Monograph on

Endemism in the Highlands and Escarpments of Angola and Namibia

Angola Cave-Chat *Xenocopsychus ansorgei*
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ABSTRACT

The bedrock geology of Angola and Namibia has been built by rifting, continental drift, ocean formation, sedimentary deposition in both marine and continental environments, continental collision and mountain building since the Archaean. The palaeo-climates that followed, particularly during humid periods lasting tens of millions of years, have shaped the surface morphology. Erosion, removal of the humid-climate regoliths and gradual exposure of the present landscape started approximately 70 million years ago. The elevated escarpment regions of western Angola and Namibia are the result of scarp retreat after the breakup of Gondwana. They are underlain by igneous, sedimentary and metamorphic rocks ranging in age from Archaean to early Cretaceous. Inselbergs consist of weather-resistant igneous rocks of highly variable compositions such as granite, syenite, gabbro, basalt, rhyolite and carbonatite. Soils derived from the variable chemistry of these rocks in combination with the microclimates at different elevations and different locations provide the basis for the evolution of endemism.

Keywords: Angola, escarpments, geology, highlands, landscape evolution, Namibia

TECTONIC SETTING, CRUSTAL EVOLUTION AND REGIONAL GEOLOGY

The geology of Angola and Namibia today is the culmination of around 2.8 billion years (2.8 Ga) of geological history involving several plate tectonic cycles of breakup of supercontinents, sedimentation, continental collision and mountain building followed by successive cycles of denudation and erosion (Miller 2008 and references therein). Plastered around the old Archaean (> 2.5 Ga) cores are broad belts of Proterozoic gneisses and granites, some with associated acid and basic metavolcanic and metasedimentary successions. The oldest, with Palaeoproterozoic ages of 2.0–1.8 Ga, occur as inliers of gneiss surrounded by younger Mesoproterozoic (1.6–1.0 Ga) and Neoproterozoic successions (0.88–0.54 Ga). Younger Phanerozoic (0.54 Ga to present) rocks form an obscuring cover in places.

The oldest rocks, the Archaean metavolcanic, metasedimentary and granitic rocks of eastern and western Angola (Units 1–5 in Figure 1) probably formed part of the supercontinent of Ur (2.8–2.4 Ga). As rifting began to break up Ur during the Palaeoproterozoic, ocean basins formed between its fragments. Continent-derived sediments with interbedded acid and basic volcanic rocks that accumulated along the basin margins or along oceanic island arcs from about 2.3 to 2.0 Ga (Units 6–8) became folded and metamorphosed as continental fragments began to collide with each other to form the next supercontinent of Colombia (also known as Nuna) by about 1.8 Ga. Associated granites intrusive into these Palaeoproterozoic metasedimentary and metavolcanic rocks range from 2.0 to 1.7 Ga in age. Such metamorphic rocks and intrusive granites occur in western Angola and northwestern Namibia, named the Epupa Metamorphic Complex in the latter area. Occurring along the Orange River is an island-arc succession of andesitic volcanic rocks about 2.0 Ga in age, the Orange River Group, that is intruded by an associated suite of calc-alkaline rocks ranging from gabbro to quartz porphyry in composition and between 1.9 and 1.7 Ga in age.

At about 1.6 Ga the plate tectonic cycle began to repeat itself. Colombia started to break up, but by 1.0 Ga continental amalgamation had built the next supercontinent, Rodinia. Two belts of rocks formed during this period in Namibia (Unit 9). The belt in the south is the Namaqua Metamorphic Complex which consists of high-grade ortho- and paragneisses. It extends in a southeasterly direction from Lüderitz and is exposed in the escarpment cliffs west of Aus. The other belt is the low-grade, lithologically variable Sinclair Supergroup of the Sinclair–Rehoboth Magmatic Arc which extends from the Helmeringhausen area to Gamsberg and thence in a northeasterly direction through Rehoboth into Botswana. Suggestion of a third but highly deformed belt in the Cunene River area is provided by the 250-km long, north–south trending Angola Anorthosite, also known as the Kunene Anorthosite Complex, with an age of 1.37 Ga. Anorthosite, gabbro and norite in the western part of the complex form highlands and inselbergs in the highlands and escarpments of Angola and Namibia (HEAN).

