis was supported by Mayr (2022) who wrote "*Recognition of the European Palaeotididae, the North American Geranoididae, and the Asian Eogruidae as stem group representatives of the Struthioniformes supports a Northern Hemisphere origin of ostriches and a dispersal into Africa toward the late Paleogene or earliest Neogene*."

Whatever the outcome of the debate, it seems that the earliest known 'true' ostriches are from the Early Miocene of Namibia. To some extent, the debate is more about ranks in classification of the ostrich-like birds (family, superfamily, etc.) and their ancestors, which may well have had an origin in the Northern Hemisphere, with the final transition to 'true' ostriches (family Struthionidae *sensu stricto*) taking place in southern Africa, as was postulated by Mourer-Chauviré *et al*. (1996), followed by dispersal into the northern continents during the Middle Miocene.

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Hominoids from Berg Aukas, Middle Miocene, Namibia – Revision of dental measurements

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Abstract :- Revised measurements of hominoid teeth from Berg Aukas, Namibia, indicate that the two species previously reported from the site were of similar body size, raising the possibility that there might be only a single species present. However comparisons of dental morphology confirm the hypothesis of two species, *Otavipithecus namibiensis* and cf *Kenyapithecus* sp. closer in dimensions to *K. africanus* than to *K. wickeri*.

Key words :- Late Middle Miocene, Hominoidea, Africa, Measurements, Dentition

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Introduction

The sample of late Middle Miocene hominoids from Namibia was recently augmented by the description of several dentognathic and postcranial specimens collected at Berg Aukas during the 1960's (Mocke *et al*. 2022). In that study, the material was interpreted to belong to a genus close to *Kenyapithecus*, because the morphology of the cheek teeth is closer to the situation in *Kenyapithecus wickeri* Leakey, 1962, from Kenya, than it was to the type material of *Otavipithecus namibiensis* Conroy *et al*. 1992

Restudy of all the Berg Aukas fossils in 2022 led to the realisation that the published measurements were taken in slightly different ways from the usual method. We herein publish revised measurements of the dental remains (Table 1).

Material and Methods

The fossils are curated at the Earth Science Museum, Geological Survey of Namibia, Windhoek, under the register numbers GSN BA 11'21, mandible and GSN BA 12'21, upper molar.

The mesio-distal length and bucco-lingual breadth of the fossil teeth were measured using metal sliding calipers to the nearest tenth of a mm.

Results

The new measurements of all the Berg Aukas hominoid teeth indicate that the recently described material (Mocke *et al*. 2022) agrees in metric details with the previously described hypodigm of *Otavipithecus namibiensis* (Conroy *et al*. 1992) (Table 1, Fig. 6). As a result, the length/breadth ratios of the teeth are slightly different from what was previously published, and now accord more closely in length/breadth proportions to the original hypodigm of *Otavipithecus namibiensis*. However, the morphology of the teeth indicate that there are indeed two taxa of hominoids in the Berg Aukas sample, *Otavipithecus namibiensis* and a *Kenyapithecus*-like form (Figs 1-4).

Comparison of the upper molar from Berg Aukas (GSN BA 12'21) with East African hominoids, reveals similarities to the species *Kenyapithecus africanus* (Le Gros Clark & Leakey, 1950) (Fig. 5).

Table 1. Measurements (in mm) of the teeth of cf *Kenyapithecus* sp. (GSN BA 11'21 and GSN BA 12'21) and *Otavipithecus namibiensis* from Berg Aukas, Namibia. (MDL – mesio-distal length, BLB – bucco-lingual breadth). In italics are the previously published measurements of the material.

Tooth	MDL	BLB	MDL/BLB	*Published MDL*	*Published BLB*	*Published MDL/BLB*
GSN BA 11'21 rt m/1	8.5	7.4	1.15	*9*	*7*	*1.28*
GSN BA 11'21 rt m/2	9.2	8.6	1.07	*9*	*9*	*1.00*
GSN BA 11'21 rt m/3	10.7	8.8	1.21	*10*	*9*	*0.90*
GSN BA 12'21 rt upper molar	8.7	10.8	0.82	*9.0*	*11.0*	*0.81*
Holotype *O. namibiensis* rt m/1	8.5	7.6	1.18			
Holotype *O. namibiensis* rt m/2	10.0	9.2	1.08			
Holotype *O. namibiensis* rt m/3	9.6	7.8	1.23			

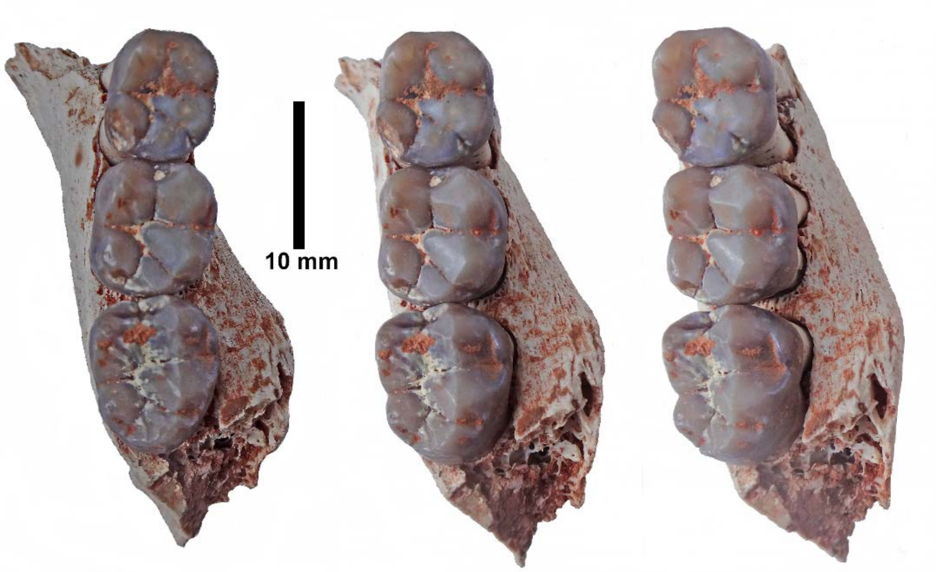

Figure 1. Stereo occlusal views of GSN BA 11'21, right mandible of cf *Kenyapithecus* sp. from the late Middle Miocene of Berg Aukas, Namibia.

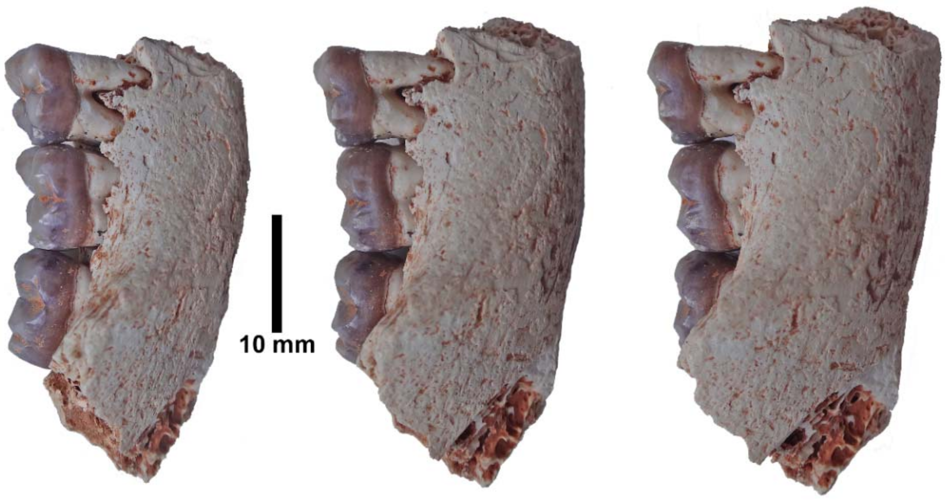

Figure 2. Stereo buccal views of GSN BA 11'21, right mandible of cf *Kenyapithecus* sp. from the late Middle Miocene of Berg Aukas, Namibia.

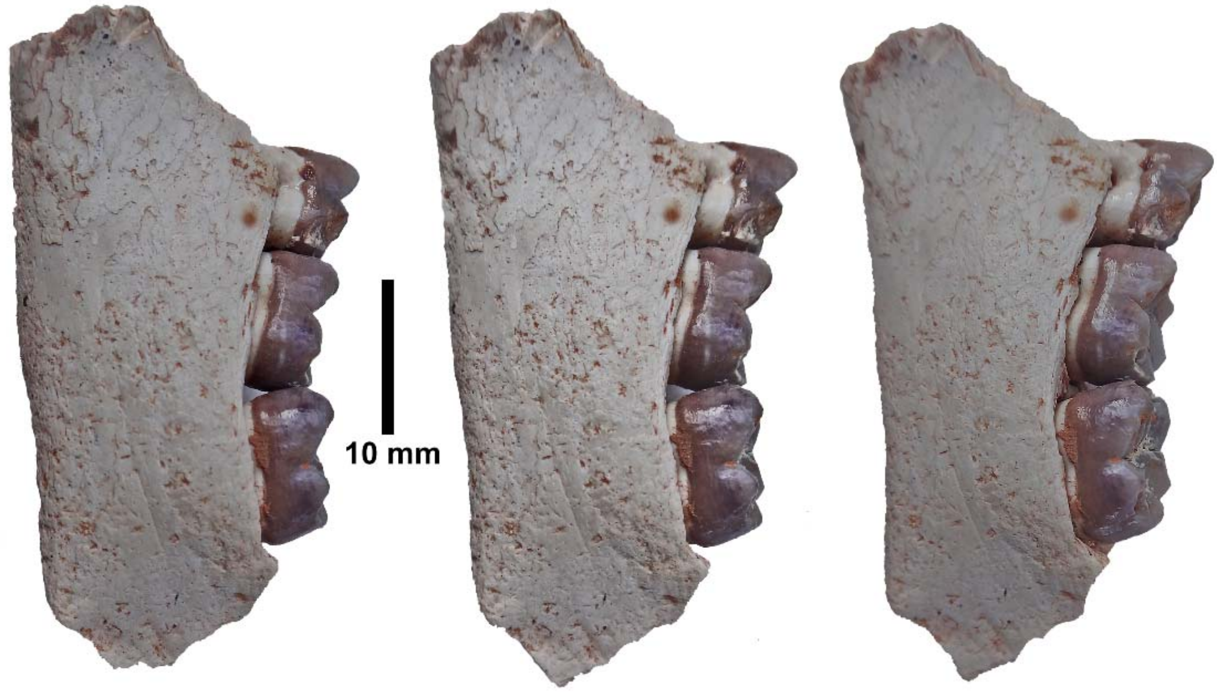

Figure 3. Stereo lingual views of GSN BA 11'21, right mandible of cf *Kenyapithecus* sp. from the late Middle Miocene of Berg Aukas, Namibia.

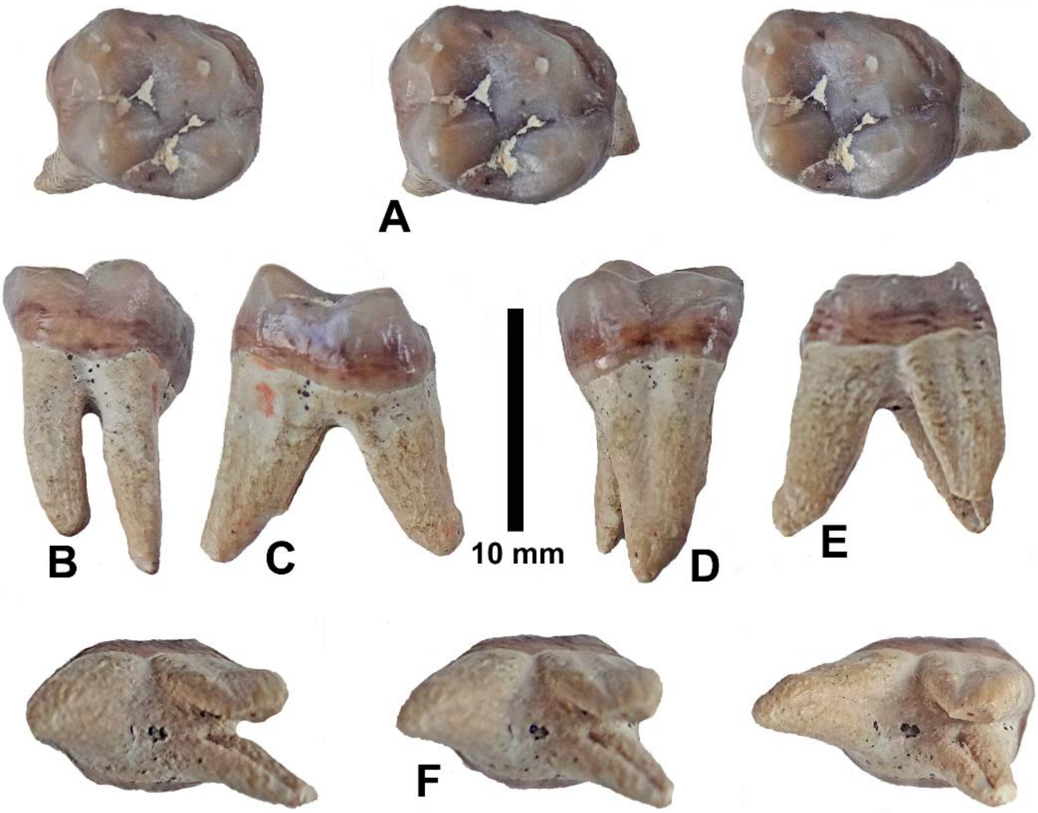

Figure 4. GSN BA 12'21, right upper molar of cf *Kenyapithecus* sp. from the late Middle Miocene of Berg Aukas, Namibia. A) stereo occlusal views, B) buccal view, C) distal view, D) lingual view, E) mesial view, F) stereo radicular view.

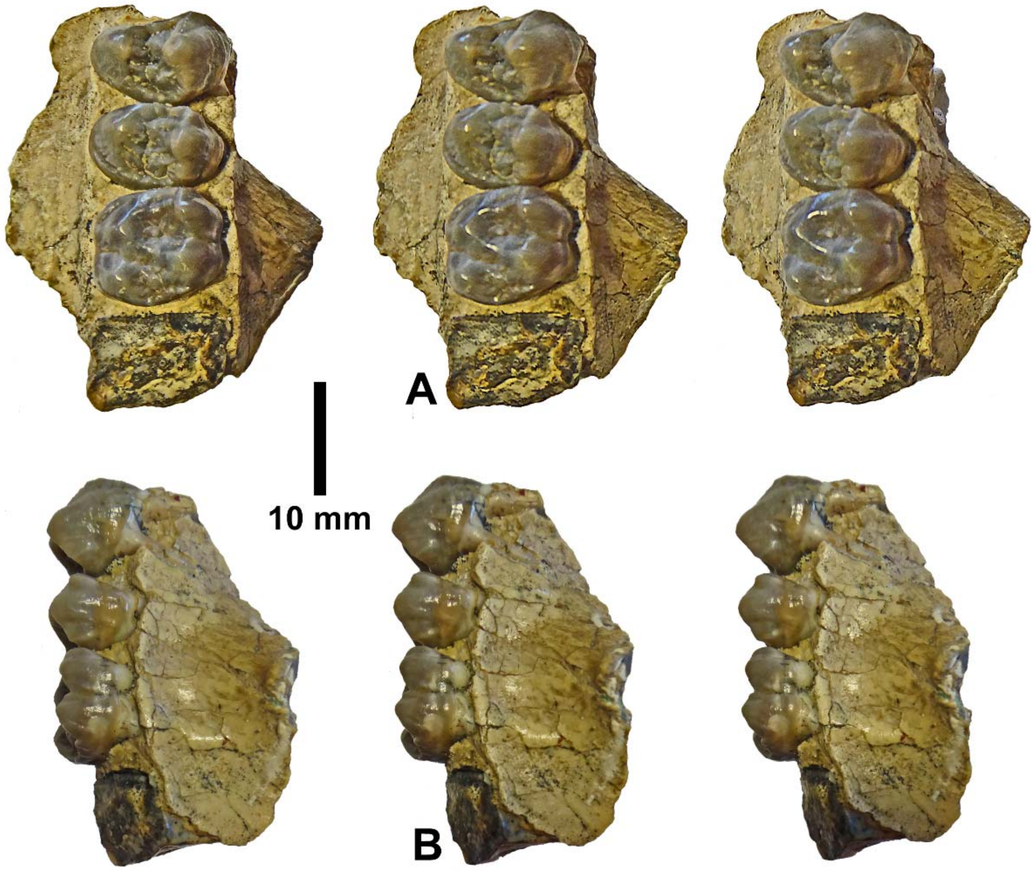

Figure 5. NHMUK M 16649, holotype maxilla with P3/-M1/ and roots of M2/ of *Kenyapithecus africanus* from the Middle Miocene of Kenya, probably Maboko. A) stereo occlusal views, B) stereo lateral views.

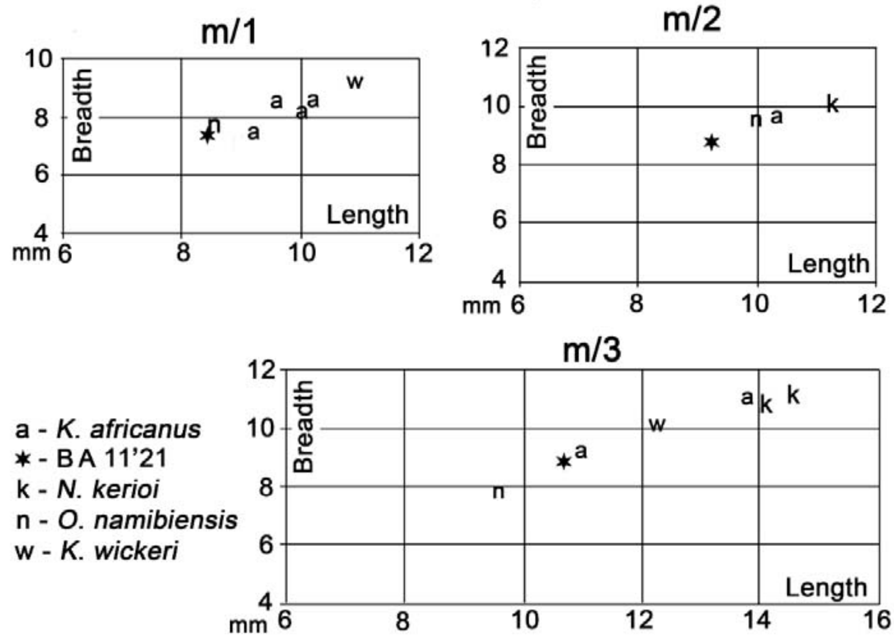

Figure 6. Bivariate metric comparisons between lower molars of cf *Kenyapithecus* sp. (GSN BA 11'21) and the holotype of *Otavipithecus namibiensis* from Berg Aukas, Namibia, and three species of Middle Miocene hominoids from Kenya. Overall, BA 11'21 is closest to *Kenyapithecus africanus* (Le Gros Clark & Leakey, 1950) (figure modified from Mocke *et al*. 2022). (Measurements of East African specimens are from Pickford, 1985; Ishida *et al*. 1999 and Kunimatsu *et al*. 2004).

Conclusion

Revised measurements and re-examination of the dental sample of hominoid fossils from Berg Aukas, Namibia (late Middle Miocene) indicate that the two species of ape-like creature that have been reported from there were of similar body size, but that the differences in dental morphology indicate that they belong to distinct genera, as was concluded in previous studies.

Acknowledgements

We thank Mr Faan Van der Merwe for providing access to the fossils for detailed study. The National Commission on Research, Science and Technology authorised the Namibia Palaeontology Expedition to carry out research in the country. The NPE is a collaborative project undertaken by the Geological Survey of Namibia and the French National Museum of Natural History/Sorbonne University (CR2P).

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Kaokoland Cascade Tufa Survey – 2023 Research

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Abstract :- The ongoing Kaokoland Cascade Tufa Survey aims to identify and document all the tufa occurrences in the Kunene Region of Northern Namibia. Documentation of the tufas represents a preliminary stage in the long term study of the deposits from palaeontological, archaeological, palaeoclimatic, geomorphological, taphonomic and biogeochemical perspectives. Twenty tufa occurrences have already been described in Kaokoland (and seven in the Naukluft Mountains) and this report adds a further 9 examples in Kaokoland. It is clear from examination of satellite imagery that, in the Kunene region, many more tufa deposits remain to be explored.

Key words :- Tufa, Pleistocene, Kunene Region, Palaeoclimate

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Introduction

Cascade tufa deposits and related superficial calcareous sediments comprise an important research base concerning Pleistocene and Recent palaeoclimatic conditions. The Kaokoland area in the Kunene Region of northwestern Namibia (Fig. 1) is today an arid steppic to desert region, but the presence of abundant tufa deposits scattered over a wide area indicates that at times in the past the local climatic conditions were probably more humid and cooler than they are at present.

Currently available evidence indicates that, during the Pliocene to Recent, there were at least three phases of active tufa deposition in Kaokoland interspersed with periods of non-deposition or of erosion. Fossils and stone tools cemented into the tufas provide a source of information concerning the ages of the tufas. The oldest occurrence of fossils so far encountered in the Kaokoland tufas is estimated to be of Middle Pliocene age, the microfauna from Okongwe correlating with that from the Makapansgat cave breccias of South Africa which are dated ca 3 Ma (3.0-2.7 Ma, Pickford, 2006; or 3.03-2.58 Ma, Herries *et al*. 2013). However, the majority of the Kaokoland tufa deposits are younger, several of them containing Middle Stone Age and Late Stone Age lithic implements (Pickford *et al*. 2016; Pickford, 2019, 2020).

Examination of satellite imagery suggests that many tufa deposits remain to be discovered in the Kunene Region, but the digital signatures of the potential occurrences need to be verified by ground control. A ten day survey was undertaken in October, 2023, in order to examine some of the potential tufa occurrences identified via satellite imagery in the country west and north of Opuwo, and southwards between Opuwo and Sesfontein.

The aim of this paper is to list the positively identified tufas and related deposits and thus to add to the inventory of known tufa occurrences in Namibia (Mocke, 2014; Mocke *et al*. 2022; Pickford, 2019, 2020; Pickford & Senut, 2010; Pickford *et al*. 1993, 1994, 2009, 2016). The fact that several of the tufas contain stone tools is of interest to the archaeological community, because few if any of these sites were previously known to yield items of archaeological interest.

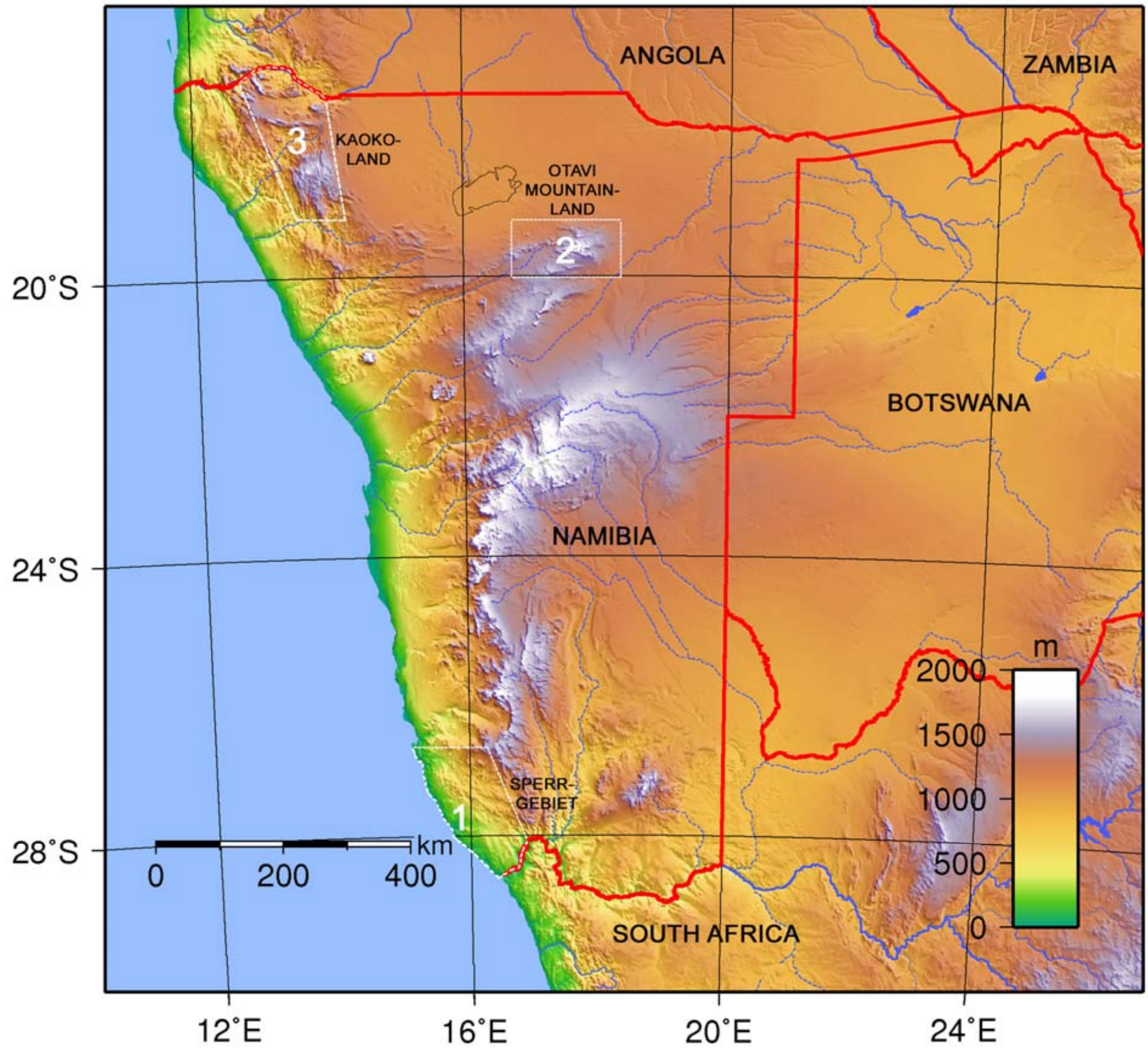

Figure 1. The three main areas in which the Namibia Palaeontology Expedition has permits to survey. 1) Sperrgebiet, 2) Otavi Mountainland, 3) Kaokoland (in Kunene Region). Other fossiliferous zones in the country are the Naukluft Mountains and the Namib-Naukluft Park.

