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GEOLOGY AND PALAEOBIOLOGY OF THE NORTHERN SPERRGEBIET, NAMIBIA

by

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Geology, stratigraphy and age of the Miocene fluvio-paludal and pedogenic deposits of the Northern Sperrgebiet, Namibia

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Most of the Early Miocene deposits in the Northern Sperrgebiet accumulated in pre-Miocene valleys that drained into the Atlantic, but there are crater facies at Chalcedon Tafelberg and elsewhere in the region that may be the same age or slightly younger. All the aeolianites in the northern Sperrgebiet except for those at Buntfeldschuh, are post Early Miocene in age, in all cases lying unconformably on Early Miocene sediments. At the time of deposition of the Early Miocene sediments, the region was semi-arid, with savanna to steppe conditions, as shown by their pedogenic features. It became arid and eventually hyper-arid during the Middle Miocene, and it was from this time that the climate changed from a summer rainfall to a winter rainfall regime and aeolian deposition commenced.

Introduction

Beetz (1926) described the Early Miocene deposits at Elisabethfeld, Bohrloch Betrieb 4 and Langental as "Posteocäne Revierablangerungen". The present report confirms their deposition in river valleys, but enters into greater detail about their facies, depositional environments, pedogenesis and positions relative to older and younger rock units in the region.

The regional climate appears to have been semi-arid, with steppe and savanna conditions under a summer rainfall regime but with a winter rainfall belt not far away. Pedogenesis was dominated by the formation of calcareous nodules and more rarely sheets of calcrete, with the development of mottling in marly silts and sands. Truly arid and hyper-arid conditions (ie annual rainfall less than 200 mm) did not become established in the region until the Middle Miocene. The Pleistocene witnessed important travertine activity at certain localities such as Grillental, Kaukausib, and Gamachab.

Greenman (1966, 1970) named the Elisabeth Bay Formation for sediments that occur in the large valley extending from the bay northwards towards Kolmanskop, but included within it a mixture of Early Miocene deposits and aeolianites. The name has been extended to include other deposits in the region, but there are problems with this for two reasons. Firstly it is now known that the aeolianites included in the unit lie unconformably on the fluvio-paludal deposits, the ones at Elisabeth Bay being Plio-Pleistocene in age, with eggshells of *Struthio daberasensis* in them. The original concept of the Elisabeth Bay Formation is thus not well founded from a stratigraphic point of view, and if it is to be useful, it should be confined to the Early Miocene fluvio-paludal deposits. Secondly, considering the fact that the various fossiliferous deposits now known in the Northern Sperrgebiet accumulated in different valleys, we prefer to treat each site as an entity to itself, the more so because the faunas from the various sites do not appear to have the same age, although all are Early Miocene. Langental seems to be the youngest, while Elisabethfeld may be the oldest.

Fiskus

Fiskus is part of a pre-Miocene valley oriented north-south, cut into metamorphic rocks of the Gariep Group, which has an infilling of Early Miocene green sands and silts, unconformably overlain by Plio-Pleistocene Fiskus Aeolianite (Plate 1). In patches at the base of the aeolianite there are small outcrops of gravel and travertine containing plant remains of Pleistocene age and there is a layer of black oxides (probably iron and manganese) of Pleistocene to Recent age, especially in the south of the deflation basin, not far from the old German mine buildings. The exposures of Early Miocene sediments are only a few metres thick. The green sands are poorly sorted, but appear to be fluviatile in origin, as there are signs of cross bedding in some outcrops. There are pedogenic carbonate nodules in patches which date from the time of deposition, but they are not well developed. There are also fossilised termite hives in the green silts.

E-Bay

Fossils from E-Bay come from Early Miocene green clays on which lies a cover of Pleistocene to Recent sands. The green clays accumulated in a wide north-south oriented valley cut into bedrock during Oligocene times and backfilled in the Early Miocene. The presence of freshwater snails, ostracods and many frog bones indicate paludal to lacustrine deposition for these clays which have been subjected to localised thrust faulting, probably when large dunes passed over the clays, squeezing them between the firm bedrock below and the dune above.

Screening of these clays yielded Early Miocene microfaunal remains, including *Protypotheroides* and