Disruption of Rodinia began at about 880 million years (880 Ma) ago, again with intracontinental rifting followed by the separation of continental fragments and the formation of oceans, one trending north–south between Africa and South America, and one extending northeast through Namibia from the Swakopmund area. Sedimentary rocks of the Damara Supergroup (Units 10–12) were deposited in the oceans and on the continental margins with only very limited associated volcanism. As this plate tectonic cycle progressed, the oceans closed and evolved into three orogenic belts, two between Africa and South

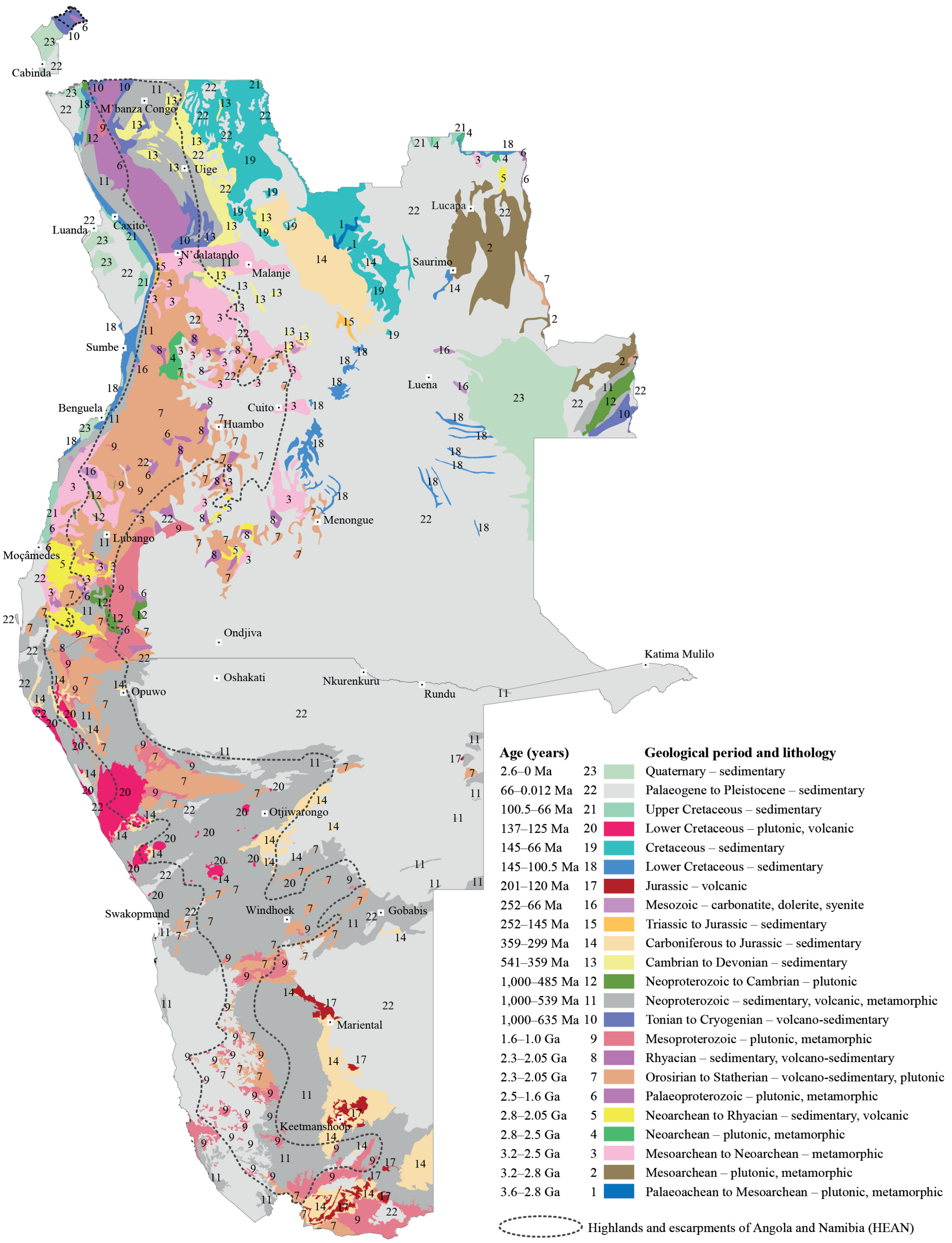

Figure 1: *Major geological units in Namibia and Angola (Adapted from https://portal.onegeology.org/OnegeologyGlobal/ and Atlas of Namibia Team (2022)).*