Results

The October, 2023 Cascade Tufa Survey resulted in the verification of nine previously unmapped Plio-Pleistocene to Recent fossiliferous tufas and related karstic and epikarstic deposits in Kaokoland, both north and south of Opuwo (Table 1). Searches in incised tufa complexes at Okombeiza and Otjitaime Downstream failed to yield any vertebrate fossils, but it is stressed that, due to time constraints, much of the outcrop area was not surveyed in detail. At most of these sites there were at least two phases of tufa deposition, with complex interfingering relationships with fluviatile conglomerates and groundwater calcretes. However, at Khowarib, there is evidence of at least three episodes of tufa deposition, with tufa lobes interfingering with fluviatile sediments that have been overprinted by incipient pedogenic calcrete (hardpan) processes and cemented slope debris.

Location maps (Figs, 2, 4, 7 etc.) are modified from Google Earth, north to the top of the page.

Table 1. Tufa complexes of Kaokoland surveyed in October, 2023 (in alphabetical order).

Tufa Complex	Latitude	Longitude	Altitude (GPS)
Ekoto Bastion Tufa	17°56'06.8''S	13°13'20.7''E	1110 m
Kaoko Otavi groundwater calcrete dome and tufa	18°17'51.3''S	13°39'48.3''E	1449 m
Khowarib calc tufa	19°16'29.4''S	13°53'39.1''E	723 m
Okombako Bastion Tufa	18°52'15.0''S	14°02'43.0''E	1308 m
Okombeiza Barrage Tufa	18°48'06.9''S	13°33'59.9''E	1146 m
Okongwe tufa lobes	18°53'50.0''S	14°04'15.0''E	1228 m
Okapiku Cascade Tufas	18°53'21.0''S	14°03'22.0''E	1306 m
Okovanatje Cascade Tufa	18°51'38.0''S	14°02'25.0''E	1347 m
Omokutu, barrage tufa *in situ* in river bed	19°16'29.1''S	13°53'58.6''E	795 m
Omungunda show cave (= Rocky 3)	17°47'56.8''S	13°41'21.0''E	1345 m
Omungunda stone tool site	17°47'55.3''S	18°41'20.2''E	1359 m
Ongongo Spring Tufa	19°08'23.0''S	13°49'10.0''E	731 m
Opuwo Cascade Tufa	18°07'14.6''S	13°53'19.1''E	1280 m
Otjisakumuka Cascade Tufa	19°05'40.5''S	13°57'01.1''E	1065 m
Otjitaime Downstream cascade tufas	18°51'59.7''S	13°44'36.3''E	1202 m
Otjitieue groundwater calcrete dome and tufa	18°43'07.2''S	13°32'19.4''E	1140 m

Opuwo (= Enough in Himba)

A cascade tufa lobe crops out 8 km southeast of Opuwo, visible from the main road between Opuwo and Etosha (Figs 2-3). The complex is just north of the road and is ca 70 metres broad by 60 metres long and ca 20-30 metres thick in the middle. There are layers of moss-tufa interfingering with more massive tufa containing moulds of plant remains, mainly sedge stems and occasional larger plants. A few land snails (*Xerocerastus*, *Sculptaria*) were observed in the tufa as were some stone tools and lithic flakes, suggesting a late Pleistocene to Recent age for deposition of the tufa. The superficial deposits surrounding the tufa lobe consist of cemented river gravels in the valley interfingering with calcrete on the flatter ground. Stone tools and waste flakes, mainly made of quartz, are scattered in many places on the surface.

Figure 2. Location of the Opuwo Cascade Tufa, Kaokoland.

Figure 3. The Opuwo Cascade Tufa, Kaokoland.

Omungunda

At Omungunda Camp, 33 km north-west of Opuwo, half a km north of the road to Epupa Falls, there is a tufa complex close to a Show « Cave » (in fact, a rock shelter) (Figs 4-7). The site was previously published as Rocky 3 by Pickford *et al*. (1993). In the Himba dialect, the name means ‘Place of the Cave’.

The floor of the rock shelter has an infilling of loose, silty deposits containing waste flakes and occasional stone tools. A few hundred metres upstream of the camp there is a cascade tufa complex blocking the valley on which is growing a large Baobab Tree. The tufas at this site comprise classic moss-tufas as well as more massive varieties rich in impressions of plant remains. On the south-western flank of the valley between the tufa lobe and the rock shelter, there is a large exposure of red breccia rich in stone tools, waste flakes and fossils, as well as slope-wash cobbles. The breccia represents cemented floor debris that accumulated on the sloping floor of a cave or rock shelter, but that is now exposed to the sky. Close examination of the breccia reveals that it has scarce, poorly preserved remains of rodents, bovids and possibly equids, and well-preserved land snail shells (mainly *Xerocerastus*).

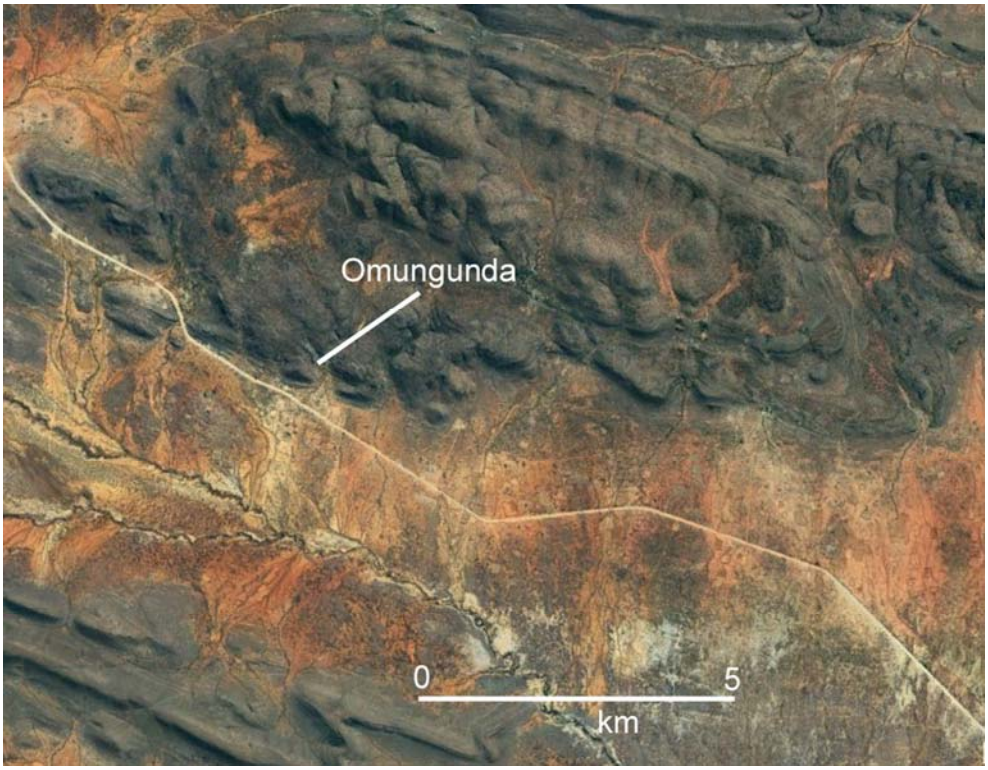

Figure 4. Location of the Omungunda area with the show cave, cave breccia and cascade tufa, Kaokoland.

Figure 5. Omungunda Cascade Tufa with its Baobab Tree, Kaokoland.

On the eastern flank of the same valley, there is an additional series of small tufa lobes, with similar overall structures to the one on which the Baobab tree is growing.

As is usual in Kaokoland, there are large areas of calcrete and cemented fluvial valley-bottom conglomerates upon which the tufa lobes grew. The age of all these superficial deposits is late Pleistocene to Recent.

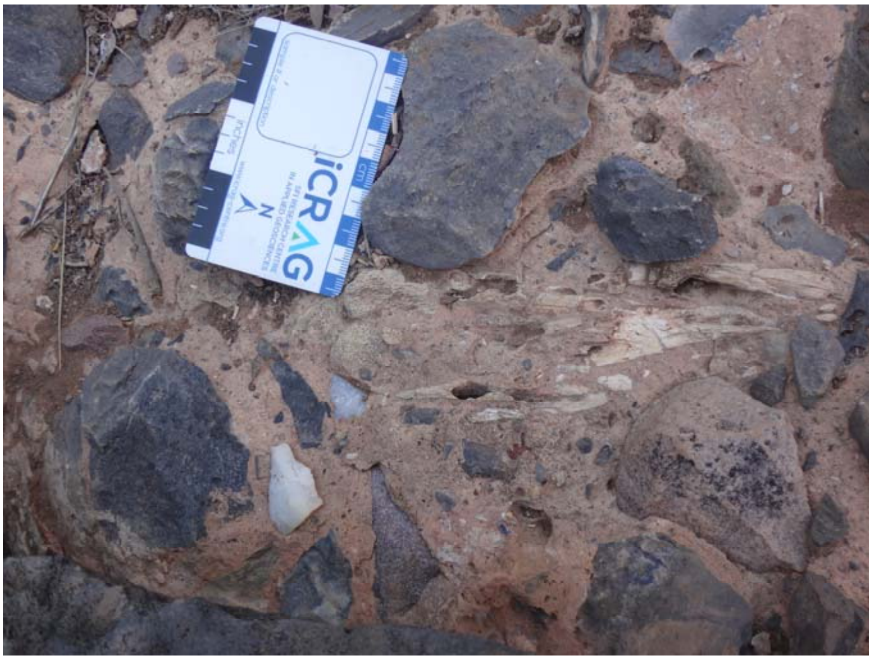

Figure 6. Omungunda cave breccia containing worked lithic flakes of quartz and quartzite plus a large bone (possibly equid).

Figure 7. Concentration of worked quartz flakes and other stones cemented into cave floor sediments at Omungunda, Kaokoland.

Ekoto

Some 67 km west of Opuwo, south of the road to Etanga, there is an impressive tufa complex known as Ekoto (= Hornbill in the Himba dialect) (Figs 8-11). This deposit is not to be confused with an immense Barrage Tufa with the same name that occurs 150 km to the southeast (Pickford, 2019).

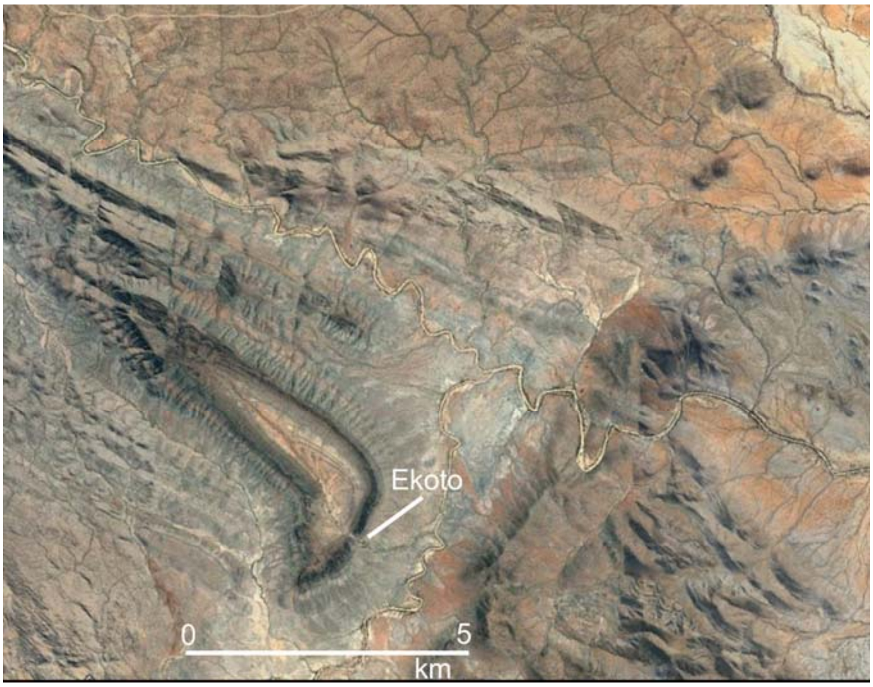

Figure 8. Location of Ekoto Bastion Tufa, Kaokoland.

This Ekoto Tufa Complex is some 50 metres tall, and comprises a Barrage Tufa that dammed the valley and then grew outwards to form a Bastion Tufa. It is ca 70 metres broad at its widest, and ca 90 metres long from the upstream margin to the downstream cliff edge. Upstream of the lobe edge, there is a relatively flat area representing sediments that infilled the ancient valley in which the tufa grew. A variety of large trees including figs grow on this flat area. Water is present in shallow depressions in this infilling, where hundreds of sheep and goats gather to feed and drink. There is also a resident population of baboons at the site, but they tend to spend the daytime hours on the steep mountains that flank the valley to its north and south.

Figure 9. Ekoto Bastion Tufa, Kaokoland, with impressive examples of bryophyte curtains along its margins.

Figure 10. Concentric layers of moss tufa exposed in the cliff at Ekoto, Kaokoland.

There are at least two generations of tufa deposition at Ekoto, and the tufas interfinger with cemented valley-bottom conglomerates and valley-flank calcretes and cemented slope debris. The only fossils observed comprised mosses and other plant remains (sedge stalks, tree roots and stems), and a single fragment of bone. There are however, stone tools and waste flakes incorporated in the tufas and the calcretes, suggesting a Late Pleistocene to Recent age for some of the deposits.

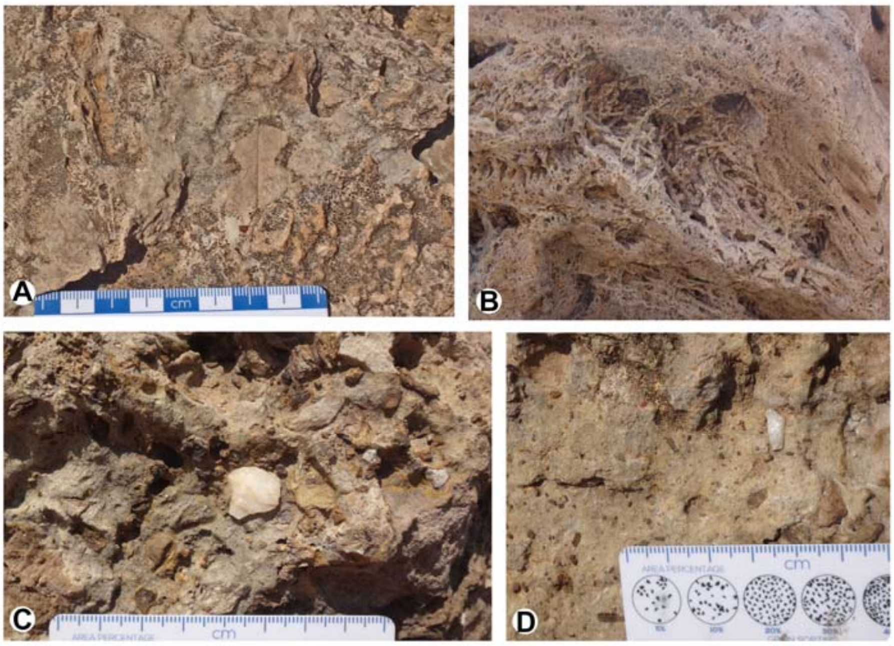

Figure 11. Fossils and stone tools embedded in tufa and groundwater calcrete at Ekoto, Kaokoland. A) dicotyledon leaf imprint in tufa, B) a mass of plant stems coated in tufa, C-D) worked flakes of quartz cemented into groundwater calcreted conglomerate.

Okombeiza

6.8 km south of Otjikondovirongo, there is a deeply incised tufa complex known as Okombeiza (= Kitchen in Himba) (Figs 12-15). The tufa fills an ancient valley which was floored by heavily cemented valley-bottom conglomerates and flanked by hill-slope debris cemented by groundwater calcrete. The barrage tufa infilled the valley for a distance of ca 800 metres and at its broadest it is some 200 metres across. The thickest sections are about 30 metres deep, thinning rapidly laterally towards the flanks of the valley. A dolomite promontary within the valley is the site of a small cave which gives the area its name. This cave has a large opening on its southern end, and a small vertical aven-like opening above. There are abundant stone tools, as well as ostrich eggshell beads in the loose soils beneath the cave entrance.

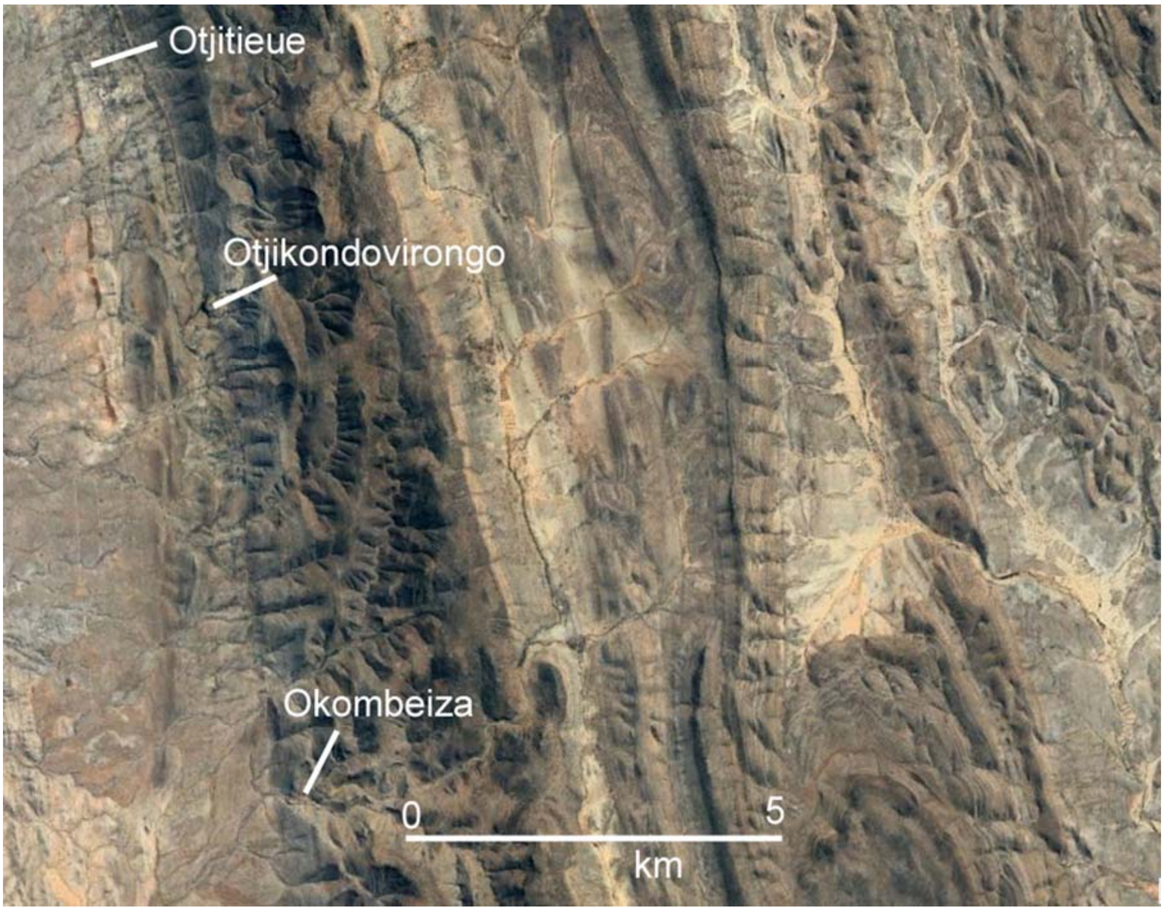

Figure 12. Location of Okombeiza Barrage Tufa, Otjikondovirongo Bastion Tufa and Otjitieue spring dome, Kaokoland.

The Okombeiza deposits comprise a complex interfingering of barrage tufas, calcretes and valley-bottom conglomerates, implying a series of depositional phases interrupted by periods of erosion, cut-and-fill and stasis. Caves that formed in the tufas were the sites of speleothem formation with classic examples of stalactites, stalagmites and flowstone. There are examples of moss tufa and denser tufa enclosing plant remains (sedges, reeds, trees, leaves). No vertebrate or invertebrate fossils were observed, but only a few hours were spent examining what is a vast area of exposure.

Figure 13. View of Okombeiza Cave, with groundwater calcrete and barrage tufa deposits close to its entrance.

Figure 14. The Okombeiza Barrage Tufa blocking the valley downstream from Okombeiza Cave.

Figure 15. Alternating layers of conglomerates and laminated tufa deposits in the Okombeiza valley, Kaokoland.

Otjitieue

3 km north of Otjikondovirongo, there is a large tufa dam, well removed from the dolomite cliffs to the east (ca 0.5 km) (Figs 12, 16). There appears to have been a resurgence at the place which built up a semi-circular dam-like wall to the west, some 5 metres tall at its greatest height. The depression uphill from the tufa wall acted as a dam in which silts and sands accumulated, completely infilling the depression, but without becoming heavily cemented.

There are many stone tools and waste flakes exposed on the surface, but none were observed *in situ* in the tufas, although lack of time meant that not all the tufa outcrop could be examined. However, the silts and calcrete that crop out widely in the area contain many shells of the land snail, *Achatina*, most easily observed in the incised parts close to the present-day drainage lines in the area.

Figure 16. Otjitieue tufa terrace, Kaokoland. A) the tufa terrace viewed from the north, B) the clay and silt infilling the 'dam-like' depression bordered by the terrace, C) the southern margins of the tufa terrace, D) stone implements scattered on the surface of the deposits.

Otjitaime Downstream

Otjitaime is known for the immensely rich and diverse microfauna that it yielded (Pickford, 2019) (Figs 17-18). The main cliff at the site is 1.1 km broad and almost 100 metres tall, making it one of the largest barrage tufas known in the world. Fittingly, in the Himba dialect, Otjitaime signifies a 'Holy Place', or a 'Place that must be revered or respected'.

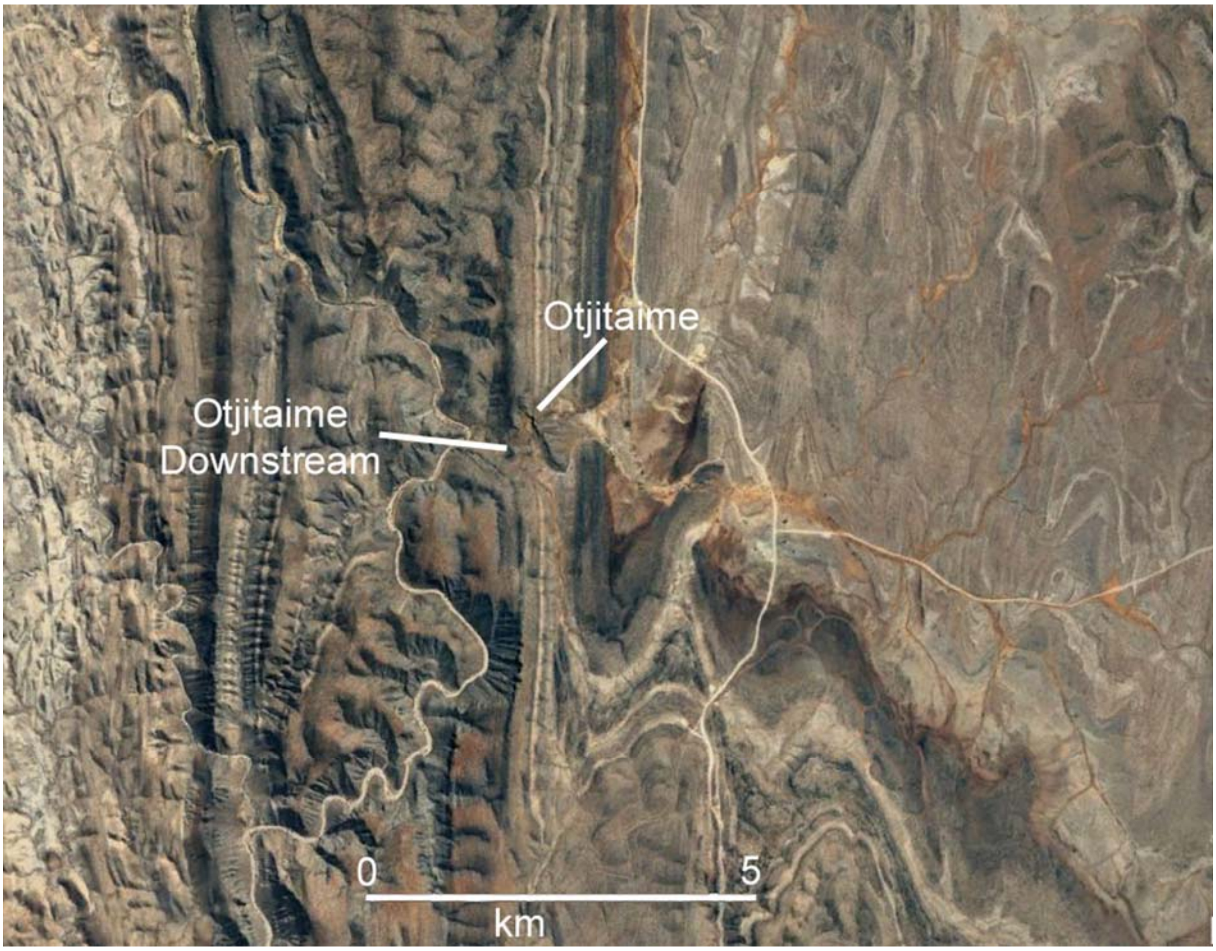

Figure 17. The Otjitaime Barrage Tufa and the downstream sector of the same complex, Kaokoland.

Downstream of the Otjitaime cliff, there are other superficial tufa and fluviatile deposits that crop out for some 800 metres along the valley, comprising a complex of cut-and-fill tufa and fluvial conglomerate accumulations, similar in many ways to those at Okombeiza, but on a larger scale. Examination of these tufas for three hours failed to yield any vertebrate or invertebrate fossils, although plant fossils occur in abundance. Despite the apparent lack of vertebrate fossils, further surveys are warranted, because at Otjitaime cliff, the fossil sites are areally minute, being less than 1 metre in diameter, but immensely rich in concentrations of micromammals (Pickford, 2019). The greatest thickness of the tufas in this downstream sector of the complex is ca 30 metres, with rapid changes in thickness observed both laterally and along the axis of the valley.

It is likely that the Otjitaime fossil concentrations accumulated in small hollows developed in the tufas which were inhabited by owls and other birds of prey, which regurgitated their pellets inside the caves. Speleothems such as stalactites and stalagmites occur near the fossil concentrations.

Figure 18. Otjitaime barrage tufa, downstream sector, some 5-6 metres thick in places.

Kaoko Otavi

Kaoko Otavi is an important spring complex named after a local chief (Kaoko) (Figs 19-20). There are two large springs north of the main road, and in the hills beyond there are signs of small barrage tufas, but time constraints prevented examination of the latter. Both of the tufa mounds have been modified by human activities, with the installation of walls, pump stations, drainage channels and pipes, but some of the original deposits can be made out, which reveal that overall, they resemble the water hole tufa domes that occur along the southern margin of Etosha Pan (Pickford *et al*. 2014).