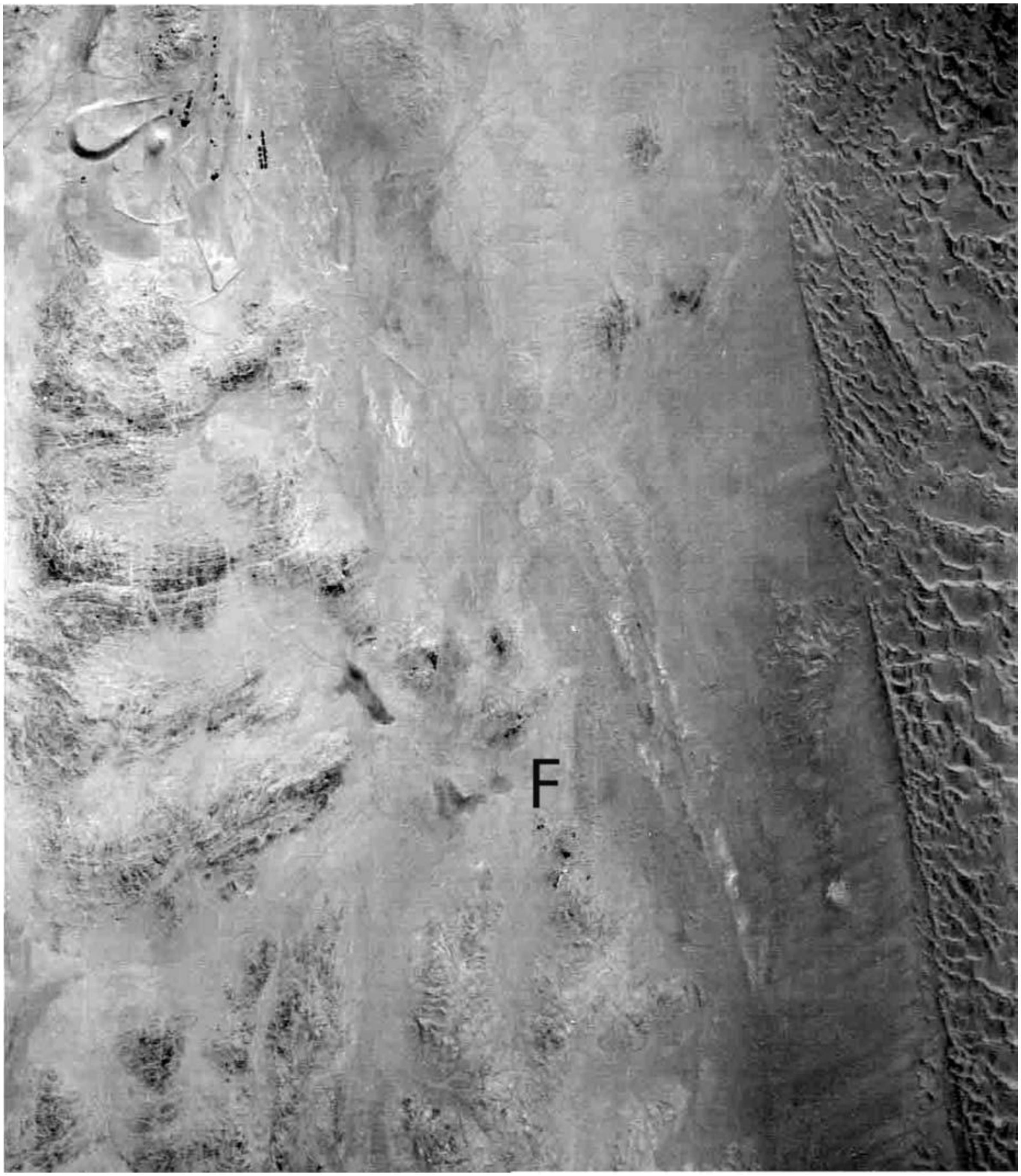


Plate 1. Aerial photograph of the Fiskus area, northern Sperrgebiet (F= fossiliferous area) (North is towards top of page).

rodents, as well as frog and snake bones. Internal moulds of *Lymnaea* and ostracods are locally common.

Elisabethfeld

The deflation basin at Elisabethfeld is an area about 2 km^2 bordered to the north and south by flat-lying travertine interbedded with aeolianite of Plio-Pleistocene age and to the east and west by hills of basement rock (Plate 2). The depression also has small basement hills within it. The fossiliferous Early Miocene deposits are predominantly red silts, marls, and impure limestone, often with abundant plate-like gypsum crystals lying horizontally in the silts. At the southern Tortoise locality, there is a wedge of boulder conglomerate that pinches out northwards and is overlain by red silts. On the northern side of the basin, less than a metre of red silts are exposed and they are overlain by green fluviatile sands with cut and fill structures and cross bedding. These and the overlying yellow sands and gravel lenses are some 4.6 metres