America, the Gariep Belt in the south and the Kaoko Belt in the north, with the third being the northeast-trending Damara Belt through central Namibia. Damara Belt metagreywacke forms the Khomas Hochland, and quartzite forms the Auas and Hakos mountains. The centres of the Kaoko and Damara Belts are characterised by high-temperature metamorphic rocks and many granite intrusions. The margins of these belts were only weakly metamorphosed. Dolomites, limestones and shales of the Otavi Group occur in the north, forming some of the northwestern highlands as well as the dolomite belt that connects them to the Otavi Mountain highlands. Shales, sandstones and limestones of the Nama Group occur in the south. The Gariep Belt consists of low-grade schists, quartzites, limestones and oceanic metabasalts. Final continental amalgamation formed the Gondwana Supercontinent at 539 Ma but granite intrusion into the central Damara Belt continued until 460 Ma.

By 350 Ma Gondwana had drifted southwards, was located at the South Pole and was covered in ice. Glacial deposits form the base of the Karoo Supergroup (Units 14–15). Early, westerly flowing Karoo glaciers cut deep canyons into the bedrock of northwestern Namibia (Martin 1981). As drifting continued, Gondwana moved slowly northwards and the climate changed progressively from glacial to arid tropical. Much of the supercontinent was covered by an extensive, post-glacial shallow sedimentary basin in which muds and sands were deposited. These lithified to shale and sandstone but are poorly exposed in several subbasins. Accumulation of dune fields during the Triassic followed gentle uplift and exposure of earlier sediments. These aeolianites form the weather-resistant cappings of the Waterberg, Mount Etjo and the Gamsberg.

The breakup of Gondwana was initiated along the eastern margin of South Africa by a deep mantle plume rising from the core-mantle boundary at 183 Ma. Evidence of this are the 183 Ma basalts of Lesotho, the Kalkrand basalts (the top unit of the Karoo Supergroup) and the dolerite sills that form the Taantjiesberge in the Keetmanshoop area (Unit 17). A second, even larger mantle plume, the Tristan Plume, initiated the separation of southern Africa and South America at 134 Ma in the early Cretaceous. Its surface expression consists firstly of the Etendeka basalts that cap the Etendeka highlands with the thick interbedded and mountain-capping layers of ignimbritic quartz latite (Unit 20) (Erlank *et al*. 1984, Milner *et al*. 1992, 1995, Ewart *et al*. 2004a, 2004b) and secondly of scattered inselbergs which are the remnant roots of several large inland volcanoes: Cape Cross, Messum, Brandberg, Doros, the two Spitzkoppes, Okenyenya, Otjohorongo, Ozongombo, Etaneno, Ondurakarume, Eisenberg, Okaruzu, Paresis, Omatako and Erongo (Unit 20). Rock types forming these inselbergs include gabbro, granite, syenite, carbonatite, basalt, dolerite and/or alkali lava, some with rims of the older Karoo sediments and Etendeka basalts that they intruded.

The eroded cores of two other volcanoes form prominent inselbergs, the 77 Ma Brukkaros south of Mariental and the 49 Ma Dikke Willem northeast of Aus, and the carbonatite Serra da Neve (91 Ma; Jerram *et al*. 2019) (Unit 16). The alkaline Klinghardt phonolites form a scattering of small black hills south of Lüderitz. Areas of marine Cretaceous sediment occur in coastal Angola and further inland (Units 18, 19, 21). Various unconsolidated to semi-consolidated sands, clays and associated calcretes ranging in age from about 80–70 Ma to the present cover much of Namibia and Angola (Units 22, 23).

Orogenic belts mark the sites of continental collision as supercontinents grow. They erode to form old palaeo-surfaces before the next cycle of continental breakup starts. Small remnants of the post-Rodinia–pre-Gondwana peneplain occur in the vicinity of Duwisib and Helmeringhausen, atop the escarpment from west of Helmeringhausen to well south of Aus, and on the Karas Mountains, commonly with outliers of basal Nama on them (Miller 2008). Similarly, erosion between 540 and 300 Ma resulted in the development of a vast post-Gondwana peneplain, the pre-Karoo surface. This was broken by high, weather-resistant mountain ranges or inselbergs of the Damara mountain belts in western Angola, the Kaokoveld and central Namibia. Remnants of this surface are present west of Khorixas. Some of the present-day bevels such as that of the Khomas Hochland, the Eros Mountains and high ridges with uniform elevations south of Windhoek may be partially reworked remnants of the pre-Karoo surface (Miller 2008).