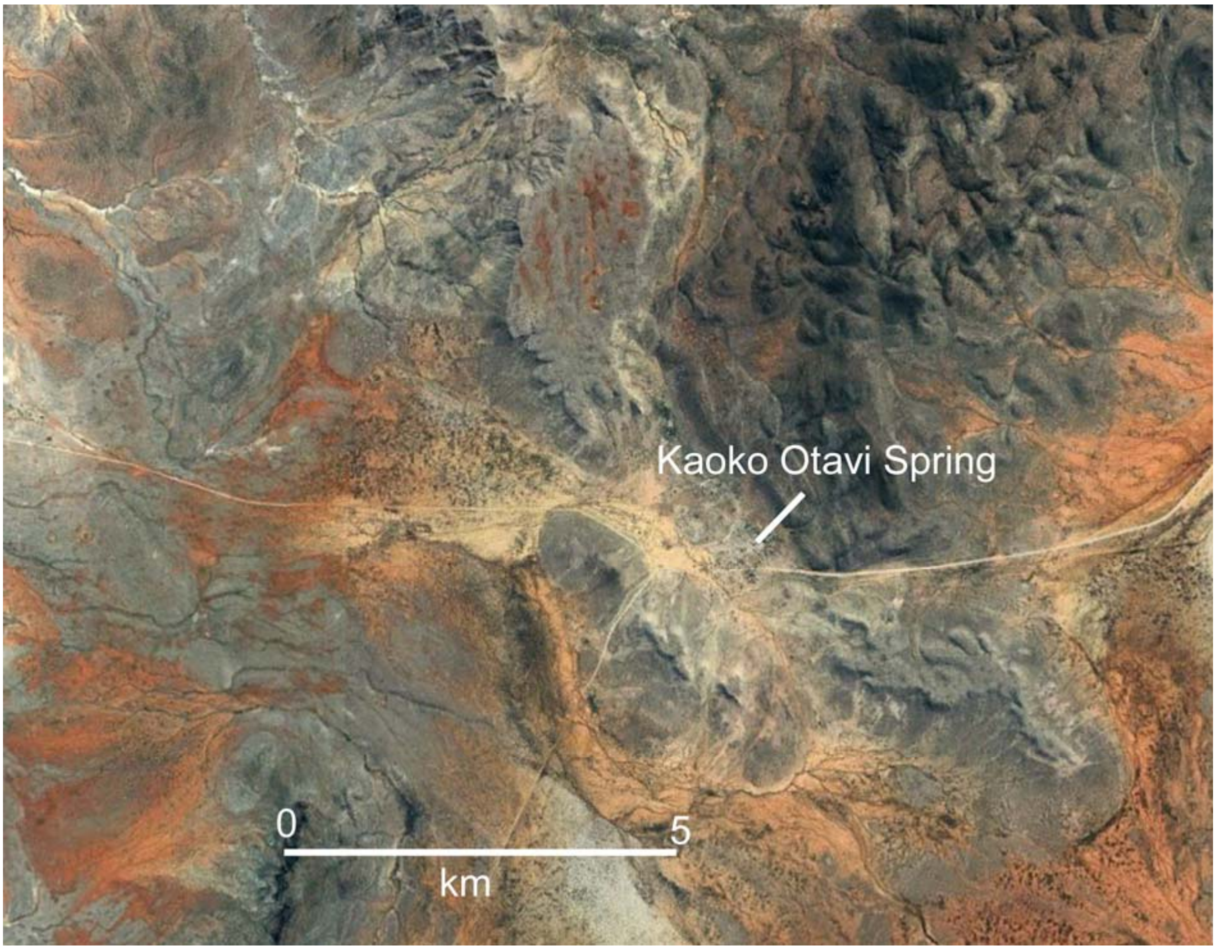

Figure 19. Location of Kaoko Otavi Spring, Kaokoland.

The calcareous deposits at Kaoko Otavi are predominantly of sedimentary origin cemented by calcium carbonate (groundwater calcrete) although there is evidence of a large diameter tufa dome and small tufa terraces as well. In many ways, the main occurrence recalls the calc tufa terrace at Otjitieue, but on a larger scale, and it is similar to some of the water hole tufa domes that occur along the southern margin of Etosha Pan (Pickford *et al*. 2014). The groundwater calcretes at Kaoko Otavi yield a few freshwater snail taxa, such as *Bulinus* and planorbids but no vertebrates were observed. As usual, there are plenty of stone tools littering the surface, and a few are cemented into the calcrete and tufa.

Figure 20. Kaoko Otavi tufa and groundwater calcrete dome, showing part of the southern slopes of the dome that have not been too altered by human developments.

Okombako

A re-examination of the tufas at Okombako (= Funnel in the Himba dialect) near Okozonduno (Figs 21-22), failed to yield any vertebrate remains. However, some plant fossils were found. The other tufa deposits in the same valley (Okongwe, Okapiku, Okovanatje) were not surveyed, but were photographed from a distance. These tufas featured in a publication by Pickford (2019).

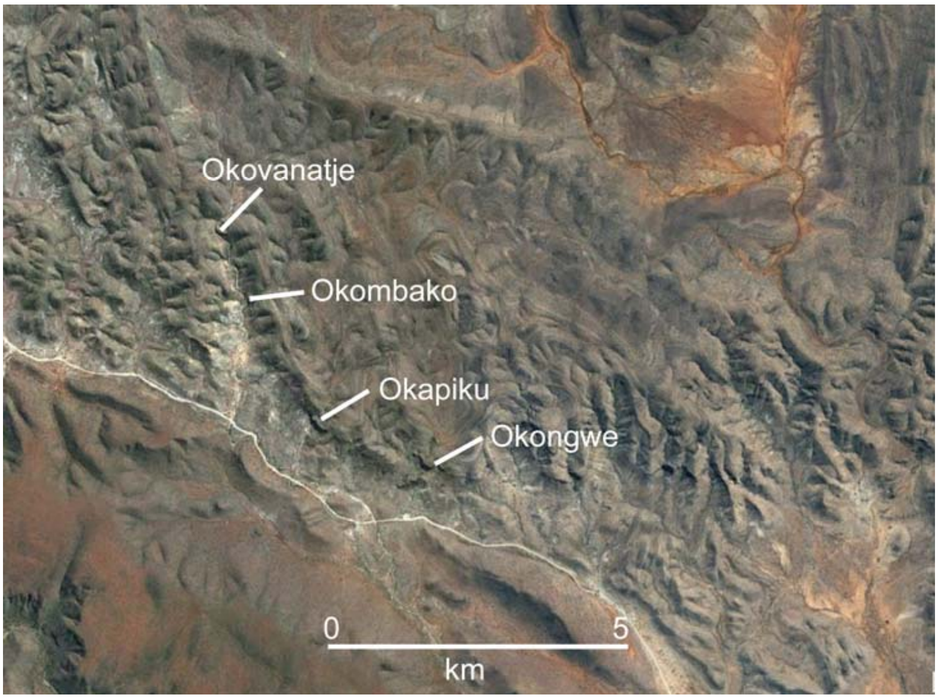

Figure 21. Map showing the distribution of four of the barrage and bastion tufas in the Okozonduno region, Kaokoland.

Figure 22. Bryophyte curtain tufas and caves in the Bastion Tufa at Okombako, Kaokoland.

Otjisakumuka

The Otjisakumuka tufas comprise a plaquage covering a tall linear cliff of Proterozoic conglomerates, oriented almost North-South (Figs 23-26). Huge pieces of the tufa plaquage have broken off the cliff, and have come to rest on the slopes and valley floor beneath. There is also a sloping apron of tufa at one point that cements and overlies slope debris. Close to the lodge, there is an extinct spring complex that forms a ridge standing out from the cliff. This ridge is composed predominantly of cemented conglomerate but has some tufa facies, as well as groundwater calcrete formation. No fossil vertebrates were observed, but there are many stone tools and waste flakes in the area, some of them cemented into the tufa and calcrete.

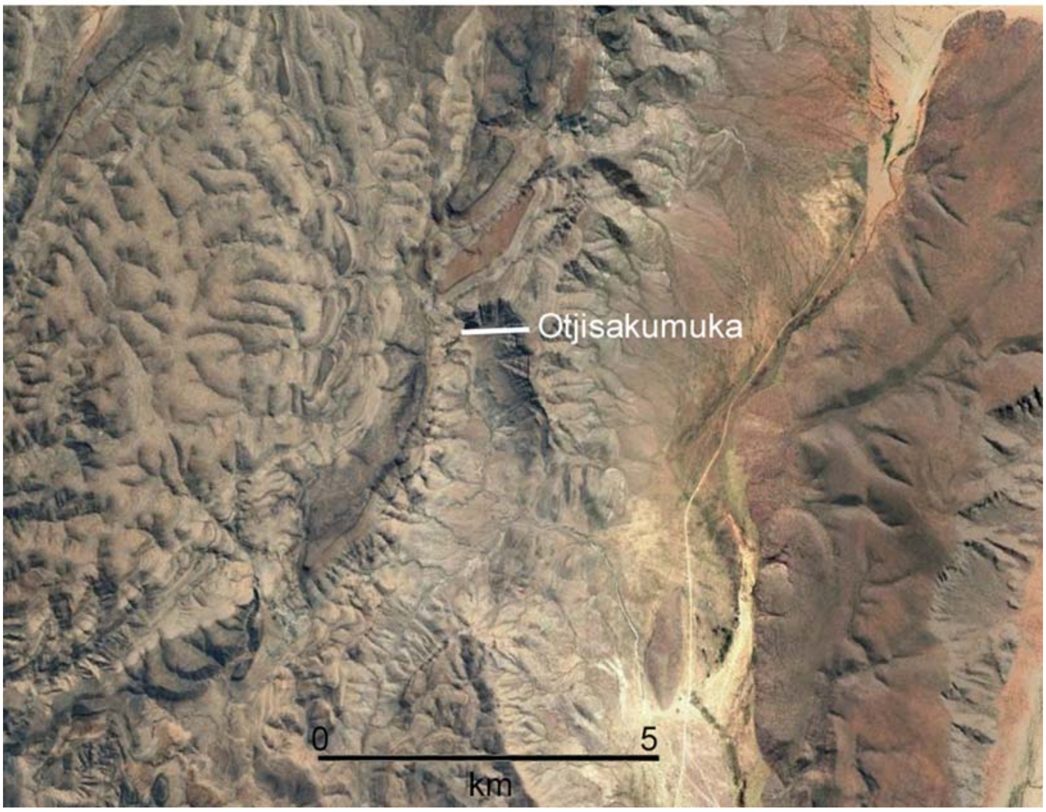

Figure 23. Location of the Otjisakumuka tufa complex, Kaokoland.

Figure 24. The tall, almost vertical barrage tufa and a sloping tufa apron overlying Proterozoic conglomerates at Otjisakumuka, Kaokoland.

Figure 25. Close-up view of the barrage tufa at Otjisakumuka, from which large blocks of bryophyte curtains have broken off.

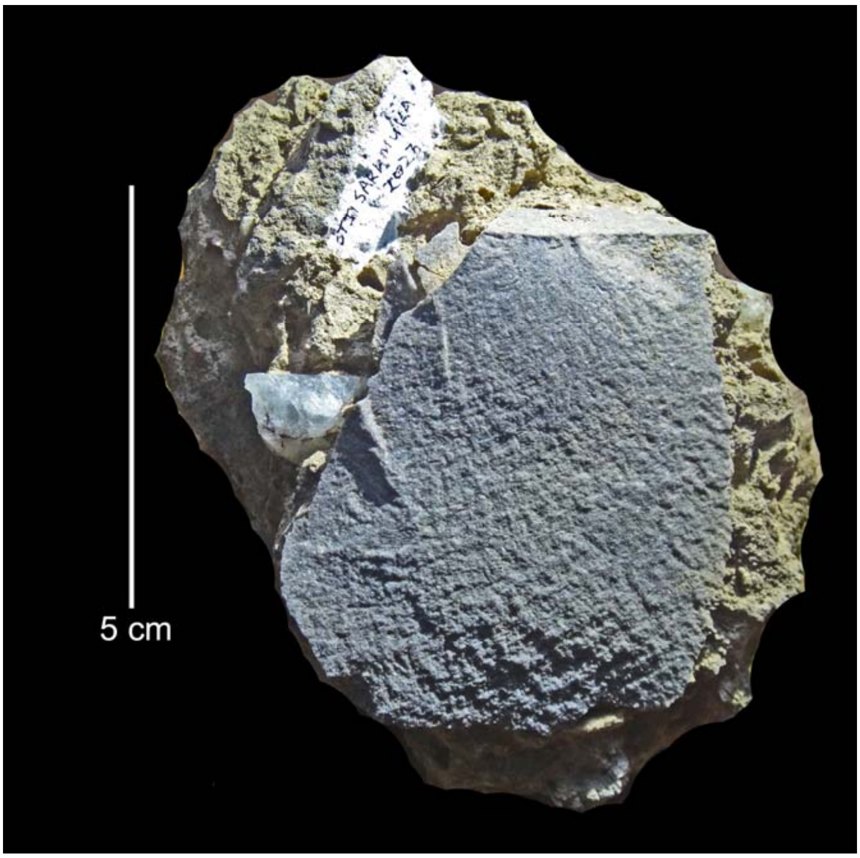

Figure 26. Worked stone embedded in tufa from Otjisakumuka (note the bulb of percussion at the top of the flake and the worked flake of quartz next to it).

Ongongo

A brief survey of Ongongo (= Amazing in Himba) (Fig. 27) confirmed the presence of at least two generations of tufa deposition, a well-cemented one immediately overlying densely indurated fluvial conglomerates which overlie bedrock, the other, more porous, overlying the former. There are also outcrops of groundwater calcrete interfingering with the tufa.

There are abundant well preserved leaves in some of the Ongongo tufas, as described by Mocke (2014) and some outcrops contain gastropods (*Achatina*, planorbids) (Fig. 28).

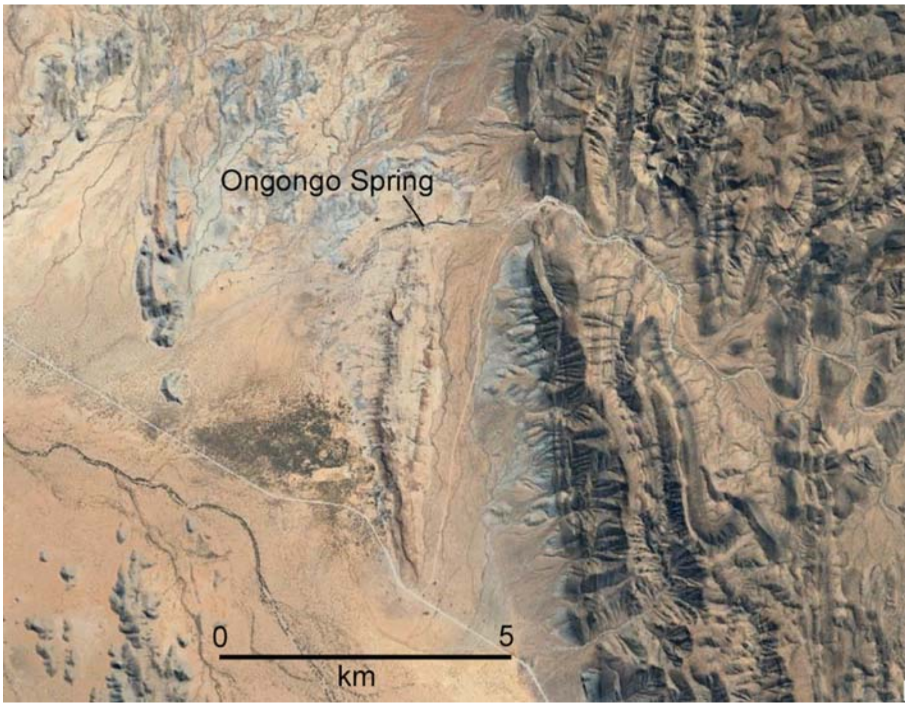

Figure 27. Location of the Ongongo Spring tufa complex, Kaokoland.

Figure 28. Fossilised leaves and land snails in barrage tufa at Ongongo Spring, Kaokoland. A-C) fossil leaves, D) shells of *Achatina* sp.

Khowarib-Omokutu

12 km south of Warmquelle is the Khowarib Valley (Figs 29-34) that has been partly infilled with stratified conglomerates, hardpan soils and tufa deposits, which have been incised by recent erosive processes, thereby exposing an impressive series of strata over a distance of about 7 km along the valley and up to 500 metres across it. A thickness of 10 metres of sediments is observed in several outcrops, comprising laterally continuous layers of semi-indurated hardpan soils, barrage tufas, tufa domes and conglomerates.

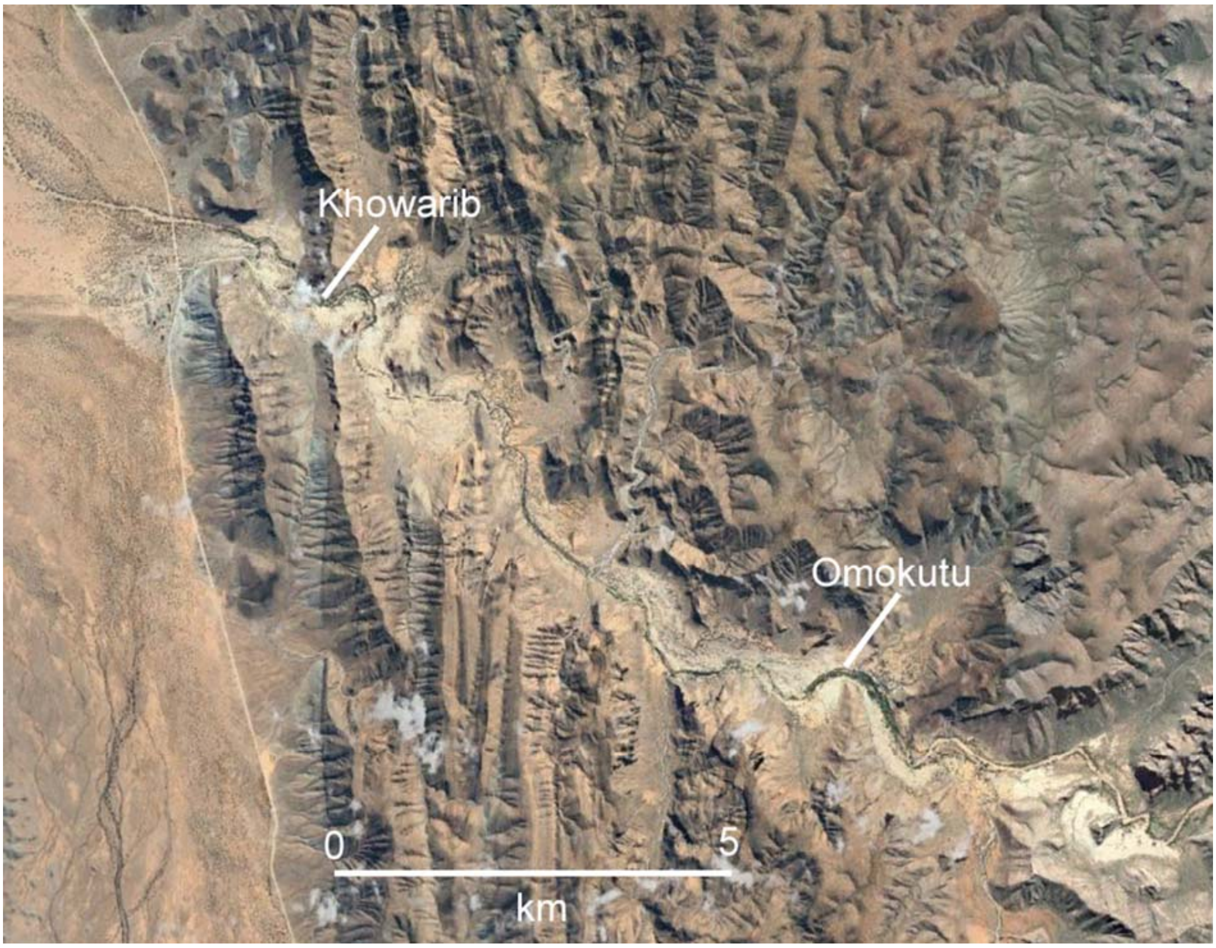

Figure 29. Location of Khowarib and Omokutu, Kaokoland.

At Omokutu (= Canyon in Himba) a barrage tufa is exposed in the bed of the present-day river, overlying a densely indurated conglomerate that itself overlies Proterozoic dolomite. The tufa is overlain by hardpan soil layers to a depth of several metres.

The Khowarib cascade tufas are extemely well endowed with plant remains, and in places freshwater and terrestrial gastropods were observed (planorbids, *Xeroceratus*). No vertebrates were encountered though. Lithic implements and waste flakes are scattered over the surface of many outcrops.

The silty sediments in the uppermost layer of the terraces close to Khowarib Camp Site yield hundreds of centimetric tufa rinds that precipitated onto plant remains that lay scattered on or close to the ancient land surface. The occurrence suggests that the valley was flooded for long enough for several layers of tufa to precipitate onto the plants, suggesting a swamp-like environment. Similar deposits occur at the Sesfontein Camel Camp (Pickford *et al*. 2016).

Figure 30. River-bed exposures, between Khowarib and Omokutu, of steeply dipping Basement dolomite, overlain by horizontally bedded basal conglomerates and interstratified layers of barrage tufas, silts, incipient hardpan soils and cascade tufas. Loose dark red sands of aeolian origin occur in many places (see Fig. 31).

Figure 31. Tufa coating the roof, walls and floor of a small cave that was eroded into hardpan soils of the Khowarib Valley, Kaokoland (see Fig. 30, cliff in the background).

Figure 32. Concentric layers of tufa forming large rounded masses exposed in the flanks of the Khowarib Valley, Kaokoland.

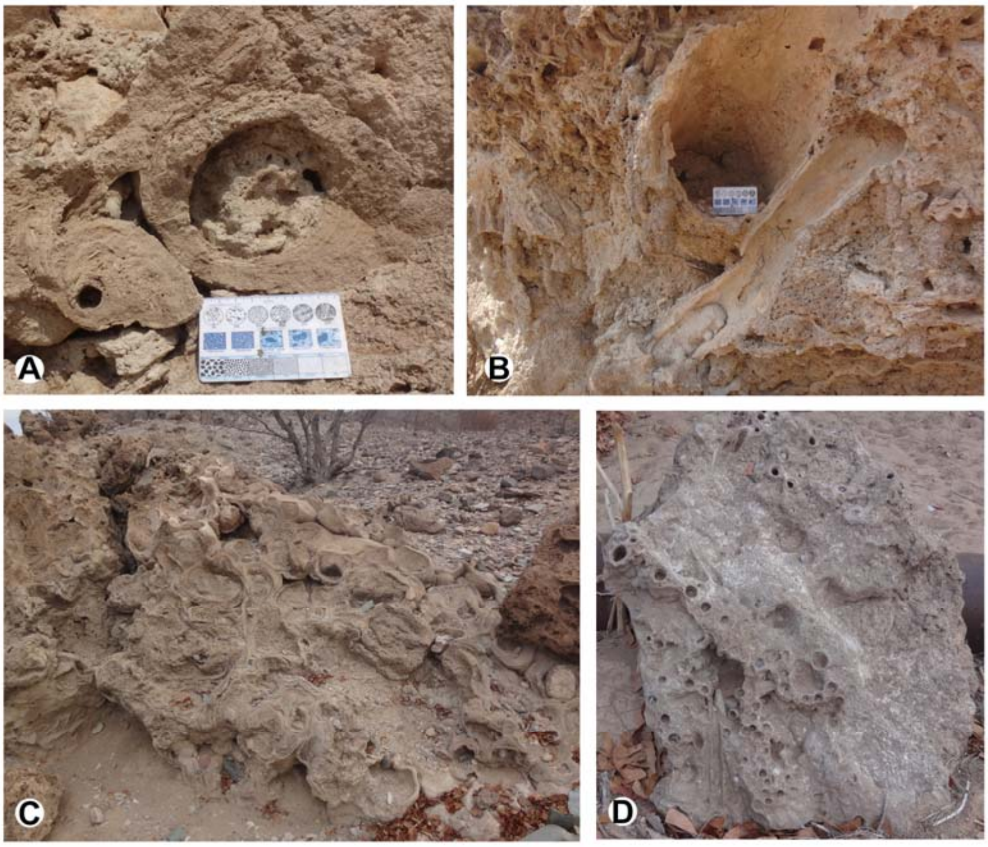

Figure 33. Plant impressions and tufa coatings in the Khowarib Valley, Kaokoland. A-B) imprints in tufa of stems of trees and reeds, C) concentric layers of tufa forming irregular conjoined masses, D) sections of plant stems coated in tufa.

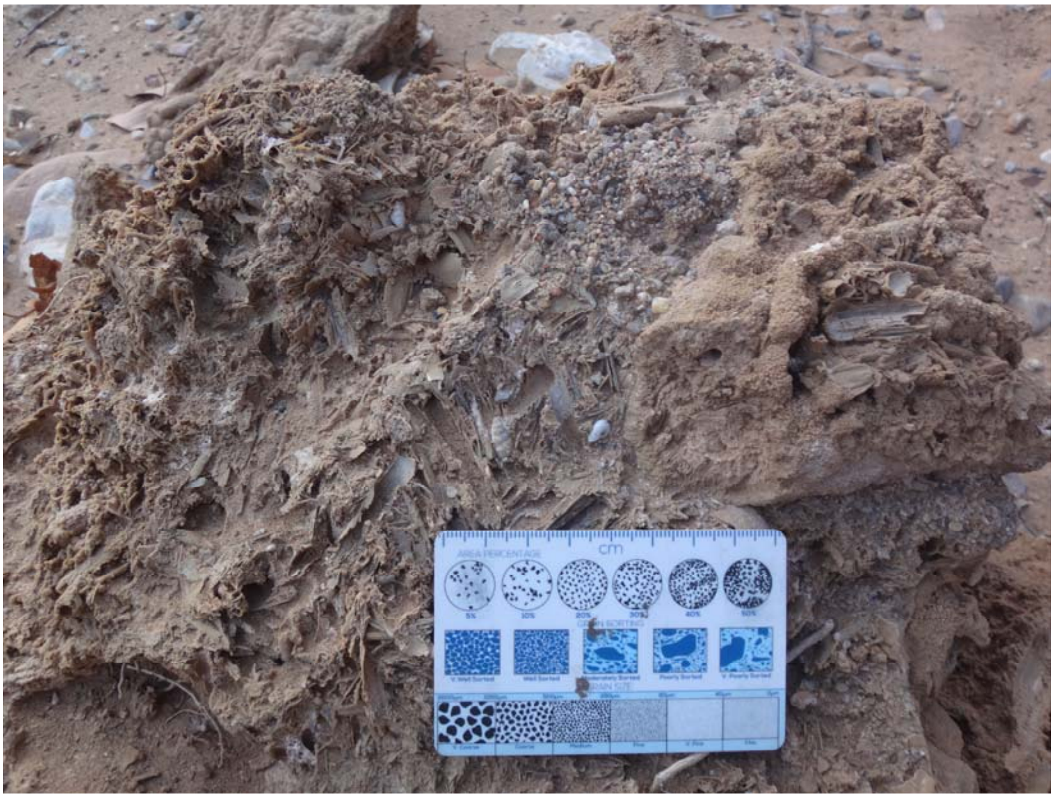

Figure 34. Fossilised shells of *Xerocerastus* and a planorbid intermingled with comminuted plant remains (fossilised elephant dung?) in a barrage tufa at Khowarib, Kaokoland.

An interesting aspect of the Khowarib Valley sequence is that there appear to have been at least three episodes of tufa formation, interstratified with accumulations of silt and clay which show evidence of moderate to clear hardpan soil development. Detailed mapping and stratigraphy of the deposits would be well worth undertaking, in order to understand better the palaeoclimatic signatures that are undoubtedly preserved in the succession.

A preliminary hypothesis is that hardpan soils accumulated and formed during warmer periods, whereas tufas tended to develop during cooler somewhat more humid periods. The Khowarib succession likely holds the key to supporting or to refuting such a suggestion.

Taphonomy

Soils and superficial sediments in areas of Miombo and Mopane woodlands are generally poorly endowed with phosphates due to low concentrations of this element in the bedrock from which the soils and sediments were derived. Kaokoland, with its dominant Mopane vegetation is no exception to this general rule. A consequence of this poverty in phosphorus, is that any bones and teeth that accumulate on or in the soils will be attacked by a variety of organisms in search of this element which is essential for life functions. Among these organisms, fungi, bacteria, small insects and even plant roots will exploit the bones and teeth for their content of phosphorus. The exploitation can occur extremely rapidly, with bones of large mammals such as zebras disappearing within a few years. An added factor in the destruction of bones and teeth in Kaokoland is the climate, with hot, arid conditions promoting the cracking and spalling of bones, eventually leading to their destruction (Fig. 35).

Figure 35. Long bones of a large mammal undergoing longitudinal cracking and flaking under hot, arid climatic conditions at Otjisakumuka, Kaokoland. The bones are also undergoing attack by fungi, bacteria and other organisms in search of phosphorus. The humerus in the middle has also been squashed by trampling.

As a result, fossil vertebrates tend to be rare in deposits that accumulated in Miombo and Mopane woodland settings. The paucity of vertebrate fossils in most of the Kaokoland tufas and sediments is probably due to low concentrations of phosphorus in the soils and sediments. However, there are exceptions such as the fossil-rich but volumetrically restricted concentrations at Otjitaime, Okongwe, Omatapati and Ozombindi (Pickford *et al*. 2019; Mocke *et al*. 2022), and these exceptions demand an explanation. In all four cases, it is likely that the bones and teeth accumulated in damp, waterlogged or flooded depths of cavities in the tufas, the water protecting them from being exploited by fungi and other organisms long enough for them to become fossilised. Furthermore, being inside dark, relatively cool cavities, the bones were protected and teeth from the hot, arid conditions that prevail at the land surface in Kaokoland, which explains why many of the fossils at these localities are well preserved and complete.

Discussion and Conclusions

The October, 2023, field survey confirmed the presence of nine previously unrecorded tufa sites in Kaokoland (Table 2). Fossil mammals were found in cave breccia at Omungunda associated with land snails and stone tools (Late Stone Age facies). The palaeocave itself has been unroofed by erosion, but the red breccia has resisted and large patches remain along the valley flank between the Show Cave and the Baobab Tufa. Fossil mammals are not abundant, but dental remains of bovids, possibly equid and rodents were observed. The quantity of worked stone cemented into the breccia is impressive, with some fine examples of flakes showing conchoidal fracture cones, bulbs of percussion and retouched edges. Most of the worked lithics are in quartz, but some are in dolomite and dark grey quartzite.

Ekoto and Otjisakumuka comprise impressive tufa complexes, the latter developed into a tourist lodge. Kaoko Otavi and Otjitieue are examples of groundwater calcretes surrounding resurgences some distance from the neighbouring hills. Most of the deposits in these occurrences comprise sediments (silts, clays, hardpan soils) with only minor development of moss tufas.

Table 2. Palaeontological and Archaeological content of Tufa complexes of Kaokoland surveyed in October, 2023 (alphabetical order : + - present, ° - not observed). In bold are previously unreported tufas.

Tufa Complex	**Plants**	**Gastropods**	**Vertebrates**	**Lithics in tufa**
Ekoto Bastion Tufa	+	°	+	+
Kaoko Otavi groundwater calcrete dome and tufa	°	+	°	°
Khowarib calc tufa	+	+	°	°
Okombako Bastion Tufa	+	°	°	°
Okombeiza Barrage Tufa	+	°	°	°
Okongwe tufa lobes	+	+	+	+
Okapiku Cascade Tufas	+	°	°	°
Okovanatje Cascade Tufa	+	°	°	°
Omokutu, barrage tufa *in situ* in river bed	+	°	°	°
Omungunda show cave (previously Rocky 3)	°	°	°	°
Omungunda stone tool site	+	+	+	+
Ongongo Springs Tufa	+	+	°	°
Opuwo Cascade Tufa	+	+	°	+
Otjisakumuka Cascade Tufa	+	°	°	+
Otjitaime Downstream cascade tufas	+	°	°	°
Otjitieue groundwater calcrete dome and tufa	+	+	°	°

Okombeiza is a deeply dissected barrage tufa complex, with impressive quantities of plant fossils, but no vertebrates were observed. However, not all the outcrops could be examined on account of shortage of time.

The Khowarib Valley is a most intriguing place, because there were at least three phases of tufa deposition interstratified with clastic deposits (clays and silts forming incipient to mature hardpan soils and conglomerates). This is one of the few places seen so far in Kaokoland that show such a complete succession of intercalated tufas and clastic deposits, so it would be well worth further detailed study in order to throw light on Pleistocene to Recent palaeoclimatic conditions in the region.

It is stressed that there are many more occurrences of tufa to be identified and mapped in Kaokoland, the results of the recent survey underlining this fact, during which nine previously unmapped occurences were confirmed. The identification of the Khowarib deposits was fortuitous as they are not clearly expressed on satellite imagery, unlike many of the tufas described thus far (Pickford, 2019). Overall, Kaokoland appears to be well endowed with a large variety of calcareous superficial deposits, ranging from tufa deposits of various sorts (barrage, cascade, terrace, bastion tufas) to groundwater calcretes, hardpan domes, cemented conglomerates, and cave deposits that accumulated within tufa complexes (Otjitaime, Okombeiza etc.).

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A note on Plio-Pleistocene insect cocoons from Prospekteerkop, Rietfontein, Northern Namibia

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Abstract :- Cocoons of invertebrates are rarely preserved as fossils, only a few reports existing in the literature. Yet many insect species produce cocoons as part of their life histories. We here report the discovery of what appear to be fossilised cocoons from Plio-Pleistocene cave breccia at Prospekteerkop, on farm Rietfontein in the Otavi Mountainland and try to identify them by comparing them to modern analogues among Lepidoptera (butterflies and moths) and Coleoptera (beetles). The specimens are most likely to have been made by a species of beetle.

Key words :- Plio-Pleistocene, Otavi Mountainland, fossilised cocoons.

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Introduction

The Otavi Mountainland (OML) is located in the north-central part of Namibia and as early as the late 19th century it received much attention on account of its base metal reserves which include copper, lead, zinc and vanadium, (Cairncross, 1997; Gebhard, 1999; Schwellnus, 1946). The OML is composed predominantly of Neoproterozoic carbonate rocks that have been modified by extensive chemical weathering processes that resulted in a rough karstic terrain endowed with many caves and fissures in which sediments and breccias accumulated. The spelean sediments of the OML have yielded abundant fossils of Middle Miocene to Recent age (Pickford & Senut, 2010).

At diverse sites in the OML, Pickford & Senut (2002, 2010) identified fossil remains among which micromammals predominated. The following groups were listed : Myriapoda (centipedes), Gastropoda (terrestrial snails - *Xerocerastus*), Amphibia, Squamata (lizards and snakes), Aves, Carnivora, Primates (Galagidae (bush babies), Hominoidea, Cercopithecidae), Tenrecidae, Macroscelididae (elephant shrews), Hyracoidea, Proboscidea, Chiroptera, Chrysochloridae (golden moles), Soricidae (shrews), Rodentia (Sciuridae, Gerbillinae, Gliridae, Muridae, Bathyergidae, Thryonomyidae, Pedetidae), Leporidae (hares), and Ruminantia (Giraffidae, Bovidae).

The mammalian fauna from the Prospekteerkop breccias, the existence of which was first mentioned by Schwellnus (1946), comprises two species of soricids (crocidurines), a macroscelidid (elephant shrew), three species of bat (two rhinolophoids and one vespertili-onid), a hare (*Pronolagus humpatensis*), a high diversity of rodents (*Graphiurus*, *Mystromys*, *Mastomys*, *Petromus*, *Steatomys*, *Malacothrix*, *Petromyscus*, *Tatera*, *Gerbillurus*, *Otomys*, *Rhabdomys*, *Zelotomys*, *Mus*, *Praomys*), a leopard (*Panthera pardus*), a dassie (*Procavia capensis*), two bovids (*Oryx*, *Antidorcas*) and a baboon (*Papio*) (Pickford & Senut, 2010; Mein, 2015). This fauna indicates correlation to the Plio-Pleistocene.

In 2022 and 2023 members of the Namibia Palaeontology Expedition discovered small ovoid fossils amongst the microfauna in the breccia occurrence at Prospekteerkop on Farm Rietfontein. Preliminary research indicates that they represent cocoons of an invertebrate, most probably of a species of coleopteran.

Stehr (2009) described a cocoon as a protective covering made of silk within which caterpillars of most moths, a few butterfly species, and several other insect orders such as Siphonaptera (fleas), Hymenoptera (ants, bees and wasps), Neuroptera (lacewings and antlions), and Trichoptera (caddis flies) pupate. Lea (1925) and Veatch (2020) reported on fossilised cocoons of the Australian weevil *Leptopius duponti* (Coleoptera) from Pleistocene localities in Australia.

According to Brasier *et al.* (2017) endogenous materials associated with pupation, such as cocoons, are not common in the fossil record. Therefore, these fossilised cocoons from Rietfontein are important and they may yield information about the environment of the area during the Plio-Pleistocene and the animals that lived here.

Moths, together with butterflies, comprise part of the order Lepidoptera. Today there are 481 genera and 890 species of Lepidoptera in Namibia (Kopij, 2017). However, according to the Namibia Biodiversity Database Web Site (Irish, 2023) 1,789 lepidopteran species currently live in Namibia and there are currently 4,058 species of Coleoptera in the country.

Out of the 4,593 lepidopteran fossil specimens described worldwide, 92.8% are body fossils and 7.2% are trace fossils. According to Sohn *et al*. (2015) only about 7% of these fossils have been formally named, and of the 145 lepidopteran fossil localities listed, 31 are Miocene, 23 are Pleistocene and Holocene, 22 are middle and late Eocene and 15 are early Oligocene.

Geological setting

The Prospekteerkop fossil site is located in the Otavi Mountainland on Farm Rietfontein (19°41’36"S 17°52’38"E) (Fig. 1, 2). It is close to the foot of a kopje which lies approximately 10 km north-north-east of the farmhouse. The fossiliferous breccia blocks lie next to and inside an old prospecting trench that is ca 2 metres wide, approximately 8 m long and 1.5 m deep (Fig. 3, 4). The trench exposes flowstone remnants (speleothems) in its southern end and the host rock surrounding the breccias is dolomite.

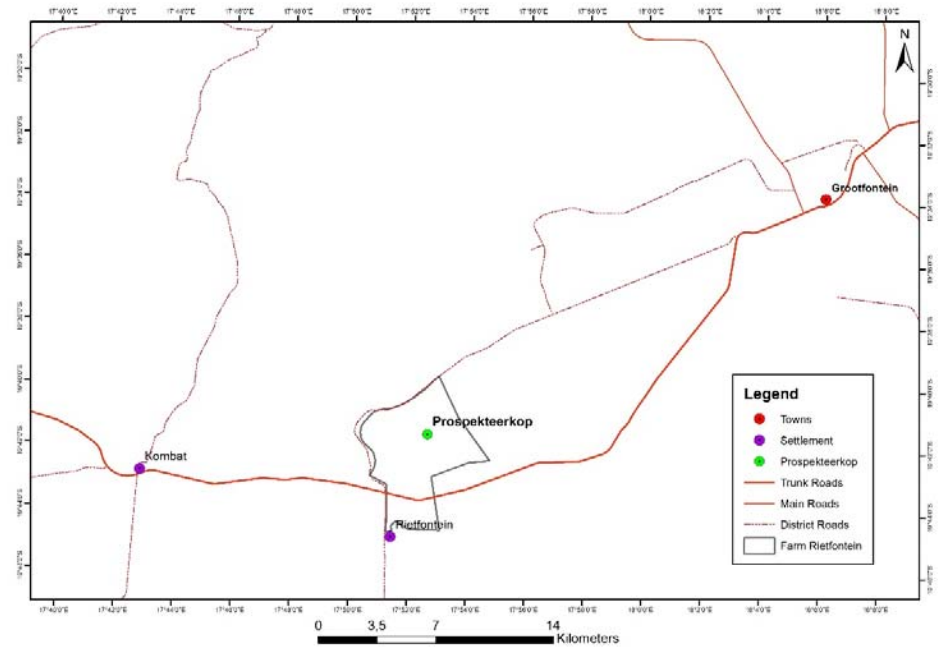

Figure 1. Prospekteerkop fossil locality on Farm Rietfontein in the Otavi Mountainland (map produced by Freddy Muyamba).

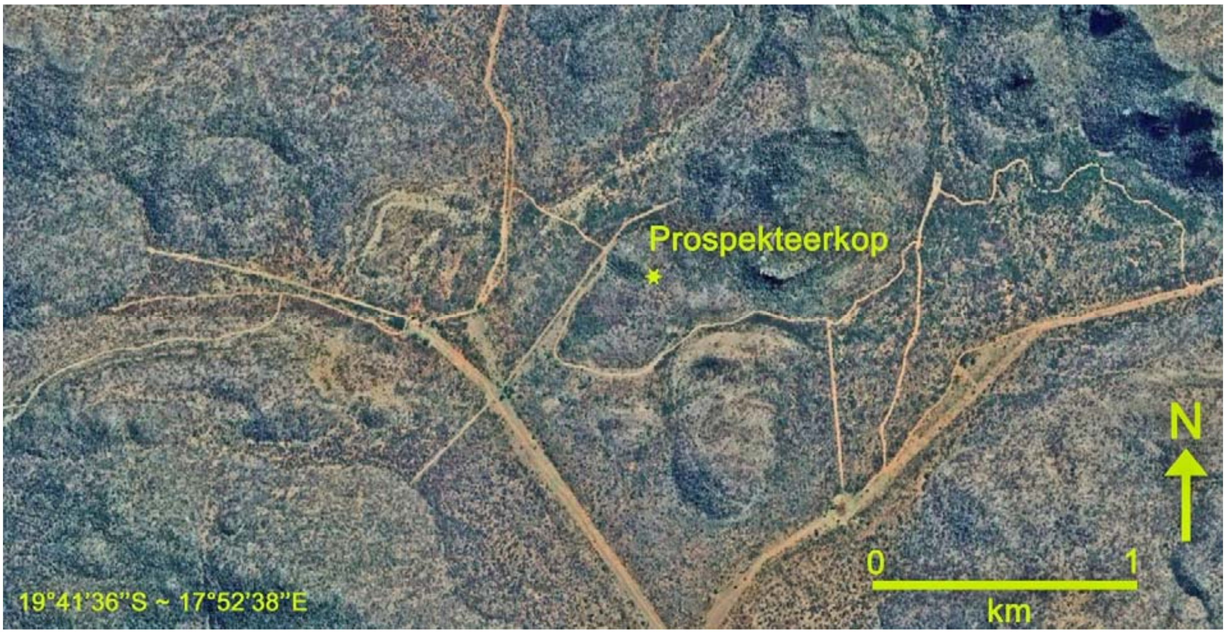

Figure 2. Position of the Prospekteerkop breccia dumps on Farm Rietfontein, Otavi Mountainland, Namibia. Map modified from Google Earth.

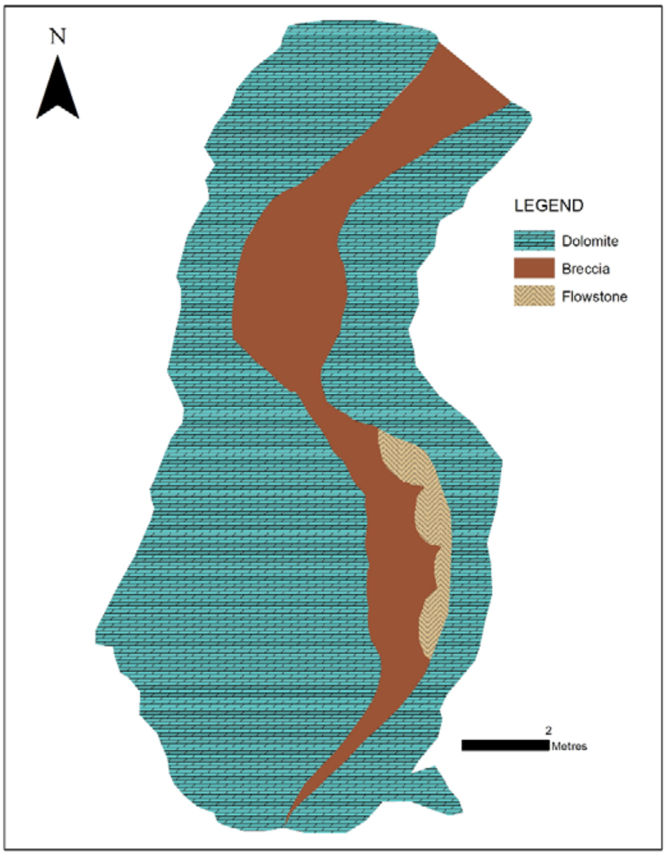

Figure 3. Prospekteerkop fossil site layout (figure prepared by Anna Upindi).

Figure 4. View of the old prospecting trench at the foot of Prospekteerkop (in the background). Grey blocks are dolomite, red ones are cave breccia.

Materials and Methods

In 2022 and 2023, palaeontological field surveys were carried out on Farm Rietfontein in the Otjozondjupa region, Grootfontein District.

Blocks of breccia containing fossilised micro- and macrofauna were collected for scientific analysis at the National Earth Science Museum of the Geological Survey of Namibia. Among the material collected were several insect cocoons.

Description of the Fossil Cocoons

The most complete fossil cocoon described herein is whitish, oval in shape and is preserved in a reddish-brown breccia. Its length is approximately 2.5 cm and its width is approximately 1.3 cm. It has a somewhat rough surface texture with several small cavities visible, which may be due to weathering, or possibly damage to the cocoon when it was still fresh. Small patches of sediment are stuck to the cocoon (Fig. 5).

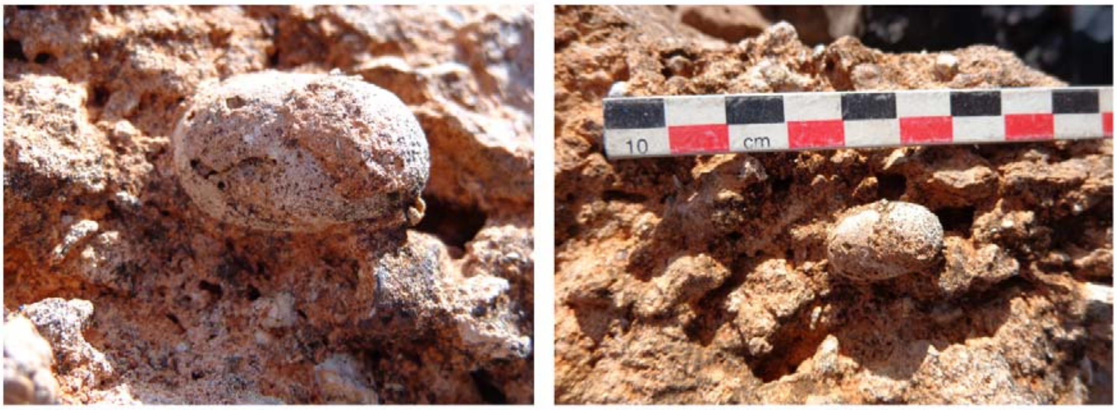

Figure 5. Fossilised cocoon from Prospekteerkop, Rietfontein.

Figure 6. Stereo images of a sectioned cocoon in cave breccia from Prospekteerkop, Otavi Mountains, Namibia. Note the greyish sediment 'halo' (in which there are fragments of petrified vegetation : yellow arrows) enclosing the cocoon for a thickness of ca 7 mm and which is partly coated by calcite crystals (blue arrows) (scale in cm).

A sectioned cocoon in breccia from Prospekteerkop is of interest on account of the fact that it is surrounded by a layer of greyish sediment ca 7 mm thick, that differs in colour from the surrounding redder sandy breccia (Fig. 6). This coating is itself covered by an irregular and incomplete layer of calcite crystals and the inner wall of the cocoon is lined with a similar layer of small crystals of calcite. The halo of sediment contains small angular fragments of petrified vegetation (Fig. 6). The length of the cocoon, as preserved, is 20.8 mm and the diameter in the middle is 12.5 mm. The surrounding halo of greyish sediment is 36.5 mm long x 22.8 mm in diameter, making for a coating that is ca 7 mm thick.

The way that the specimen is preserved suggests that it had a coating of organic matter, only parts of which were fossilised, but which persisted long enough for calcite to precipitate over parts of the surface. Most of the organic matter then rotted away slowly, leaving space for fine-grained sand to infill the void, much of the iron in the sand being reduced as it was replacing the organic matter. If this scenario is correct, then it suggests that the cocoon belonged to a beetle such as the garden fruit chafer (*Pachnoda*) that coats its cocoons in a relatively thick layer of organic debris (Fig. 12). These beetles typically construct their cocoons in compost-like debris in the soil profile.

Interpretation of the Cocoons

The entomological collections of the National Museum of Namibia were studied to determine whether any cocoons have been accessioned into the collections. The cocoons of the moths *Gonometa postica* and *Schausinna regia* were photographed and compared to the Rietfontein fossil cocoons. However, these were larger, more elongated and more irregularly shaped than the fossil ones.

Two entomologists who are experts on Namibian insects, Dr John Irish and Dr Rolf Oberprieler were consulted for advice on the identification of the fossil cocoons.

Dr Irish postulated that we may well be dealing with a cocoon, possibly of a Saturniidae moth, such as *Gonimbrasia* (Mopane moth), because its size and shape correspond well with the fossils from Rietfontein. However, he questioned what he saw as "*a possible longitudinal seam, especially visible along the left and bottom sides of the object*". We interpret this as an artefact of weathering.

Dr Oberprieler observed that the find is interesting, but that it may be difficult to propose a definite identification of the cocoon or cocoon-maker. He emphasised that there are many moth caterpillars that produce cocoons, but most of these cocoons look quite different from the Prospekteerkop cocoons. They tend to be more elongate, larger and less symmetrical. The smaller ones are soft, and as moth cocoons are made of silken fibre, they might not fossilise at all. According to the shape of the Rietfontein cocoons and the fact that they needed to be durable in order to be fossilised, he postulated that the most likely candidate, if indeed we are dealing with a moth cocoon, would be the slug moth, *Coenobasis amoena* of the family Limacodidae, which has also been recorded in Namibia. Its cocoon however is smaller, about 10 mm in length and it is attached to a tree branch. However, no fossil twigs have been observed at Prospekteerkop. Dr Oberprieler is currently studying weevils in Australia and alerted us that there are beetles whose larvae produce cocoons underground. Their cocoons become hard and can easily fossilise if the ground chemistry is suitable, especially if calcium is present. Articles about fossilised beetle cocoons, in particular weevils, have been published about Australian specimens, but so far little has been reported from Africa.

Figures 7-11 show various extant moth species from Namibia and their cocoons.

Figure 7. *Argema mimosa* moth and cocoon (images from Oberprieler, 1995b).

Figure 8. *Epiphora bauhiniae* moth and cocoon (images from Oberprieler, 1995a).

Figure 9. *Gonometa postica* moth and cocoon.

Figure 10. *Schausinna regia* moth and cocoons.

Figure 11. *Coenobasis amoena* moth, caterpillar and cocoon on a twig (images from Staude *et al*. 2023).

In contrast to moth cocoons, those of coleopterans, such as the garden fruit chafer, *Pachnoda sinuata*, have larger, rounder and more symmetrical cocoons that the beetle constructs in compost. The cocoon is approximately 2.5-3 cm in length and 2.5 cm in diameter. Plant matter is attached to the surface of the cocoon, as can be seen in Fig. 12.

Figure 12. *Pachnoda sinuata* A) adult beetle, B) cocoons coated in vegetable debris and C) larva inside broken cocoon (photo credits : Alexander Mocke).

Discussion

The literature on the fossil record of terrestrial arthropods from Africa is not extensive, but what has been described comprises body fossils (Leakey, 1952; Paulian, 1976; Morris, 1979; McKay & Rayner, 1986; Rayner & McKay, 1986; Rayner & Waters 1991; Rayner *et al*. 1991; Pickford & Senut, 2002; 2010) as well as bioconstructions made by insects (termite hives, termite mounds, ant nests, diverse cocoons) and spiders (spider webs) and other traces (foraging tunnels) (Coaton, 1981, 1973, 1975; Corbett, 1989; Crossley, 1986; Duringer *et al*. 2000; Harrison & Baker, 1997; Moore & Picker, 1991; Pickford, 2000, 2005, 2008; Ritchie, 1987; Sands, 1987; Seely & Mitchell, 1986; Tessier, 1959a, 1959b; Thackeray, 1994; Ward, 1988; Wilson & Taylor, 1964).

Among the body fossils described in the literature, beetles predominate (Paulian, 1976) whereas among the trace fossils, those attributed to termites are the most commonly described (Seely & Mitchell, 1986; Pickford, 2008). Soft tissue fossils are exceptionally rare in Africa but are known from Cretaceous crater infillings at Orapa, Botswana (Insects : Rayner & McKay, 1986) and from aeolianites of the Namib Desert (Spider webs : Pickford, 2000, 2005)

Kitching (1959) described a fossilised puparium from Plio-Pleistocene cave breccias at Makapansgat, South Africa, and the presence of insect cocoons has been listed at various Early Miocene localities in Kenya (Rusinga, Mfwanganu, Koru, Songhor, Kirimun : Pickford, 1982, 1986a, 1986b) and Uganda (Napak :

Musalizi *et al*. 2009; Pickford *et al*. 1986) but none of the material has been described in detail, although measurements of the Kirimun specimens were published (Pickford, 1982). For many years, East African fossil cocoons were misidentified as snake eggs (Musalizi *et al*. 2009).