Palaeo-climates, particularly during the Cretaceous (135–65 Ma) and Cenozoic (last 65 million years), have exerted a strong influence on the present-day geomorphology of western Angola and Namibia. This includes broad, fluvially incised highlands, weather-resistant ridges and inselbergs surrounded by lower-lying plains, as well as the Great Escarpment separating the elevated interior from the low bedrock bevel of the Namib Desert. Geology, present-day climate and relative elevation determine the composition and volume of soil cover and the ecosystems that they support (Burke 2001, 2002).

During the 50–60 million years that followed the breakup of Gondwana, Africa's Cretaceous climate was humid. The resulting African Erosion Cycle culminated in the formation of an Africa-wide peneplain, the African Surface (King 1963, Partridge & Maud 1987), which, depending on the weather resistance of the bedrock, occurs at different elevations in Namibia: 1,800–2,000 masl, 1,200 masl and 0–800 masl. In the latter case, it forms the lithologically variable bedrock bevel of the Namib Desert as erosion cut deeply down and landwards into the elevated rift shoulder of the early Cretaceous continental margin. The present-day Great Escarpment, some 100 km inland from the coast, is all that remains of this rift shoulder. Older planation surfaces were reworked (Burke & Gunnel 2008) but the remnants described above have remained intact. An intensely weathered regolith about 50 m thick underlaid the African Surface. This is only preserved where it has been protected by an overlying layer of weather-resistant calcrete, such as in the Weissrand and north of Kamanjab, or by silcrete in the southern Namib. Deep river systems were incised during the humid Cretaceous. Most obvious are the re-incised, early Karoo glacial valleys of northwestern Namibia, but Kalahari sands now cover two others. One, trending northeast, arose southeast of the Waterberg, curved around to the northwest as it skirted the Otavi mountainland and disappeared into the Owambo Basin. The other is the palaeo Aranos River of southeastern Namibia that flowed in a southeasterly direction in a valley 300 m deep cut into the sub-Kalahari Karoo rocks of the Stampriet Artesian Basin. Sediments transported by this river washed down into the palaeo Molopo River in Botswana and then joined the sediments of the Orange–Vaal system as they built out the offshore, 7-km thick Orange River delta. Areas of marine Cretaceous sediment also occur in coastal Angola.

The supply of sediment from inland southern Africa down the Orange River to the offshore Orange Basin dropped dramatically between 80 and 70 Ma (Muntingh 1993, Brown *et al.* 1995) as the climate changed from humid to semiarid. With reduced flow in the inland rivers, the sands, clays and calcretes of the Kalahari Group began to slowly fill up the river systems and the great inland Kalahari Basin throughout the Tertiary by means of fluvial deposition and periodic aeolian reworking of the fluvial sediments. Sediment transport into the basin ceased at 4–3 Ma when Africa became hyperarid (deMenocal 2004, Miller *et al.* 2010). Approximately three million years of hyperaridity resulted in accumulation of the Kalahari dunes before a more humid climate returned at about 1.2 Ma; at this time the valleys of Namibia's eastern rivers were incised (Miller 2014).

The weathered remnants of the syn-Etendeka volcanoes were already inselbergs by the end of the African Erosion Cycle. Tertiary erosion and weathering rates have been slower since then but the relative elevation of the inselbergs has been enhanced by a greater degree of removal of the surrounding lithologies. Furthermore, the deeply weathered regolith below the African Surface, where not protected by weather-resistant cappings, has been totally removed leaving only hard bedrock. Dating of the African Surface reveals that it was periodically reworked during wetter periods up to about 30 Ma (Partridge & Maud 1987, Burke & Gunnel 2008).