In most of the publications dealing with fossil arthropods and their traces, there were discussions about their palaeoenvironmental significance. For this reason, it is important to put on record the discovery of fossilised cocoons at Prospekteerkop, Namibia.

Conclusion

The fossil cocoons from Prospekteerkop, Rietfontein, in northern Namibia, are not attributed to a specific invertebrate maker, although the available evidence suggests that two of them may have been made by a beetle such as the fruit chafer. Nevertheless, the specimens do indicate that an organism was living in northern Namibia during the Plio-Pleistocene that needed a cocoon to protect the pupa against adverse environmental conditions (e.g. aridity, heat), parasites or predators.

Taking into account the size, shape and symmetry of the cocoons, the most plausible conclusion is that they may have been constructed by a beetle which deposited its resistant casing, coated in vegetable matter, in the soil so that the pupa could pupate safely.

To date, there is no evidence that the cocoons were attached longitudinally to twigs, which, had this been the case, would have indicated that the cocoons might belong to a species of moth that attached its cocoons to the branches or twigs of trees well above ground level.

Therefore, on the basis of the available information, especially the symmetry and dimensions of the specimens and the halo of greyish sediment containing angular fragments of petrified plant debris, and the calcite crystals that surrounds one of them, we conclude that the most likely maker of the Prospekteerkop fossil cocoons was a species of coleopteran that constructed its cocoon in compost in the soil profile, and that attached organic debris to the surface of the cocoon, as is done by fruit chafers. Until the maker of the cocoons is securely identified it will be difficult to base reconstructions of the palaeoenvironment upon them.

Other research methods such as X-ray Tomography may shed light on the possible contents and immediate surroundings of the cocoons. If so this could narrow down the identification of their maker.

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Geochemistry of intrusive rocks in the Aus area, Southern Namibia

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Abstract :- Aus is located in the southern part of Namibia within the Aus Domain of the Palaeo- to Mesoproterozoic Namaqua-Natal Metamorphic Province. The area is characterised by voluminous granitoids which intruded supracrustal rocks of the pre-tectonic Garup group. In this study, the geochemical characteristics of the intrusive rocks were investigated, showing them to be acidic, peraluminous and derived from shoshonitic and high-K calc-alkaline magmas of an-orogenic origin. Chondrite-normalised spidergrams display characteristics of rocks originated in an arc environment, while plots of K_2O vs SiO_2 exhibit considerable scatter indicative of crustal contamination. Three geotectonic settings are indicated, i. e. Syn-Collisional, Volcanic Arc and Within Plate, supporting collision of continental fragments.

Keywords :- Namaqua – Natal Metamorphic Province, Geochemistry, Tectonic setting, Granitoids

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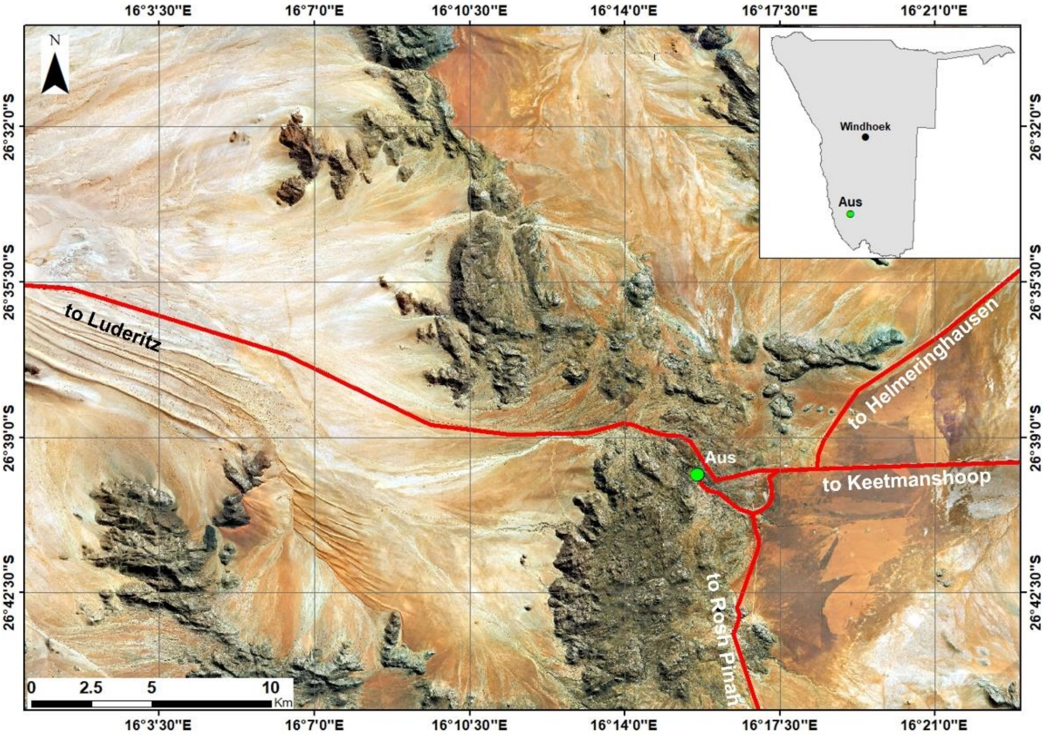

Figure 1. Locality map showing the extent of the study area

Introduction

The study area is located near Aus, southern Namibia, some 125 km northeast of Lüderitz (Fig. 1). Geologically, the area lies within the Aus Domain of the Palaeo- to Mesoproterozoic Namaqua-Natal Metamorphic Province (NNMP). Effects of the ca. 1200 Ma Namaqua Orogeny include voluminous intrusions of syn- and post-tectonic granitoids (e. g. Cornell *et al*., 2006; Miller, 2012) and high-grade metamorphism (amphibolite facies and higher; e. g. Waters, 1986; Moen & Toogood, 2007; Macey *et al*., 2015; Diener *et al*., 2013).

The oldest rocks in the Aus area belong to the pre-tectonic Garub group, which comprises metapelitic and metapsammitic gneisses, quartzite, mafic granulite, marble, calc-silicate and ironstone, metamorphosed under amphibolite to granulite facies conditions (Jackson, 1976). These rocks were extensively intruded by pre-, syn- and post-tectonic granitoids (Figs. 2-6); the garnet-bearing tonalitic to granodioritic Tsirub augen gneiss, represents the oldest igneous suite and pre-tectonic intrusive in this area, having been emplaced shortly before the peak of granulite facies metamorphism (Jackson, 1976; Diener *et al*., 2013). Widespread syn-tectonic magmatism led to the emplacement of the schlieren-rich, leucocratic, sheeted Kubub granite gneiss and the coarse-grained, K-feldspar-megacrystic Aus leucogranite gneiss (Jackson, 1976). U–Pb zircon dating of pre-, syn- and post-tectonic granitoid intrusions indicates that plutonism occurred at ~1120-1085 Ma, whereas metamorphic overgrowths on the same zircons constrains the age of metamorphism to between ~1065 and 1045 Ma (Diener *et al*., 2013). A granite dyke believed to be post-tectonic intruded after the domain cooled to subsolidus temperatures and records an age of 1004±6 Ma (Diener *et al*., 2013). This study investigates the geochemistry of the intrusive rocks in the Aus area with the intention to determine its geotectonic setting.

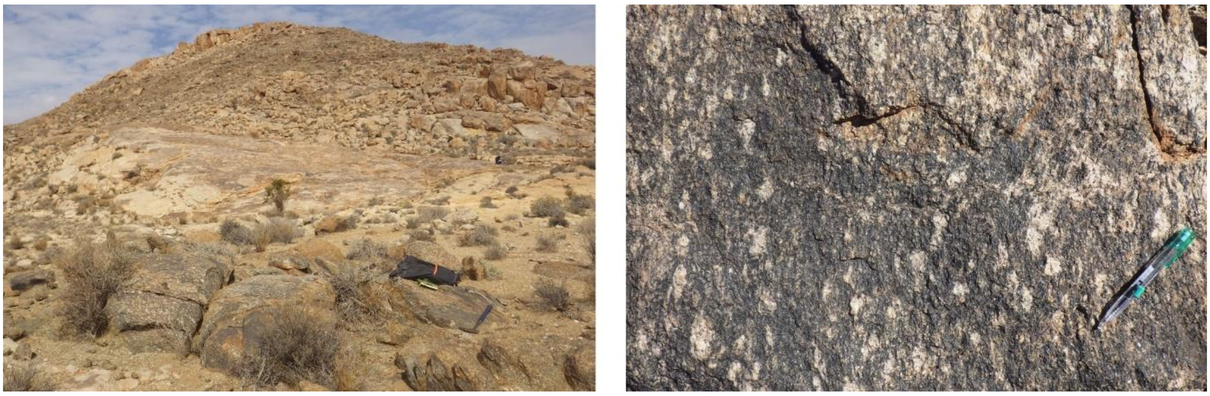

Figure 2. Coarse-grained megacrystic granodioritic Tsirub augen gneiss

Figure 3. Coarse-grained megacrystic Aus granite gneiss

Figure 4. Medium- to coarse-grained Kubub granite gneiss (Type 1) with schlieren texture

Figure 5. Very coarse-grained pegmatitic Kubub granite gneiss (Type 2)

Figure 6. Weakly foliated leucocratic Warmbad granite

Regional Geology

The Namaqua - Natal Metamorphic Province is represented by a ~400 km wide belt extending for more than 1500 km from southern Namibia to southeastern South Africa (Blignault, 1977; Blignault *et al*., 1983; Hartnady *et al*., 1985; Joubert, 1986; Thomas *et al*., 1994; Frimmel, 2000; Cornell *et al*., 2006). Rocks along the belt were assembled during the Namaqua Orogeny between ca. 1200 and 1000 Ma, and are variably deformed and metamorphosed (Cornell *et al*., 2006; Miller, 2012). They form the southern African portion of the global Mesoproterozoic orogen linked to the assembly of the Rodinia Supercontinent between ca. 1350 and 1050 Ma (Hoffman, 1991, 1992). This amalgamation has traditionally been associated with a series of crustal blocks being accreted onto the southern and southwestern margins of the Kaapvaal Craton of southern Namibia and South Africa, (Hartnady *et al*., 1985; Joubert, 1986; Humphreys & Van Bever Donker, 1987; Eglington & Armstrong, 2003; Colliston & Schoch, 2013), which led to the establishment of different litho- and tectonostratigraphic subdivisions. However, Macey *et al*. (2015) hold some rather different views about these domains, which they consider to have resulted from reworking rather than accretion.

The NNMP has been divided into two segments, i. e. the Natal Sector in southeastern South Africa and the Namaqua Sector in southern Namibia and northwestern South Africa (Cornell *et al*., 2006; Frimmel, 2000). Recent work by Macey *et al*. (2015) redefined and recognised different crustal blocks within the Namibian part of the Namaqua Sector (Fig. 7). These are from north to south a) the Konkiep Domain (formerly Konkiep Subprovince), b) Kakamas Domain (formerly Gordonia Subprovince, subdivided into the Kakamas and Grünau Terranes), c) Aus Domain (formerly Aus Terrane) and d) Richtersveld Magmatic Arc (formerly Richtersveld Subprovince), which comprises the Vioolsdrift, Pella and Sperrgebiet Domains (Blignault *et al*., 1983; Hartnady *et al*., 1985; Joubert, 1986; Thomas *et al*., 1994; Colliston

& Schoch, 2000; Miller, 2008; Macey *et al*., 2015). These crustal blocks are separated by major structural discontinuities and differentiated on the basis of lithostratigraphy, tectonic history and metamorphic grade (Hartnady *et al*., 1985; Colliston & Schoch, 1996; Cornell *et al*., 2006; Miller, 2008). However, many of the determining criteria remain debatable, and multiple interpretations have evolved (Joubert, 1986; Thomas *et al*., 1994; Moen & Toogood, 2007; Macey *et al*., 2017).

A number of authors (e. g. Cornell *et al*., 1992; Colliston & Schoch, 2013; Bial *et al*., 2015; Macey *et al*., 2015; Indongo, 2017) have described the processes which led to the current configuration of tectonic domains, in an attempt to understand the specific geodynamic setting responsible for the regional Mesoproterozoic upper amphibolite to granulite signature. Their various interpretations of the regional tectonic setting encompass 1) a continental collision model (e. g. Blignault *et al*., 1983; Thomas *et al*., 1994; Eglington, 2006), 2) a continental back-arc setting (e. g. Waters, 1986; Bial *et al*., 2015), and 3) magmatic under- or intraplating accompanied by compressional tectonics (e. g. Diener *et al*., 2013) under medium- to low-pressure and high-temperature granulite facies metamorphic conditions. Colliston & Schoch (2013) and Colliston *et al*. (2015) presented evidence for extended compressional tectonics and proposed a model involving the collision of crustal fragments. A detailed review on the evolution of the NNMP is given by Cornell *et al*. (2006) and Macey *et al*. (2015), and references therein.

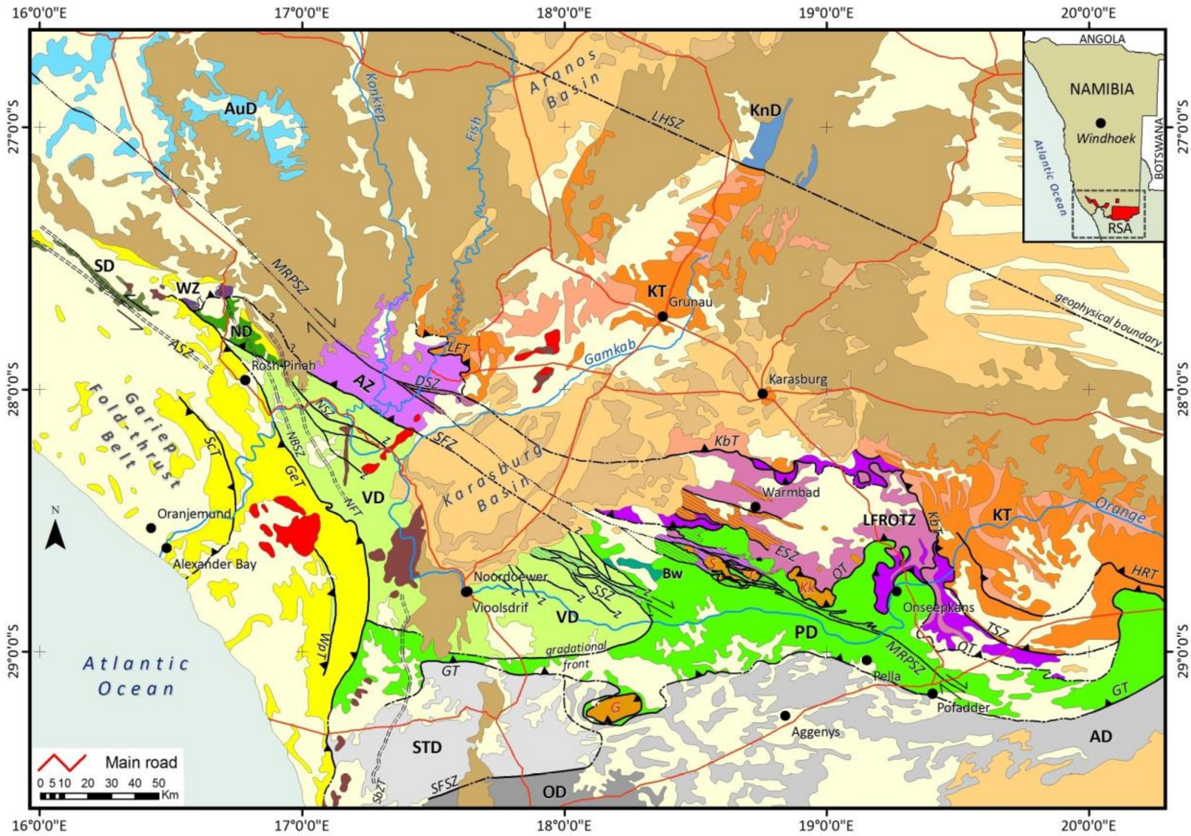

Figure 7. Tectonostratigraphy of the Namaqua Sector (after Beukes, 1973; Colliston & Schoch, 1998; Cornell *et al*., 2006; Moen & Toogood, 2007; Moen, 2007; Miller, 2008; Macey *et al*., 2015; Gresse *et al*., 2016; Thomas *et al*., 2016). KnD – Konkiep Domain; AuD – Aus Domain; KT- Kakamas Domain; LFROTZ + WZ + AZ – Lower Fish River-Onseepkans Thrust Domain; SD – Sperrgebiet Domain; VD – Vioolsdrif Domain; PD – Pella Domain

Local Geology

The Aus Domain is dominated by voluminous and extensive Mesoproterozoic (1220-1050 Ma) upper amphibolite to granulite facies, aluminous paragneisses and granitoids rocks (Blignault *et al*., 1983; Macey *et al*., 2015). Similar rock types and metamorphic grades occur in the adjacent Kakamas Domain, although the age of tectonism and metamorphism differs (Diener *et al*., 2013). The high-grade gneisses and granitoids of the two domains are believed to be derived from pre-existing older crust of the Palaeoproterozoic Richtersveld Magmatic Arc and the early Mesoproterozoic Areachap Arc (South Africa; Joubert, 1986; Macey *et al*., 2015) through reworking during mid-Mesoproterozoic high-grade metamorphism and associated intense plutonism. Subsequently, this reworked crust, represented by the high-grade rocks of the Kakamas and Aus Domains, was thrusted as imbricate sheets over the medium- to low-grade rocks of the Richtersveld Magmatic Arc along the Lower Fish River-Onseepkaans Thrust Zone during the mid- to late-Mesoproterozoic D_2 phase of the Namaqua Orogeny (Nordin, 2009; Samskog, 2009; Macey *et al*., 2015; Blignault *et al*., 1983; Colliston & Schoch, 2000, 2013; Macey *et al*., 2015; Miller, 2008, 2012; Moen & Toogood, 2007).

Sample preparation and analytical procedure

A total of eighteen granite samples were submitted for geochemical analysis at the University of Stellenbosch Laboratories, South Africa. Five of these samples were prepared at the Geological Survey of Namibia Laboratories by the author. The samples were crushed with a jaw crusher into <2 cm chips, which were milled to <75 μ powder fraction. Some 50 – 100 g of the sample were submitted for major and trace element analysis. Major elements were analysed by X-Ray Fluorescence (XRF) and trace elements by Inductively Coupled Plasma Mass Spectrometry (ICP-MS).

For major element analysis, the milled sample (<75 μ fraction) was roasted at 1000°C for at least three hours to oxidise Fe^{2+} and S and determine the loss on ignition (LOI). Glass disks were prepared by fusing 1.5 g of the roasted sample and 9 g flux consisting of 66.67% $Li_2B_4O_7$, 32.83% $LiBO_2$ and 0.50% LiI at 950°C. For trace element analysis, 12 g of the milled sample and 3g Hoechst wax were mixed and pressed into a powder briquette by a hydraulic press with an applied pressure of 25 tonnes per square metre. The glass disks and wax pellets were analysed by a PANalytical Axios X-ray fluorescence spectrometer equipped with a 4 kW Rh tube. ICP-MS trace element and rare earth element (REE) analyses were carried out on a Perkin-Elmer ELAN 6000. A three-step HNO_3 acid digestion described by Le Roex *et al*. (2001) was used to obtain solutions. Approximately 50 mg of sample were placed in Teflon containers (Savilex beakers) and 4 ml of a 3:1 HF/HNO_3 were added. The container underwent a 48-hour digestion on a hot plate. After drying, 2 ml of concentrated nitric acid (HNO_3) were added and reheated until dry again. This process was repeated once. Following the final addition of 5% nitric acid, the container was transferred to a centrifuge tube and placed in an ultrasonic bath for dissolution, after which the sample was ready for use in the ICP-MS spectrometer. Errors were better than 3% and detection limits within the lower ppb range.

Granitoid geochemistry

Major elements

The granitoid samples display trends of decreasing Al_2O_3, CaO, FeO_t, MgO, TiO_2, P_2O_5 and MnO, but a slight increase in K_2O and Na_2O with increasing SiO_2 on the Harker variation diagram (Fig. 8). Some trends are much better defined (e. g. CaO, MgO, Na_2O and P_2O) than others which appear more scattered (K_2O and MnO). The positive trends of K_2O and Na_2O against SiO_2 could relate to contamination of the granitic magma by silicate rocks. Cr_2O_3 is present in very insignificant amounts of 0.002 - 0.01 wt.%. Similarly, samples show very low volatile (LOI) content between 0.15 and 1.58 wt.%, which implies a low degree of weathering.

The analysed granitoids have SiO_2 contents of between 65 and 73 wt.% (mean 70 wt.%), and Na_2O + K_2O between 5.5 and 9.1 wt.% (mean 7.3 wt.%), while the SiO_2/Al_2O_3 ratio varies between 3.9 and 6.4. They range in composition from granodioritic to granitic and plot in the sub-alkaline field as defined by Cox *et al*. (1979) on the total alkali versus silica (TAS) diagram (Fig. 9a). In the K_2O versus SiO_2 diagram (Fig. 9b) the granitoid samples fall in the shoshonitic and high-K calc-alkaline fields. The high content of SiO_2 in all the granitoids shows that they are highly fractionated.

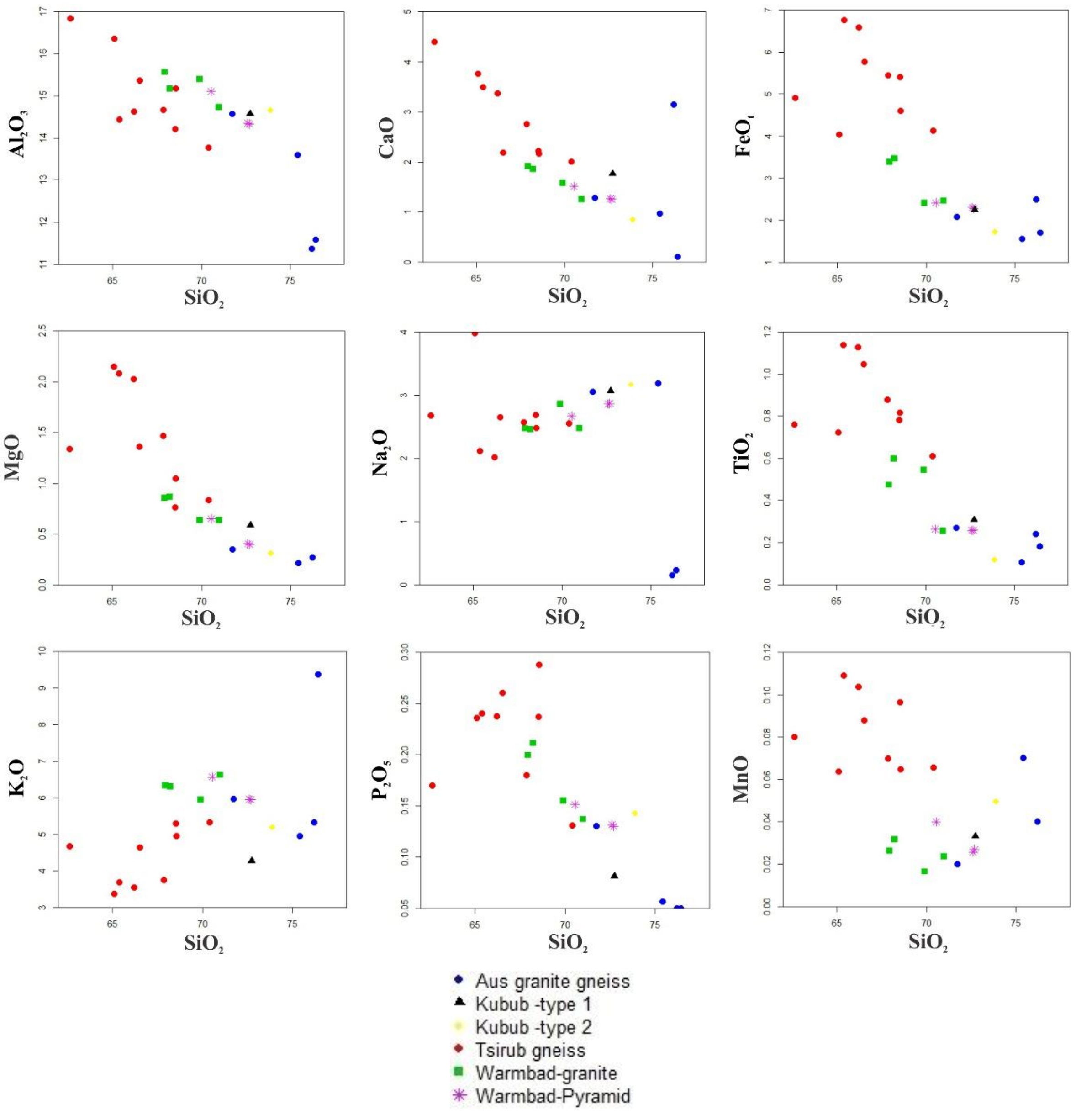

Figure 8. Harker (1909) diagrams for bivariate major elements (in wt.%)

The granodiorite and granites display a linear trend that falls in the calc-alkaline field on the AFM diagram, with high Na_2O and K_2O and moderate FeO_t and MgO (Fig. 9c). However, four samples of the Tsirub augen gneiss plot at the boundary between the tholeiite and calc-alkaline series (Fig. 9c). The samples are strongly peraluminous with an average Alumina Saturation Index (ASI) of 1.5; only three samples plot in the metaluminous field on the A/NK vs A/CNK diagram (Fig. 9d).

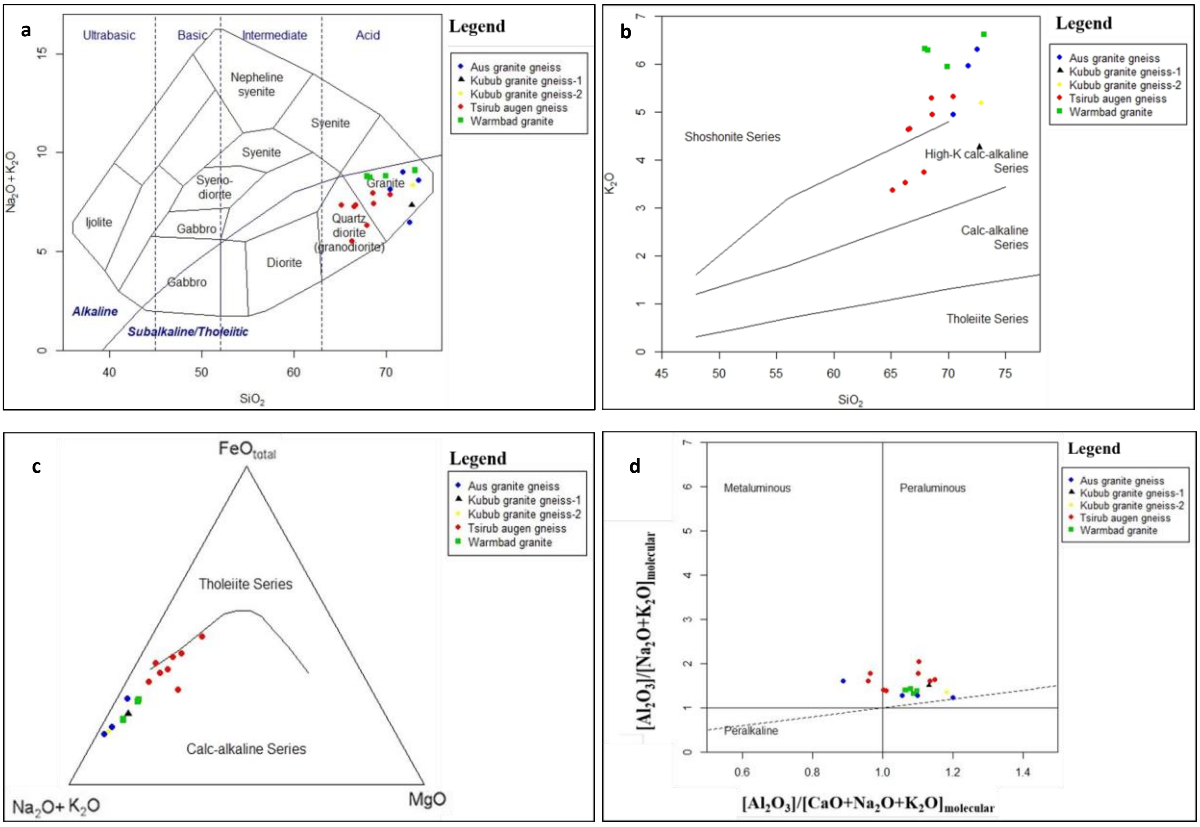

Figure 9. a) TAS plutonic classification by Cox *et al*. (1979); b) SiO_2-K_2O plot (Peccerillo & Taylor, 1976); c) AFM diagram (Irvine & Baragar, 1971); d) Shand (1943) classification of peralkaline, metaluminous and peraluminous rocks

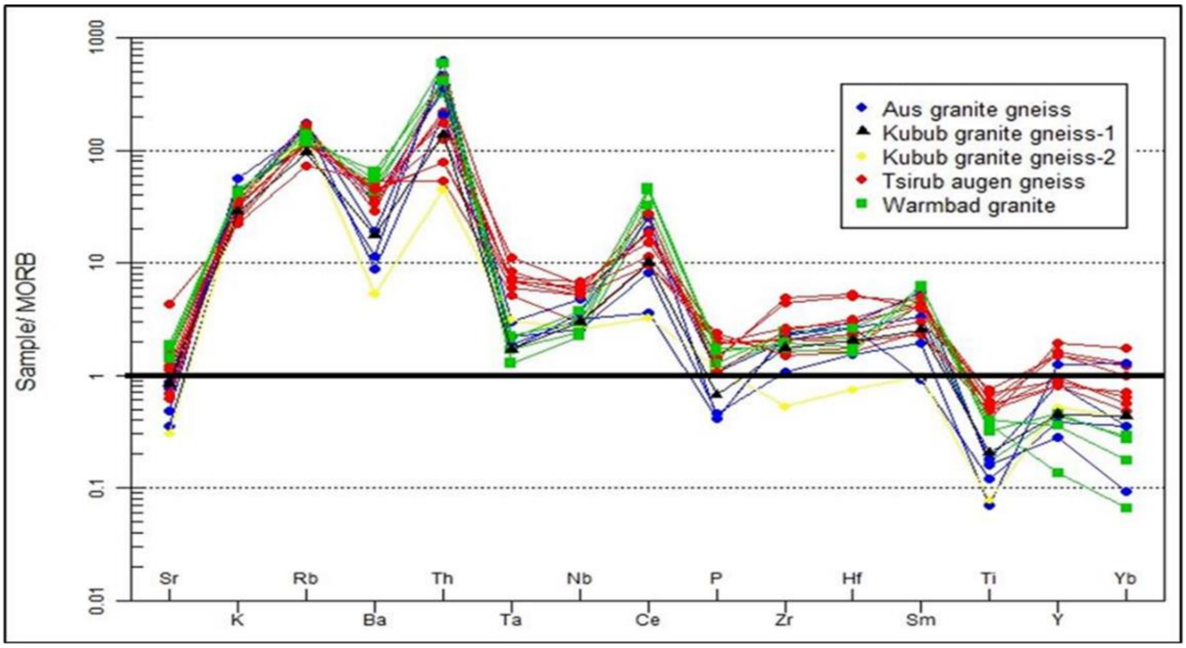

Figure 10. MORB-normalised spidergram after Pearce (1984)

Trace elements

Trace element analytical results are presented in Figure 10, showing high concentrations of Rb (up to 353 ppm), Sr (up to 511 ppm), Zr (up to 443 ppm), Ba (up to 1298 ppm), La (up to 216 ppm), Ce (up to 458 ppm) and Nd (up to 164 ppm). V and Cu show moderate concentrations of up to 90 and 86 ppm, respectively. Other trace elements have concentrations of < 50 ppm.

Rare Earth elements (REE)

The REE diagram exhibits enrichment of light rare earth elements (LREE) relative to heavy rare earth elements (HREE), with a sharp negative Eu anomaly related to plagioclase fractionation (Fig. 11). The slope of LREE is distinctly steeper than for HREE, which is generally very shallow. All samples are enriched in REE relative to chondrite-normalised values (Nakamura, 1974). A degree of fractionation in HREE toward Lu is evident.

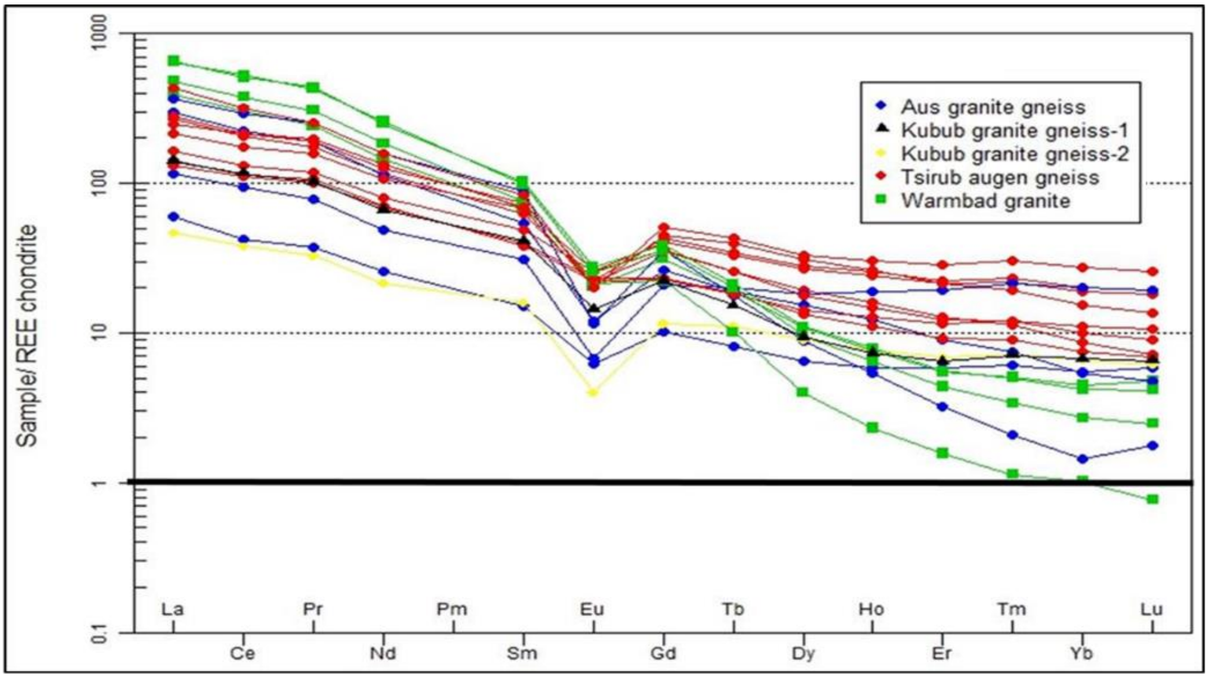

Figure 11. Chondrite-normalised REE concentration patterns of the sampled granitoids (normalised values from Nakamura, 1974)

Typically, granites are classified as A (anorogenic), I (igneous), or S (sedimentary) - type. The Ga/Al ratio in granites serves as an indicator of petrogenesis, tectonic setting, magmatic processes and potential for associated mineralisation (Whalen *et al*., 1987). Plots of Ga/Al versus certain major and trace elements identify the granitoid rocks of the Aus area as A-type granites; on plots of Zr+Nb+Ce+Y versus major element ratios such as FeO*/MgO and $(K_2O+Na_2O)/CaO$ some samples plot in the I and S- type fields (Fig. 12). Samples classified as granites (Fig. 9a; Aus granite gneiss, Kubub granite gneiss types 1 & 2, Warmbad granite) plot within the syn-collisional Granite (syn-COLG) and Volcanic Arc Granite (VAG) fields, whereas samples classified as granodiorite (Tsirub augen gneiss) fall in the Within Plate Granite field (WPG) on tectonic discriminations diagrams after Pearce *et al*. (1984; Fig. 13) on the basis of Nb, Y, Ta, Yb and Rb trace element concentrations.

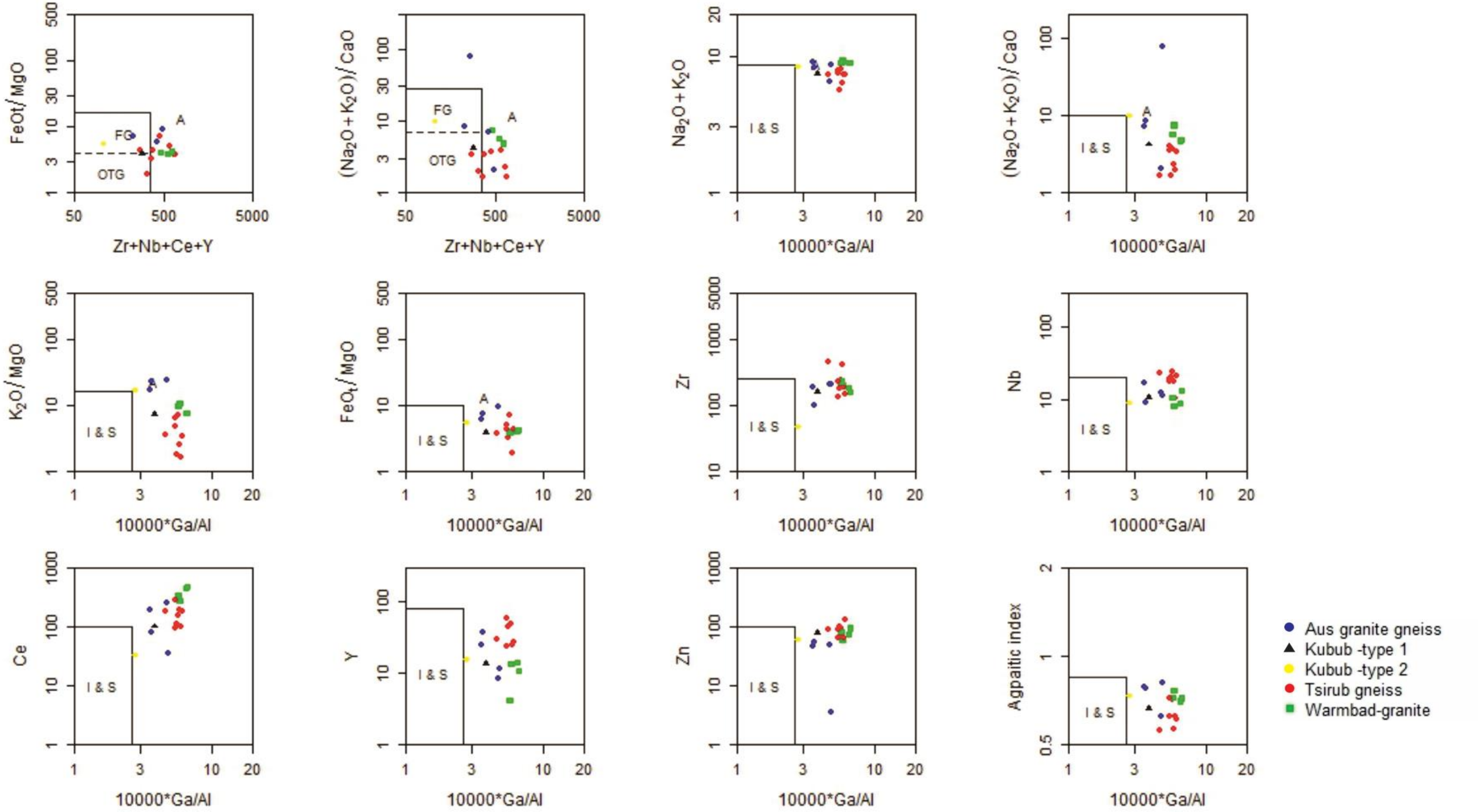

Figure 12. A-S-I-type classification of granitoids in the Aus area (after Whalen *et al*., 1987; FG – Fractionated, OTG – unfractionated I- & S-type granite)

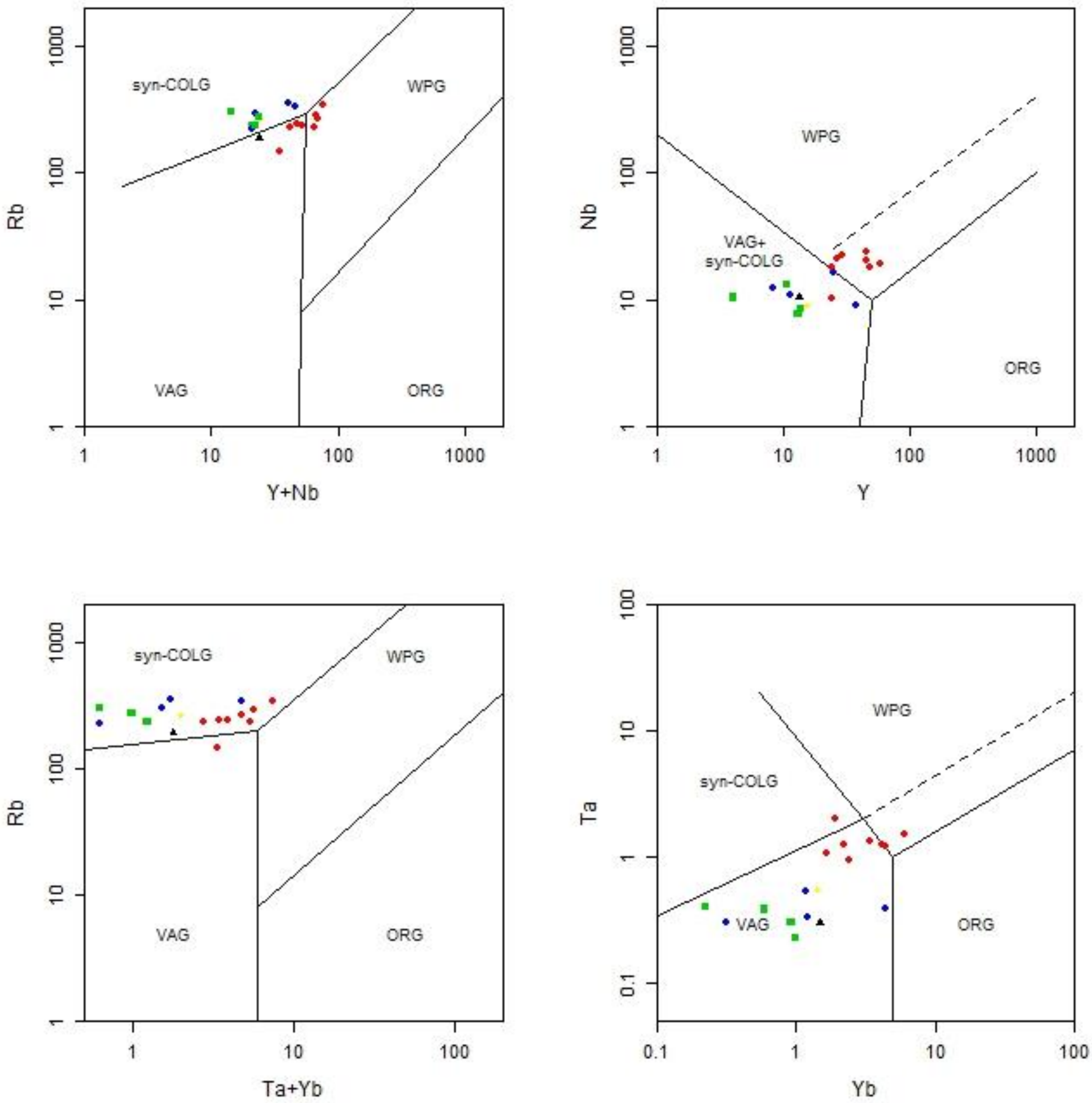

Figure 13. Tectonic discrimination diagrams for granitoids around Aus (after Pearce *et al*., 1984; for symbol explanation see Fig. 12).

Summary and Discussion

Geochemical analyses reveal that all plutonic rocks of the Aus area are acidic, with compositions ranging from granitic to granodioritic. These granitoids are products of shoshonitic to high-K calc-alkaline magmas within the calc-alkaline series, which points to their formation in a magmatic arc environment (Liégeois *et al*., 1998; Clarke, 2019). They are also strongly peralumious, with only a few samples plotting in the metalumious field (Fig. 9d), reflecting their commonly garnetiferous, pelite xenolith-rich nature; on the discriminatory diagram after Whalen *et al*. (1987) they are identified as A-type granites (Fig. 12). On Harker diagrams, the granitoids display trends of decreasing Al_2O_3, CaO, FeO_t, MgO, TiO_2, P_2O_5, MnO, Sr, Ba, Ta and Nb, but an increase in K_2O, Na_2O, Th, Ce, Sm, Y, Hf and Rb with increasing SiO_2 (Fig. 8). The MORB-normalised spidergram displays a strong depletion in Sr, P, Ti, Y and Yb and a simultaneous strong enrichment in K, Rb, Th and Ce. These trends suggest the progressive fractional crystallisation of plagioclase, amphibole, monazite, sphene and zircon, but limited fractional crystallisation of K-feldspar and biotite (Macey *et al*., 2015). The broadly coherent trends of mobile elements such as Rb, Sr and Ba indicate little or no alteration during metamorphism or weathering (Whalen *et al*., 1987). Ba, Ta, Nb, Hf and Sm are mildly enriched relative to MORB (values from Pearce, 1984). Figure 10 shows the Aus and Kubub (type 2) granite gneisses as the most depleted in Sr, P and Ti.

Relatively higher Al_2O_3 and K_2O, and lower Fe contents of the Aus area granitoids are probably due to a greater contamination by pelitic rocks. Negative Ta, Nb, P and Ti anomalies, with enrichments in Th and LREE, which are typical of arc-derived rocks (Whalen *et al*., 1987) suggest continental crust involvement.

Based on the tectonic discrimination diagrams (Fig. 13), three geotectonic settings are indicated, i. e. syn-collisional-Granite (syn-COLG), Volcanic Arc Granites (VAG) and Within Plate Granites (WPG). These inconsistent results may be attributed to hydrothermal alteration and / or sharing of varying degrees of fractionation within multiple flows. They are, however, in support of the collision of crustal fragments model proposed by Colliston & Schoch (2013) and Colliston *et al*. (2015). Additionally, plots of K_2O vs SiO_2 (Fig. 8) show a considerable degree of scatter, which may be attributed to the effects of crustal contamination in an active continental margin environment (Wilson, 1968). Similarly, the geochemistry of high-silica rocks, such as the Tsirub augen gneiss, indicates crustal participation in their parental melts and within-plate extensional affinities (Whalen *et al*., 1987). Based on this evidence it is inferred that the peraluminous A-type granitoids of the Aus area formed as a result of crustal contamination during the continental extensional phase and subsequently were subjected to compressional deformation.

Acknowledgments

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Report: A Geoscientific Data Base for Namibia

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Abstract :- Earth Data Namibia (EDN) is the Geological Survey of Namibia's (GSN) multi-disciplinary geoscience data base, incorporating data from mineral and water exploration, geoscientific research and mapping. Since its launch in 2003 it has evolved from a relatively simple mineral exploration data base, designed to store and make freely accessible tens of thousands exploration reports and maps accumulated since the 1950s - thus preserving irreplaceable information - to a complex system with a variety of modules accommodating most of the data held by the Geological Survey. After 20 years of operation and various upgrades, EDN is a powerful software tool, for both GSN staff and the public, who can search its content on site at terminals in the National Earth Science and Energy Information Centre of the Ministry of Mines and Energy or access it online via the Ministry's website.

Keywords :- Data management

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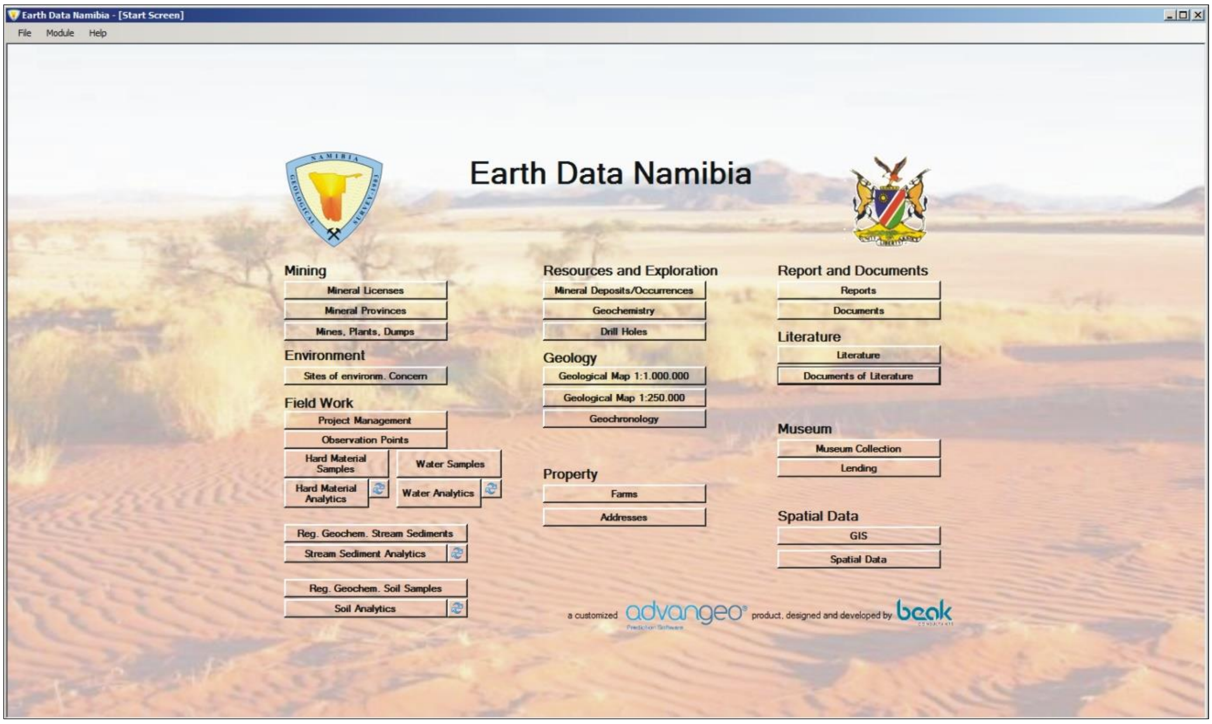

Figure 1. Log-in screen of EDN

History of Earth Data Namibia (EDN)

Up to the end of the 1990s the public was given access to original archival mineral exploration documents - many of them the only copies in existence - at the Ministry of Mines and Energy's National Earth Science and Energy Information Centre. As a result, this valuable data source deteriorated noticeably over the years, through frequent use and occasional misuse. With the widespread introduction of advanced information and computer technology, it was decided to gradually convert all analogue documents into digital format: a project that soon brought about the realisation that the generated profusion of digital files could only be handled and used effectively by means of a dedicated data base/information system.

BEAK Consultants of Freiberg, Germany, were contracted to develop and maintain the system in accordance with specific user requirements, which initially were only to store and search scanned exploration documents. Additional GIS facility allowed to display spatial reference data, such as mineral licence areas, mineral occurrences, farms and administrative entities, as well as geological data, topographic maps and satellite imagery (Landsat 5). However, before long the obvious advantages of storing data in an organised and searchable environment led to the demand for further modules to host geochemical, drill hole, geochronological, environmental and literature information (Fig. 3). The accommodation of this influx of data required the move from MS Access as the initial data base component to ORACLE and eventually to SQL, while GIS functionality switched from ARCVIEW 3 and a free GIS-viewer to ARCGIS. In addition to these system upgrades, several of the modules have undergone significant modification during the years of operation in response to advanced data and user requirements.

The web presence of EDN made its debut in 2012, enabling the public to search the system not only on site but through the internet, albeit with limited functionality. This service received a "face lift" early in 2023 (Fig. 2) to allow access to a broader spectrum of data stored in EDN and offering improved search, display and download options.