During the Tertiary and Quaternary, i.e. since 65 million years ago, the global climate has fluctuated between cold glacial and warm interglacial periods which consequently caused huge changes in sea level (Haq *et al.* 1987). In contrast to the limited evidence of climate variation we have been able to glean from the Kalahari Group sediments, the Namib Desert and the immediate offshore do record a – somewhat different – history. Minor marine deposits in the southern Namib Desert dating from around 40 Ma and diamonds at Kolmanskop indicate that sea level during the upper Eocene was up to 175 m higher than at present. A sea level fall of possibly as much as 500 m during the extremely cold upper Oligocene (30–25 Ma) initiated the incision of V-shaped valleys 90 m deep into the bedrock of the Namib plain. The coastline was approximately 200 km west of its present position. As sea level rose again, fluvial gravels filled the Oligocene valleys. Since the beginning of the Miocene (23 Ma) there have been repeated glacial events during which the sea level fell by as much as 130 m. Each fall of sea level exposed vast expanses of marine sediment which the strong southwesterly winds began to blow onshore. An early, partly consolidated erg (area of shifting dunes) was deposited throughout the Namib between about 21 Ma and 5 Ma. Fluvial sediments were deposited by very sporadic flooding of westerly-flowing escarpment rivers and larger rivers further inland which were either trapped by the dune fields or occasionally broke through them to reach the sea (Ward *et al.* 1983, Brain *et al.* 1990). Deposition of the present unconsolidated sand seas in the Namib began at about 5 Ma and continues today (see Miller 2008 for references). Raised beaches along the coast record just a few of the many warm interglacial marine high stands, i.e., at 90 m (19–17 Ma), 50 m (7–5 Ma), 30 m (3–2.5 Ma), and 10 m and below (200,000 to > 10,000 years ago) (Pickford & Senut 2000).

GEOMORPHOLOGICAL EVOLUTION OF ANGOLA AND NAMIBIA

The western Angolan highlands within the boundaries of the HEAN contain highly deformed and metamorphosed basement rocks ranging in age from Mesoarchaean (3.2–2.8 Ga) to Neoproterozoic (1,000–635 Ma) with some significantly less deformed and metamorphosed Neoproterozoic to Ediacaran (635–539 Ma) platform successions, some remnant patches of Cambrian to Devonian (539–360 Ma) rocks and Mesozoic alkaline intrusions of carbonatite, syenite and dolerite. Younger Palaeogene to Holocene (66 Ma–present day) cover encroaches from the east.

Repeated episodes of plate tectonic accretion progressively amalgamated highly deformed and metamorphosed terranes of metasedimentary, metavolcanic and intrusive granitic and mafic rocks of Mesoarchaean to Neoproterozoic age onto each other to build the Precambrian Angolan/Congo Craton, an integral part of Gondwana.

An understanding of the post-Gondwana sedimentary succession offshore of Namibia and Angola helps to elucidate the concomitant evolution of the continental onshore from which the sediments were derived. The Gondwana breakup between Africa and South America opened like a zip with the opening starting in the south at about 134 Ma and progressing northwards. It was initiated by the hot, mantle-sourced, early Cretaceous Tristan Plume that generated the Paraná basalts of Brazil and the chemically identical Etendeka basalts of Namibia. Breakup took place through stages of rifting, sag of the incipient continental margins and then drifting apart of the now separated continents. Rifting between Angola and Brazil began at about 123 Ma resulting in the development of a deep, north–south, low-elevation rift basin with high rift shoulders similar to today's East African rifts. Tristan Plume volcanism produced the Cape Fria High which separated the rift into contrasting northern and southern parts. That to the south was a narrow, open ocean basin. The section to the north was initially a closed lacustrine rift lake in which basal, organic-rich, sapropelic muds were deposited. Overlying thick salt accumulations point to periods of seawater influx followed by evaporation.

As rifting evolved to final continental breakup and spreading, both basins separated into eastern and western parts and continent-sourced clastic sediments began to cover the developing continental margins. Shallow reef limestones accumulated locally just south of the Walvis Ridge and more extensively further north. The Angolan margin and its South American equivalent became the oil-rich Angolan and Campos basins.

Africa was very humid throughout the Cretaceous (135–65 Ma). Deep chemical weathering and intense erosion produced a gently undulating Africa-wide peneplain, the African Erosion Surface, which by the end of the Cretaceous was located inland of the Great Escarpment that encloses most of southern Africa. Large river systems dissected this surface and fed the erosion products into the expanding Atlantic and Indian oceans. Concomitantly, scarp retreat induced by short, high-energy rivers originating along the elevated and steep western edges of the Namibian–Angolan rift shoulder physically cut this back eastwards forming a much lower-elevation continental margin peneplain time-equivalent to the inland African Erosion Surface. This is the bevel west of the HEAN. Archaean, Proterozoic, Cretaceous and Cenozoic rocks and sediments form the outcrops on this bevel. The highlands and escarpments that comprise the HEAN are the remnants of the rift shoulder.

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