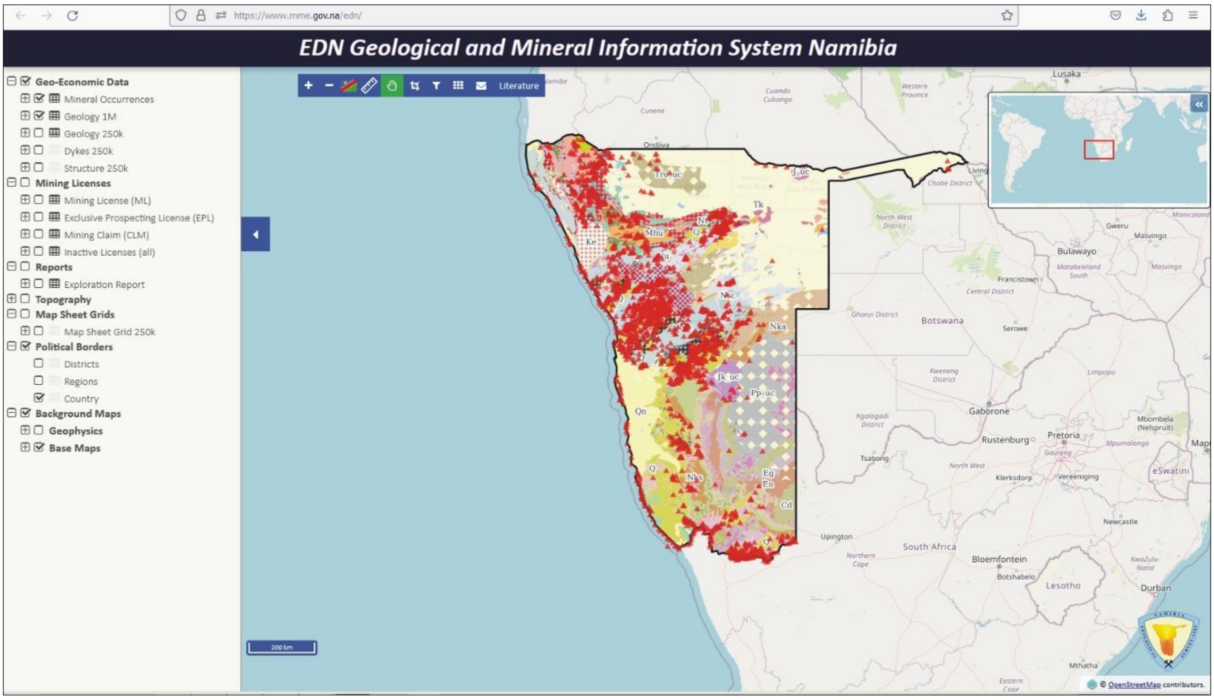

Figure 2. EDN Geological and Mineral Information System (https://www.mme.gov.na\edn)

Challenges

With this powerful tool to hand, it nevertheless became evident that population of the data base, which requires a dedicated full-time work force, was not doing justice to the potential benefits of EDN. A period of stagnation led to a substantial backlog of information, including exploration reports, scientific publications and spatial data (e. g. geochemical/geochronological data, drill holes) from research and exploration. With its usefulness depending on the accuracy of the information contained as well as regular updates, this situation threatened to defeat the purpose of EDN, on whose development and maintenance millions of Namibian dollars had been spent since its inception.

In order to remedy this state of affairs and restore the efficacy of EDN as an up-to-date source of geoscientific information for the exploration industry, researchers and the public in general, at the end of 2020, BGR (Federal Institute for Geosciences and Natural Resources), through the German - Namibian Technical Cooperation Project «Sustainable Use of Namibia's Mineral Potential», recruited six temporary assistants, mostly graduate students, with the object of furthering the population of the various modules of the data base. Work being done by project staff involves not only the uploading of new and archival data, but also the updating and checking of existing records. After three years of operation and an increase of the temporary work force to eight, significant progress has been made throughout the multi-faceted structure of EDN (Fig. 3). At the same time, however, it has become clear that to keep up the momentum the Geological Survey of Namibia will have to consider the assignment of permanent staff to this task to ensure the maximum benefit from its investment.

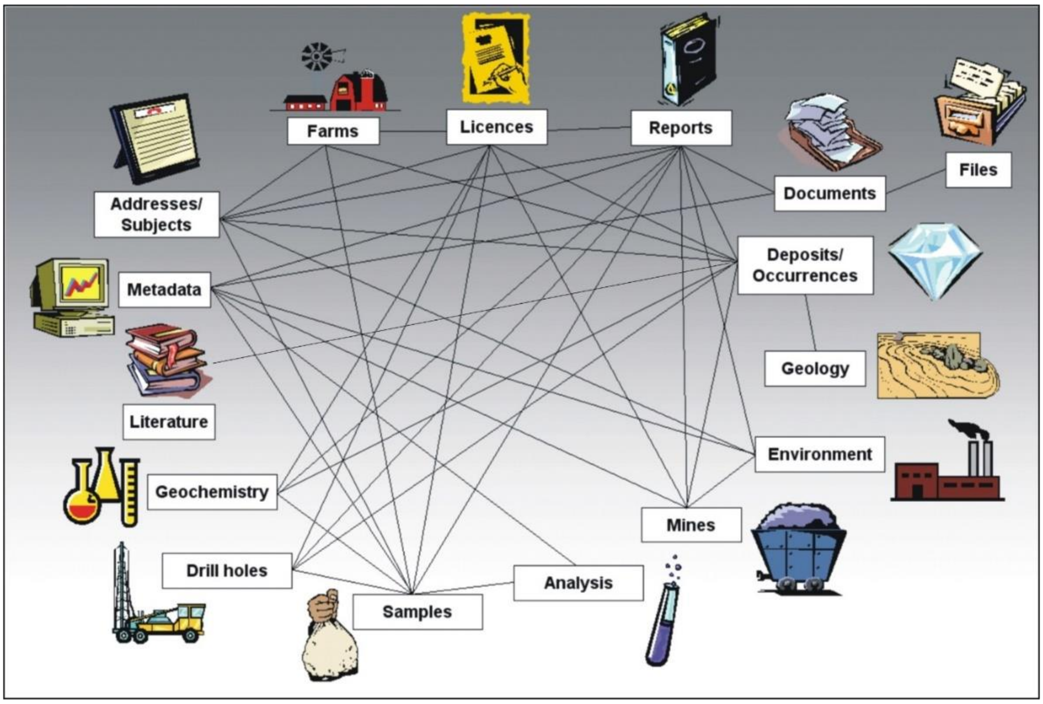

Figure 3. Simplified structure of EDN: All modules are interlinked, resulting in a complex "spider web" with hundreds of data base tables

Current status

The following section gives a brief overview of the content and current status (November 2023) of the main modules of the data base. As the graphs indicate the present initiative has given a significant boost to the image of EDN after years of little activity following the inception phase (note that with the exception of the "Documents" Module, data entered prior to 2011 when EDN moved from ORACLE to SQL are not differentiated).

Mineral licences:

20600 active and inactive licences (incl. those still under application); update is carried out daily by automated import from Namibia's Mining Cadastre Portal.

Metadata include: Name of Applicant (licence holder), mineral group applied for, licence status, validity dates, work carried out and reports available.

Reports:

More than 5200 titles, mostly from mineral exploration, but also other relevant works, such as GSN-reports on mineral deposits, stratigraphy and environmental studies. Reports and related documents pertaining to inactive/historic licences are publicly available under the "Open File" system, while active licence information submitted to the Ministry of Mines & Energy remains confidential ("Closed File") until the licence is relinquished/expired.

Metadata include: Author, report date, number of pages, work done, mineral licence under which the report was generated (where applicable).

Documents:

More than 24000 digital documents, including some 6250 text documents, 11000 maps (geological, geophysical, geochemical, etc.), 4250 bore hole logs and sections, and 2300 data tables mostly from mineral exploration activities, but also from other sources (Fig. 4). Uploaded files include all common Microsoft Office and image formats (e. g. pdf, doc(x), xls(x), ppt(x), jpg, tif), while additional digital material generated by specialised software can be accessed via an external link. The latter information can be viewed/obtained upon request.

Metadata include: Document content, commodity (where applicable), mineral licence.

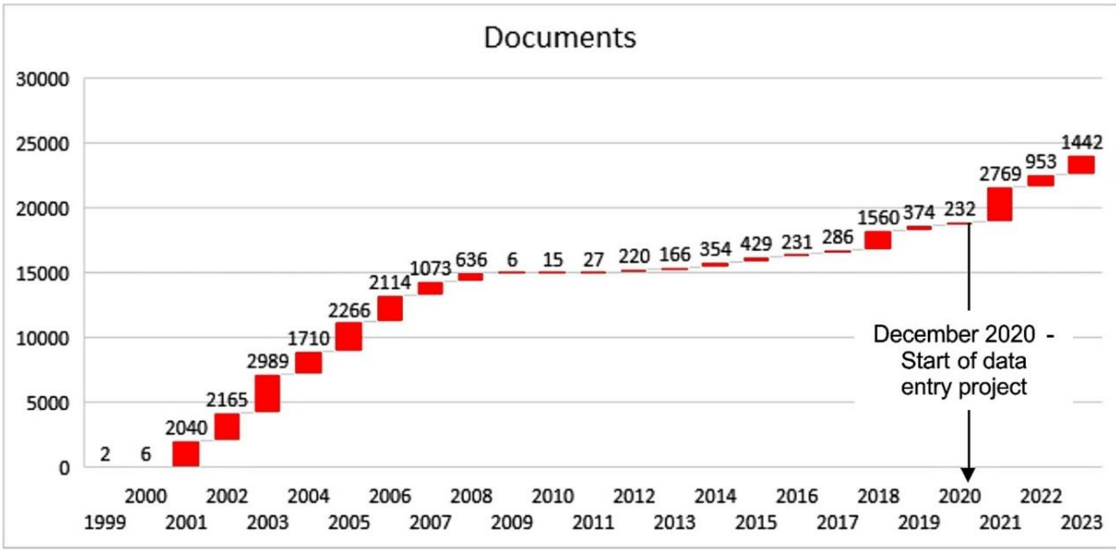

Figure 4. Population history of the "Documents" Module

Mineral occurrences/deposits:

2667 reported occurrences from mineral showings and magnetic / geochemical anomalies to development projects and operating or abandoned mines (Fig. 5); apart from entering new discoveries / anomalies from current exploration activities, major effort is spent on updating and completing existing records with only rudimentary or basic information.

Metadata include: Deposit geology, regional geology, host rock, commodity(ies), ore mineral(s), resources, reserves (if known/applicable), mineralisation type, economic status and spatial reliability of data point.

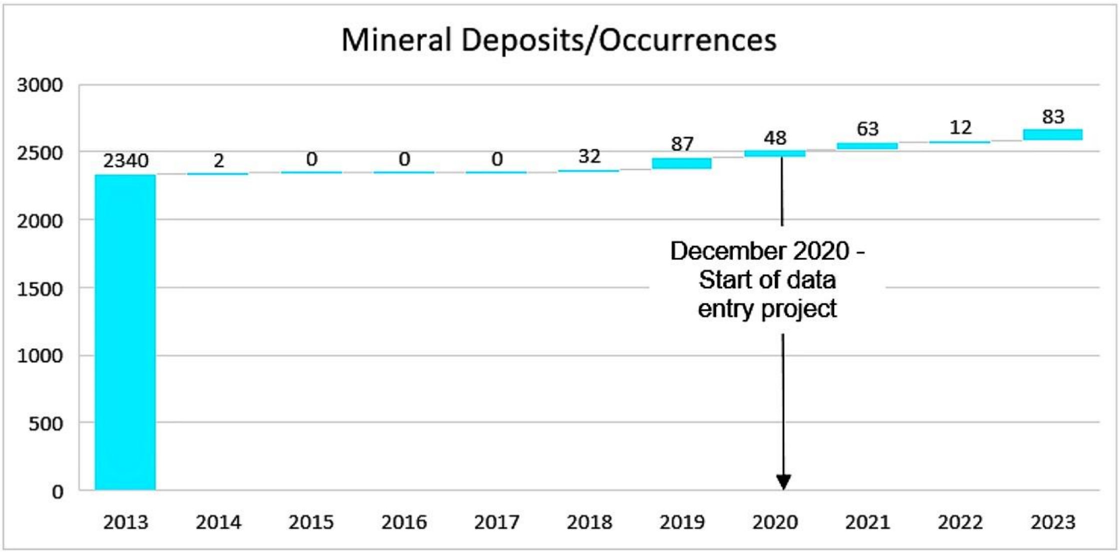

Figure 5. Population history of the "Mineral Deposits/Occurrences" Module

Drill holes:

Water drill holes – 51475 drill holes, many with water analysis, were imported from the Department of Water Affairs' (DWA) GROWAS data base before the launch of EDN; since then 4785 more (some dating back to the early 20th century) have been entered from bore hole completion reports, to bring the current total to 56260 (Fig. 6). Apart from entering bore hole locations and metadata, more than 14 000 bore hole completion reports/logs from GSN and DWA archives were scanned for upload into EDN.

Metadata include: Depth of hole, depth of water strike, yield, spatial reliability of data point.

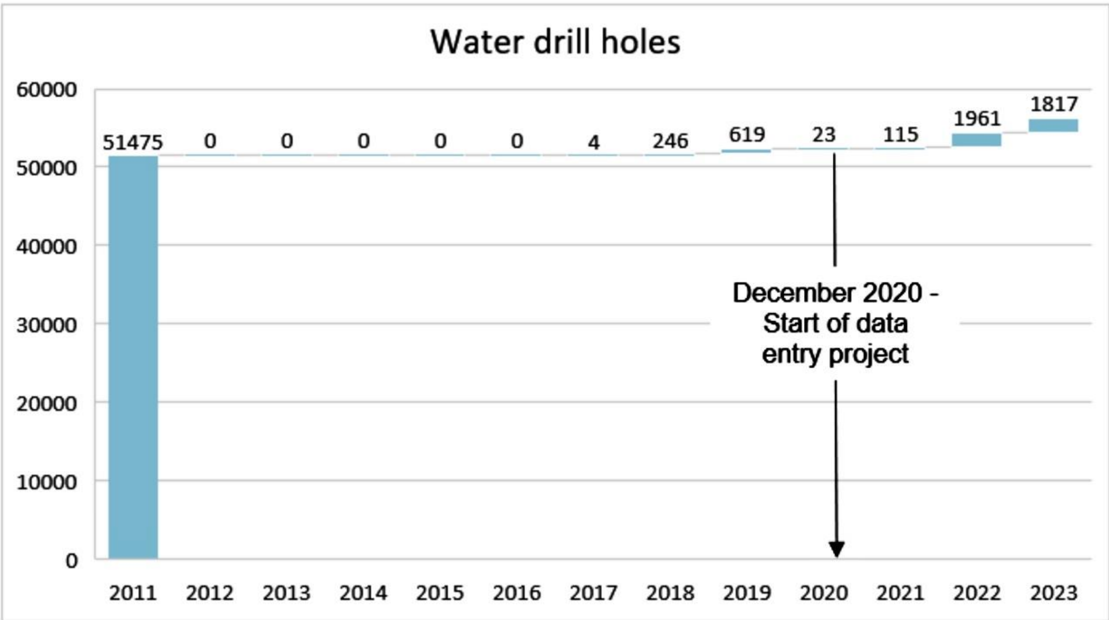

Figure 6. Population history of the "Drill Holes" Module (Sub-module: water drill holes)

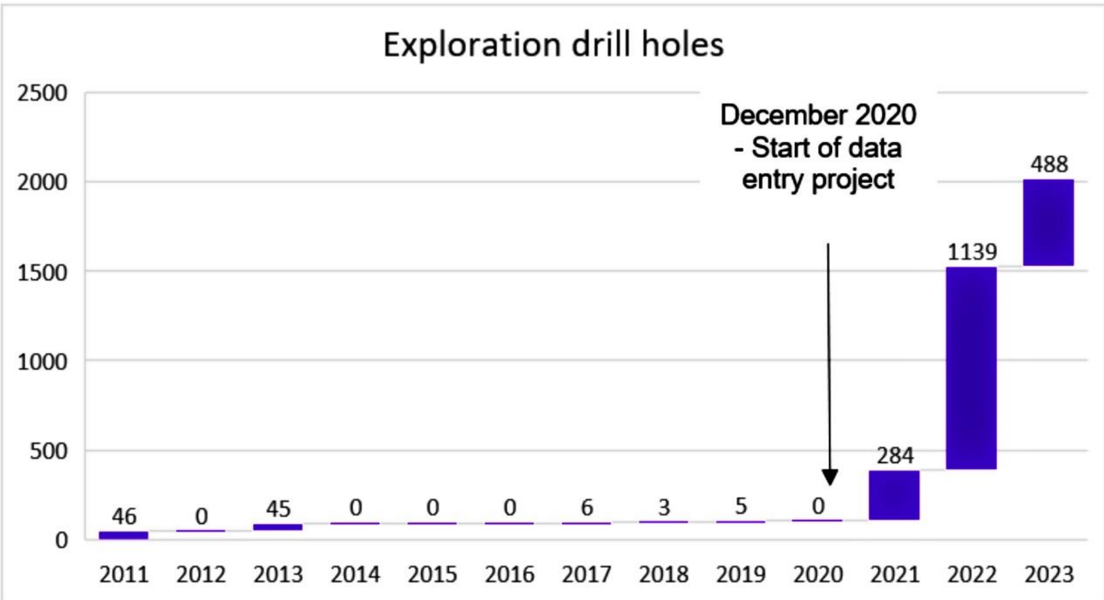

Figure 7. Population history of the "Drill Holes" Module (Sub-module: exploration drill holes)

Exploration drill holes – 2016 records from mineral and hydrocarbon exploration, linked to logs and other relevant information (e. g. down hole surveys, core photographs, drill sections, locality maps), where available (Fig. 7).

Metadata include: Length of hole, inclination/ azimuth, drilling target, drilling method, mineral licence, drilling year, project name, drilling/contracting company, core size, core availability (incl. storage facility/place of storage).

Up to the beginning of the present data entry campaign, very little work had been done on this important aspect of mineral exploration. Considering the vast amount of drilling undertaken in Namibia only over the last few decades, the data currently available in EDN only represent a small portion of the information held by the Geological Survey, but - aided by the complete restructuring of the module involving the separation of water and exploration holes, each new sub-module with its own set of specific metadata – considerable progress has been made during the last couple of years.

Spatial data:

1035 georeferenced geological, geophysical and topographic maps from GSN and exploration surveys, 365 orthophotos and scanned aerial photographs as well as 258 satellite images (ASTER & LANDSAT; Fig. 8). High-resolution imagery is stored at linked server locations outside the data base, owing to their great file size and existing system limitations. Current work on this module included updating of existing records as much as entry of new data. In June 2022, it was temporarily shelved in favour of continuing with the population of the Geochemistry module (see next paragraph), but will resume soon.

Metadata include: Data type, author, production year, map scale and/or image resolution.

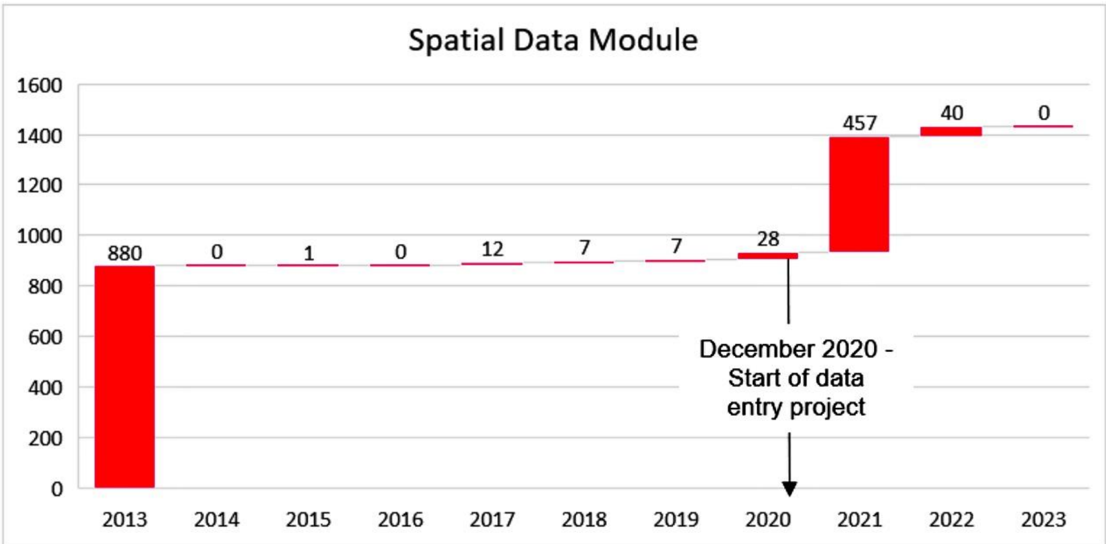

Figure 8. Population history of the "Spatial Data" Module

Geochemistry:

Over 915000 sampling points, predominantly from mineral exploration, but also from regional mapping campaigns, analysed for one to 60 elements (mostly for base metals and/or gold; Fig. 9).

Metadata include: Sample type, fraction analysed, analytical method, sample preparation, laboratory, spatial reliability of data point, sampling year, mineral licence and exploration company (where applicable).

Geochronology:

1651 records from research publications and mapping projects, with concordia diagrams, where available (Fig. 10).

Metadata include: Sample number, age, error, method, material analysed, age interpretation, reference.

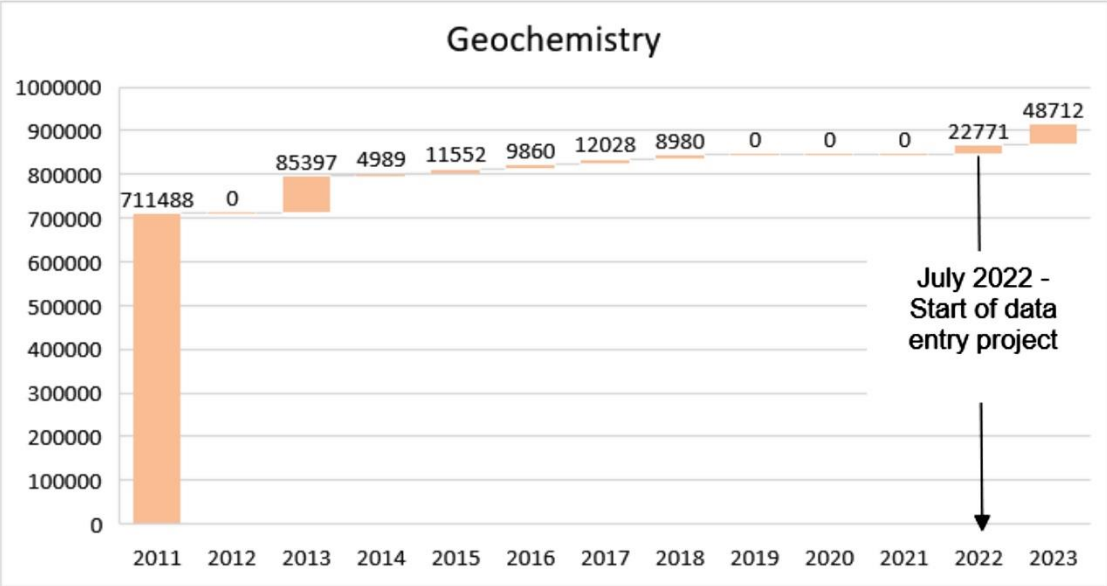

Figure 9. Population history of the “Geochemistry” Module

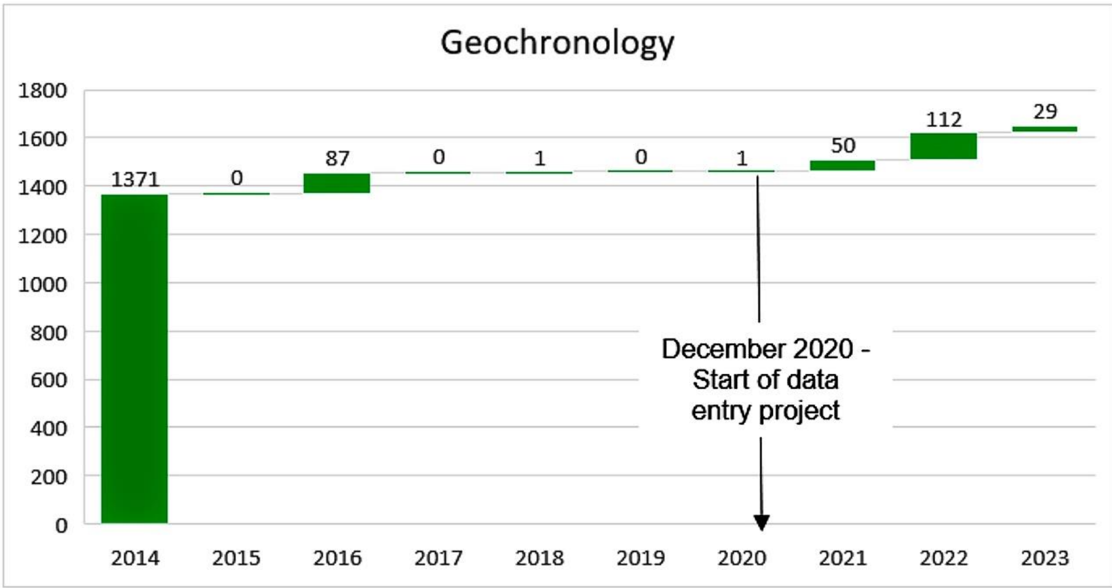

Figure 10. Population history of the “Geochronology” Module

Literature/Documents of Literature:

Nearly 10000 research and review papers, theses, conference abstracts, posters and news articles, with some 4000 linked digital files (Documents of Literature, Fig. 11), predominantly on Namibian geology and related fields, but also on topics of regional/global interest (e. g. geological correlation, mineral economics) and methodology (e. g. GIS technology, geostatistical techniques for the presentation of survey data).

Originally a “stand-alone” module, the latest version of EDN also allows links between mineral occurrences, drill holes and geochronological data points and relevant publications in the “Literature” module.

Metadata include: Author, publication type, title, keywords, publication year, publisher, editor, ISBN/ISSN number and web link (where applicable).

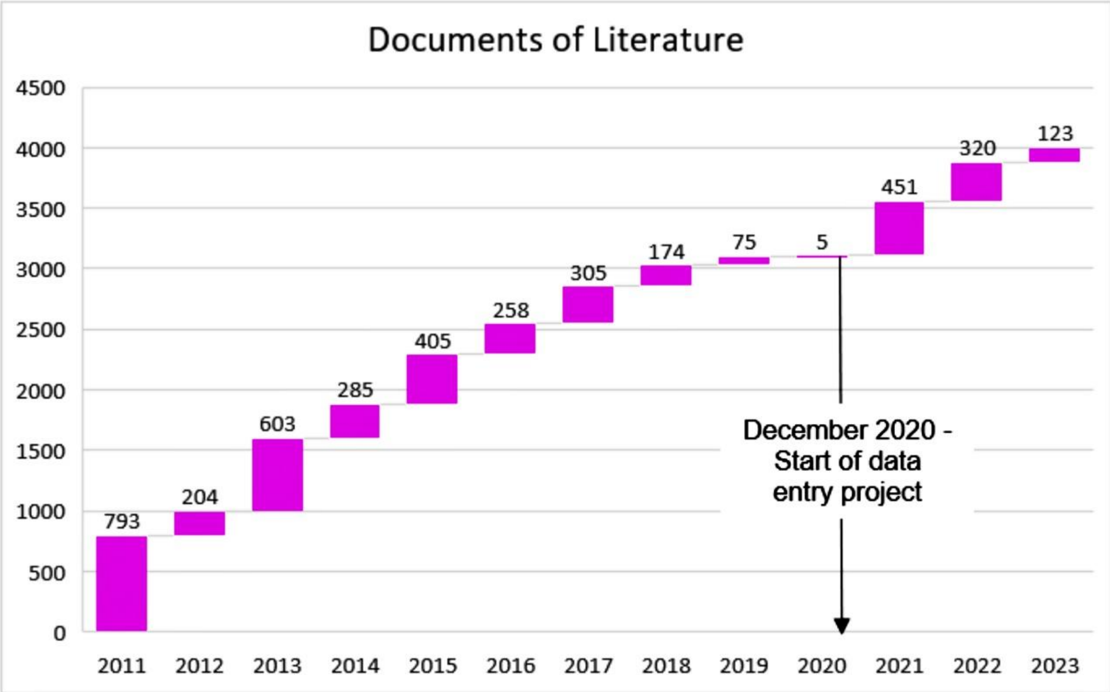

Figure 11. Population history of the "Documents of Literature" Module

Additional features:

Apart from the modules described above, EDN also contains geological vector data at 1:250 000 and 1:1 000 000 scale, a "Field Work" module for internal use to store field data collected by the various divisions and a "Museum" Module to catalogue mineral and fossil specimens held by the National Earth Science Museum and administer inter-institutional lending. Record modification tabs and a "User Administration" module keep track of data entry and quality control, and regulate data access.

Towards the Future

As EDN is increasingly used, both by GSN staff and the public, expectations with regard to software performance and capability also grows. Constant interaction with the developers results in two to three upgrades per year to allow EDN to keep pace with the demands made of it. The latest major modification, i. e. the reprogramming of the so far dormant "Environmental Sites of Concern" module, was implemented in October 2023, and is now in the testing phase; some "fine-tuning" may be necessary as data entry commences to iron out initial shortcomings. The restructured module is designed to contain information on abandoned mines, current mining operations, and any other sites presenting potential or actual geohazards, with links to the "Mineral Deposits / Occurrences", "Documents" and "Documents of Literature" modules.

On an operational level, the GIS component of EDN will move from ESRI ARCGIS to open source Quantum GIS, primarily to provide independence from new ESRI releases and the resultant necessity for recurring system upgrades and adaptations. Initial developing costs for this conversion are expected to be soon equalised by a drop in licence fees for proprietary software, as well as in EDN maintenance expenses.

Although the information contained in EDN is as yet by no means complete and much remains to be done - both in the way of capturing archival information and coping with the steady influx of new data – the current effort has contributed considerably towards establishing EDN as Namibia's number one all-round geoscience data base.

Report: Introducing the Namibian Committee for Stratigraphy

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Abstract :- Geological and geoscientific research has been carried out in Namibia for well over a hundred years ever since the earliest colonial days. Enormous advances in science and technology during this period of time have led to a rather heterogenous data set, compiled from maps of greatly varying vintage and detail. Up to the time of Namibian independence in 1990, the South African Committee for Stratigraphy (SACS) included the geology of Namibia within its framework, but since then geological research in the country has been ongoing without the benefit of an overseeing agency to regulate activities, set standards and incorporate new results into a consistent and unambiguous stratigraphic data base. For these reasons it was deemed desirable to establish a Namibian Committee for Stratigraphy.

Keywords :- Stratigraphy, Data management

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Background

With its multi-faceted geology, encompassing rocks and semi- to unconsolidated deposits from the Archaean to Cenozoic and spanning more than 2.5 billion years of earth history, Namibia has attracted geoscientists, both from academia and natural resource exploration since the late 1800s. During this time, a mass of information of vastly different vintage, accuracy and state of knowledge has accumulated in the archives of the Geological Survey of Namibia (GSN) and among the pages of international scientific literature. However, at present there is no formal framework guiding researchers from home and abroad with respect to stratigraphic nomenclature and hierarchy. This lack of guidelines has repeatedly led to conflicts such as identical names accorded to different stratigraphic units or disparate names assigned to the same one (Table 1) – a situation creating problems not only for stratigraphic integrity, but also for the compilation of geological maps, which is one of the core functions of GSN.

One of the first concerted efforts towards unravelling the existing information and modern data management was the conception of a “map library”, containing descriptive attributes of lithostratigraphic units from the entire country that could be linked to spatial information in a GIS environment. This project, started in the early 1990s in co-operation with the Finnish Geological Survey, provided the basis for an index of almost 1000 formal to semi-formal stratigraphic and tectonostratigraphic units up to 2020. In addition to the primary hierarchical and descriptive attributes, it also contains synonyms/obsolete names, original reference and type locality, if known. It is to expand this index and resolve existing conflicts, as well as to institute formal procedures for the introduction of new stratigraphic units / names and to promote common standards in stratigraphic nomenclature, that the Geological Survey of Namibia decided to form a national Committee for Stratigraphy similar to its South African counterpart, in 2021.

The Namibian Committee for Stratigraphy (NACS)

The initiative to establish NACS rested with the Regional Geoscience Division of GSN, as the custodian of geological information in charge of map production and maintenance of the “map data base”, with its initial Secretariat / Executive Committee re-

Synonym/old name	Name	Status	Age	Reference	Remarks
Bergfriede, Nuremberg, Husab	Karibib	Formation	Ediacaran	SACS (1980)	
Karibib Formation	Bergfriede	Formation	Ediacaran	Clifford (1962; 1967; 2007)	Local name (Fransfontein Ridge)
Karibib Formation	Nuremberg	Member	Ediacaran	Clifford (1962; 1967)	Local name (Okonguarri Antiform)
Karibib Formation	Husab	Formation	Ediacaran	Jacob (1974)	Local name (southern Central Zone)
Lower Omao Formation	Beesvlakte	Formation	Tonian	Hoffman and Halverson (2008)	
Beesvlakte Formation	Lower Omao	Formation	Tonian	Woodhead (2007)	Study by Colorado School of Mines
Upper Omao Formation	Okakuyu	Formation	Tonian	Hoffman and Halverson (2008)	
Upper Omao Formation	Devede	Formation	Tonian	Hoffman and Halverson (2008)	
Okakuyu & Devede Formations	Upper Omao	Formation	Tonian	Woodhead (2007)	Study by Colorado School of Mines
Huab Formation	Rhino Wash	Formation	Permian	Miller (2008)	Renamed because of Huab MC
	Huab	Formation	Permian	Ledendecker (1992)	Obsolete
	Huab	Metamorphic complex	Palaeoproterozoic	Huab MC	
Approved names in red ("Reference" refers to entries in the "Name" column)					

Table 1. Examples for naming ambiguities past and present

cruited from present and past members of the division. It was decided that to be effective and to attain official and legal status, NACS should be registered as part of the National Spatial Data Infrastructure (NSDI) framework of the Namibian Statistics Agency (NSA), which regulates data standards and provides guidelines for data capture, presentation and distribution.

Local and international experts, whose long-term work in Namibia - often spanning decades - qualifies them to guide NACS/GSN in streamlining their efforts to achieve an unambiguous stratigraphic data base, were requested to join the committee and participate in its activities. With positive responses received from most of the selected candidates, NACS currently has 25 members from Namibia (12), South Africa (3), Canada (1), Germany (3), France (1), Brazil (1), Australia (1), Norway (1) and the United Kingdom (2). Further specialists may be invited as permanent or advisory members, if additional expertise is required in the execution of the committee's duties.

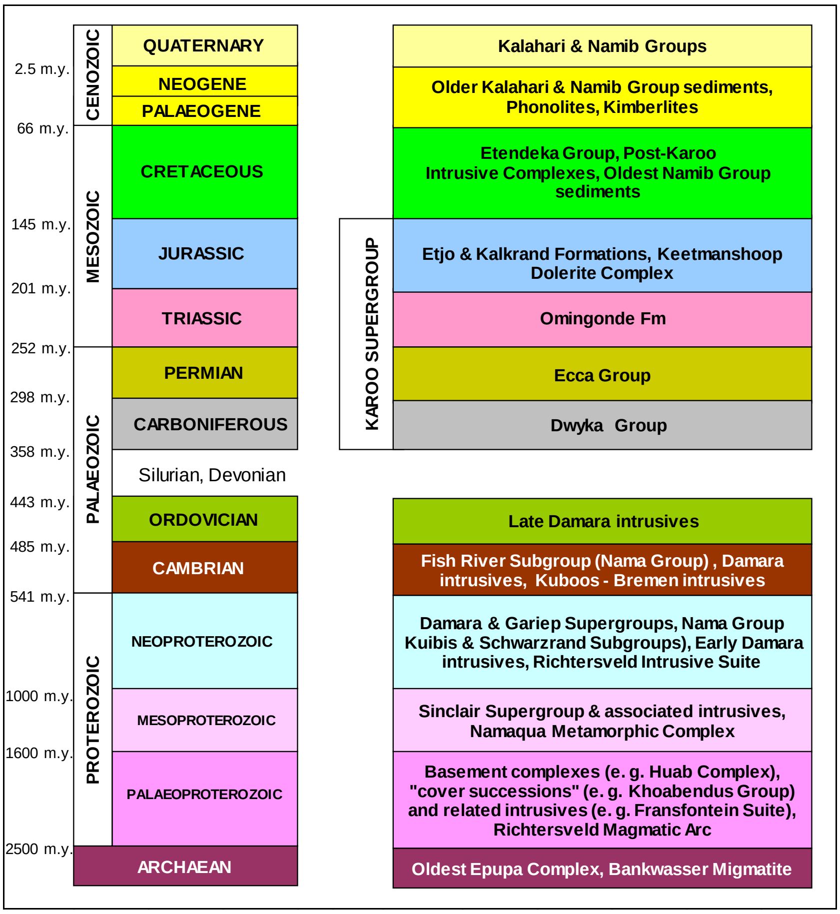

Table 2. Schematic stratigraphic column of Namibia

Aims and Objectives

A first meeting to discuss aims and expectations of the committee as well as general matters such as communication channels, was held in October 2022, with nine members of the committee and secretariat present on site at the Geological Survey's boardroom in Windhoek, and eight connected by means of an online service. Due to other commitments, it was almost a year until a follow-up session was scheduled at the Mercure Conference Centre in Windhoek in September 2023, during the 29th Colloquium of African Geology. At this meeting 13 secretariat and committee members were present, while six asked to be excused.

Committee members were requested to form three main working groups based on their expertise, i. e. "Pre-Damara" (Archaean to Mesoproterozoic), "Damara" (Neoproterozoic to Early Cambrian) and "Post-Damara" (Late Cambrian to Cenozoic), as the Pan-African Damara Orogen and related features form a conspicuous central part of Namibia's geological landscape (Table 2). Working groups may be further subdivided into specialty groups - if warranted by the number of participants - at the unanimous decision of their members. Terms of reference outlining the structure and respective duties of the secretariat, executive committee and working groups will be published separately in this journal, and on appropriate official platforms.

The first task of the above working groups will be to make recommendations towards the resolution of existing ambiguities in the stratigraphic nomenclature, and to formulate procedures and requirements for the introduction and naming of new stratigraphic/intrusive units in accordance with international standards, under consideration of specific Namibian conditions. A proposal should contain at least the following

- Reason for proposal
- Proposed name
- Description of unit
- Stratigraphic affiliation/relationship
- Type of contact(s)
- Type locality (with coordinate)
- Type section
- Geochemical and/or petrographic characterisation
- Geochronological analysis (igneous rocks)

but may also include other information as required by circumstance (e. g. fossil content). Proposals should be submitted to the NACS secretariat, which will publish the executive committee's decision in the GSN's in-house journal "*Communications of the Geological Survey of Namibia*"; the establishment of a NACS website is also being considered as a means of information exchange and to disseminate news items. In this way it is hoped to avoid future naming and related conflicts as outlined above (Table 1), which are difficult to eradicate once they have become established in the literature. International scientists, who are required to be in possession of a research permit when conducting field work in Namibia, are confidently expected to welcome this initiative, and support NACS in achieving its objectives by adopting the proposed procedure.

In addition to these immediate tasks to tie up loose ends and develop a consistent, unequivocal stratigraphic database, a number of long-term objectives of the committee and its workings groups were raised at the above meetings. Looming large among these is the appositeness of employing formal stratigraphic terms (e. g. formation, member), which by ICS (International Committee on Stratigraphy) standards require the definition of mappable upper and lower boundaries, in high-grade metamorphic and / or structurally complex terrains. In the past various solutions have been applied to this problem, such as the introduction of an "informal unit" (Geological Survey of Namibia map data base) or the use of small instead of capital letters to indicate the informal status (e. g. Möwe Bay formation; Miller, 2008). Following a review of various options (in the form of stratigraphic codes employed by other countries), the committee proposes to make such adjustments to the current stratigraphic data base as are deemed necessary to record new research and mapping results accurately, but otherwise retain the existing nomenclature and structure until such time as new work produces fresh insights and justifies a review of the established terminology.

All existing stratigraphic documentation in the form of tables (e. g. Table 3), indexes and papers, will be shared with committee members and is also available to the public on request. As contribution by the Regional Geoscience Division of GSN, which will continue in close co-operation with NACS, it is planned to compile brief descriptions / summaries of all stratigraphic and intrusive units for reference purposes, and to regularly update GSN's geochronological database from new publications, as well as to obtain fresh dates on stratigraphic key units providing the availability of funds.

Reference:

Miller, R.McG. 2008. Neoproterozoic and Early Palaeozoic rocks of the Damara Orogen. *In*: Miller, R.McG. (Ed.). *The Geology of Namibia*, Vol. **2**, chapter 13, 410 pp. Geological Society of Namibia, Windhoek.

SEDIMENTARY AND VOLCANIC ROCKS			INTRUSIVE ROCKS		
Group	**Formation**	**Member**	**Suite**	**Intrusive unit**	
KONKIEP	Aubures				
				Sonntag Granite	Post-Guperas
	Guperas				
				Rooikam Granite	Post-Barby – pre-Guperas
				Nubib Granite (incl. Verweg Granite)	
			Chowachasib		
				Awasib Granite	
				Bushman Hill Quartz Diorite	
			Haisib		
			Saffier		
				Kumbis Gabbro	
	Eensam*				
	Zwartmodder*				
	Keerweder*				
	Welverdiend				
	Haiber Flats				
	Barby	Aruab			
	Kunjas				
				Tumuab Granite	Pre-Barby
				Haremub Granite	
				Kotzérus Granite	
				Okarus Granite Porphyry	
	Nagatis				
				Neuhof Granite	Post-Kairab – pre-Nagatis
				Hauchab(fontein) Granodiorite	
				Shangri La Diorite	
				Hammerstein Tonalite	
			Neisip River	Klein Tiras Granite	
				Houmoed Granodiorite	
				Tiras Gneiss	
				Tierkloof Diorite	
			Diar 9		
				Aunis Tonalite	
				Neuhof Reserve Amphibolite*	
				Mooirivier Granite*	
				Witwater Granite Gneiss*	
	Kairab	Mooirivier gneiss**			

*local name (position uncertain, probably equivalent with Welverdiend Fm)
** informal unit (formerly part of Moorivier Metamorphic Complex)

Table 3. Stratigraphy of the Konkiep Group (Sinclair Supergroup) and related intrusives as an example for stratigraphic tables to be compiled for each major geological unit by GSN/NACS

Note: Namibia hosts the Colloquium of African Geology

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Keywords :- Geoscience, Conference

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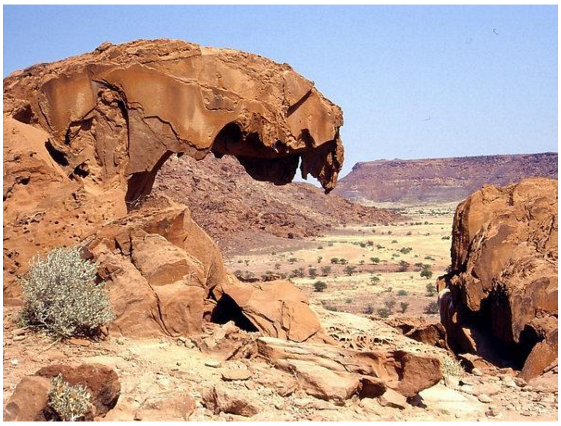
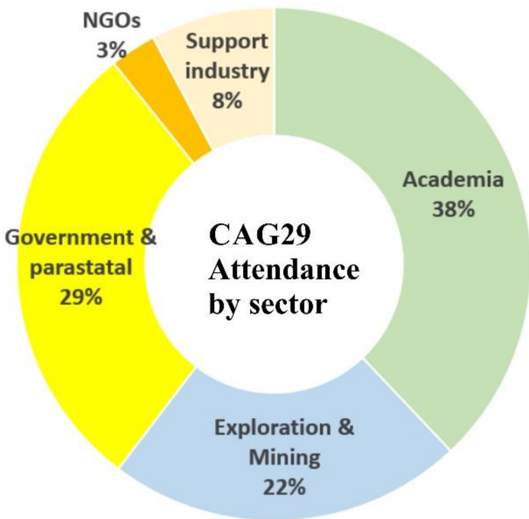
The Colloquium of African Geology (CAG) is a major biennial meeting, held under the auspices of the Geological Society of Africa (GSAf). Launched in Europe in 1964 at the University of Leeds (England), it was called into being by Professor W. Q. Kennedy and Dr Tom Clifford, themselves notable experts in the field of African geology, to provide a platform for earth scientists from around the globe engaging in research on the African continent to gather and exchange information and ideas. Since then, CAG has grown exponentially and become a forum not only for academics but for exploration geologists, mineral economists, IT specialists and a host of others, covering the entire spectrum of geoscientific applications and supporting services. Of the 28 events held to date, 18 were staged in Europe, while 10 were hosted by various African countries, i. e. South Africa, Ethiopia, Tanzania, Zimbabwe, Nigeria, Mozambique, Swaziland, Morocco (twice) and Tunisia.



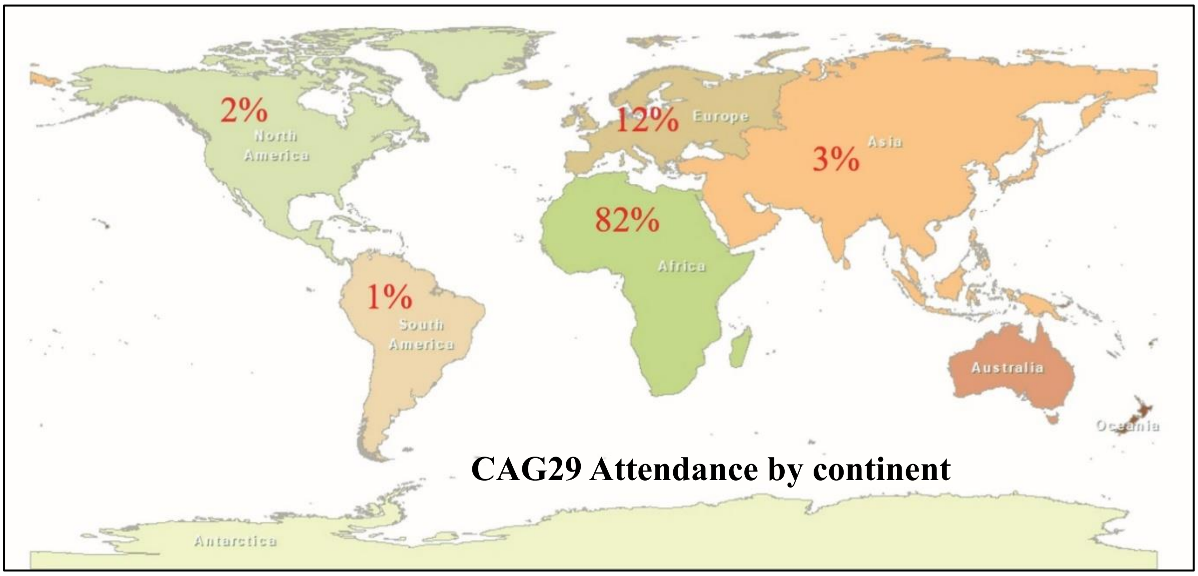
"Namibia – the World's Geological Paradise" (Lion's Claw, a distinctive sandstone formation at the Twyfelfontein - /Ui-//aes World Heritage Site)

The 29th Colloquium of African Geology (CAG29)

With its acclaimed geodiversity covering some 2.6 billion years of earth history and abundance of natural resources and mineralisation styles, which have contributed - and still contribute - immensely to the country's economy, Namibia was well qualified to host the 29th Colloquium of African Geology during the final week of September 2023. Under the challenging theme "The earth sciences and Africa's development: Current realities and future projections," the four-day event took place at the Mercure (formerly Safari) Conference Centre in Windhoek, the country's capital city. Principal organiser on behalf of GSAf was the Geological Survey of Namibia (Ministry of Mines and Energy), supported by various local stakeholders including the Young Earth Scientists' (YES) Network Namibia, the Geoscience Department of the University of Namibia, the Geoscience Council of Namibia, the Namibian Hydrogeological Association and the Department of Mining and Process Engineering (Namibia University of Science and Technology), as well as by the generous financial and in-kind contributions of several local and international sponsors.



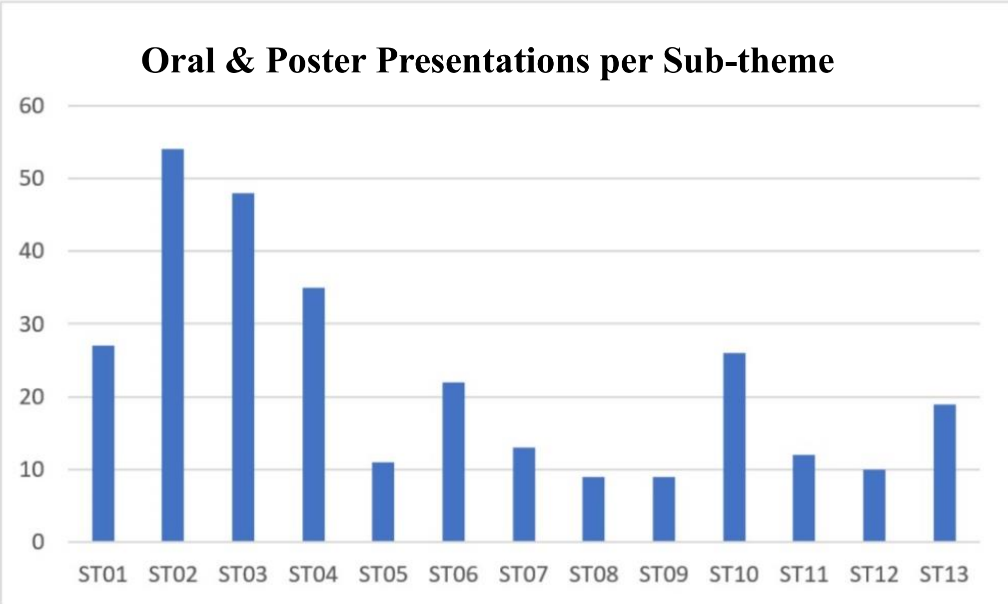
More than 400 senior and early-career earth scientists from academia, mining and exploration, government and various NGOs, plus representatives from supporting industries, such as information technology, financial and legal institutions, registered for CAG29. Attendance statistics show that hosting this prestigious event in Africa provides a greater number of geoscientists from the continent with the opportunity to present their work to an international and diverse audience, as well as to initiate, develop and implement collaboration projects, and discuss current challenges from mineral resource policy to a changing energy landscape with their peers across Africa. Thirty-one African and eighteen non-African countries were represented at CAG29, with the host country contributing roughly half of the delegates. Speakers at the opening ceremony, which was hosted by Acting Executive Director (Ministry of Mines and Energy) Mr Bryan Eiseb, included Namibian Prime Minister Dr Saara Kuugongelwa - Amadhila, Prof Olugbenga Okunlola (President of GSAf) and Dr Leake Hangala (CAG29 Patron).



CAG29 Attendance by continent

SUB-THEMES CAG29			
ST01	African Geological Record: Palaeontology, ancient environments, and palaeoclimate	ST07	Geoparks, Geotourism and Geo-ethics for Promoting Earth Heritage
ST02	Geodynamic evolution of the African continent	ST08	The role of Minerals and Fossil Fuel Industri in Africa's Energy Transition to Carbon Neut and Green Hydrogen Energy Economies
ST03	Ore deposit geology of Africa (Mineral Resources and ore forming processes)	ST09	Africa's Nuclear Resources
ST04	Geophysics, Geochemistry and Remote Sensing– Peering into the subsurface and Integrated approaches in Geosciences	ST10	Hydrocarbon Potential in Africa
ST05	Hydrogeology and water sustainability under a changing climate	ST11	Investment in the Mineral Industry: policy issues, legislations, challenges, governance, best practices
ST06	Geology in the service of society: Applied Geosciences in Africa	ST12	Geoscience Education for Sustainable Development
		ST13	The fourth Industrial revolution, Artificial intelligence, and Information management

CAG29 featured four days of nearly 300 technical presentations in four parallel sessions, including 22 keynote lectures, ten plenary talks and two panel discussions. Sub-themes covered the whole range of geoscientific and related fields from the African geological and palaeontological record and ore deposit geology to mineral investment and economics, data management, geo-tourism, climate change and energy transition, and the relatively new disciplines of medical and agro-geology to name but a few. While the lion's share of presentations predictably came from the classical fields of geology, a goodly number also discussed topics such as mineral policy, geo-ethics and the Fourth Industrial Revolution, and its expected impacts on the geoscientific sector.



Surrounding the technical sessions, a variety of activities encompassing nine pre- and post-conference field excursions and twelve workshops and short courses were scheduled, while 16 exhibitors from governmental and parastatal organisations, tertiary institutions, NGOs and the private sector took the opportunity to showcase their services and products to an international audience. Field trips included excursions to the famous "Sperrgebiet" of southern Namibia, the Damara Orogen, the southern margin of the Congo Craton, visits to Namibian gold, lithium and REE mines and development projects, as well as a look at Windhoek's water supply system and the inspection of a proposed Geopark site in the Kunene Region. More than 120 participants joined the one- to six-day excursions across Namibia. Workshops and short courses were manifold and varied, covering, among others, subjects such as data management, with an emphasis on African geodata organisation, IT solutions, artisanal and small-mining, UNESCO Global Geoparks in Africa, career opportunities in geosciences, geoscience diplomacy, modern drilling and core

logging techniques and a seminar for geoscience teachers.

Taking into account that the organisation of CAG29, owing to financial limitations, rested entirely in the hands of volunteers from the above institutions without the aid and benefit of professional conference coordinators, the

event, which – including associated activities – lasted from 20 September to 4 October, unfolded much as projected. Despite a number of shortcomings, it generally was commented on favourably by participants, who specially commended the core organising team for their untiring efforts in the face of many difficulties during the preceding year to make CAG29 a success.

Conference abstracts and excursion guides can be downloaded from the Ministry of Mines and Energy's website https://www.mme.gov.na/publications/?designation=gsn