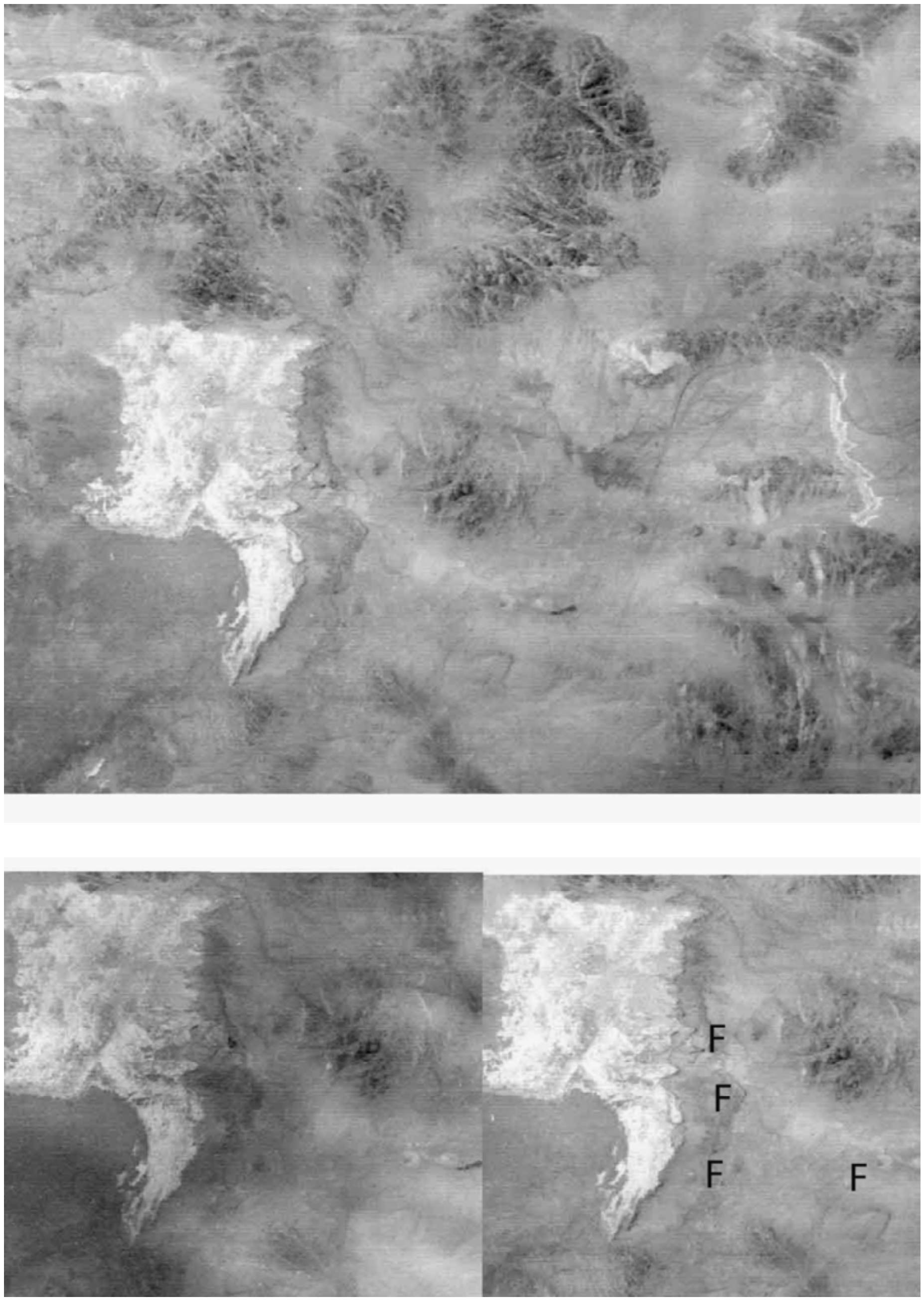


Plate 2. Aerial photographs of the Elisabethfeld area, northern Sperrgebiet. Top: general view, bottom: stereo view of Elisabethfeld and the travertine plateau to the north (F = fossil occurrence) (North is towards left of page).

thick. Unconformably on the Miocene deposits lie grey aeolianite and travertine of Plio-Pleistocene age (Pickford and Senut, 2000, figs 4.10, 4.11). The travertine, in particular, forms a large plateau to the north of Elisabethfeld.

Grillental

Grillental is an east-west valley some 5 km long and 1 to 2 km wide extending from the abandoned borehole and pumphouse complex in the east to the travertine plateau in the west. Sediments in this valley consist of green clays overlying basement rocks, capped by an areally impressive series of coarse-grained generally white to pale green fluviatile sands with large scale trough bedding a few metres thick (Corbett, 1989) (Plate 3-5). At the western end of the Grillental there is a large plateau of interbedded travertine and grey aeolianite, the latter attributed to the Wüstenkönig Sandstone. The travertine forms layers and dyke-like structures within the aeolianite, and was evidently deposited at the same time as it. North of the eastern half of Grillental there is an extensive terrace deposit which extends northwards and eastwards into the Kaukausib valley. These deposits are composed of coarse angular gravels and have yielded an upper molar of the white rhinoceros *Ceratotherium*, indicating a post-Miocene age for them.

Most of the green silt deposits in the Grillental accumulated under overbank, low energy conditions and in localised swamps, quite different from the overlying trough cross-bedded coarse sands, which are high energy deposits. There was paludal deposition, especially in the depression at GT 6.

Eight fossiliferous sites were found within the Grillental (Pickford and Senut, 2000, fig. 4.9). Indeed, wherever green silts crop out there is a good chance of finding fossils. Petrified termite hives were found in them at GT 4 and GT6. At GT 6 there is evidence of aquatic deposition, with layers rich in freshwater gastropods, charophytes, ostracods and frog bones. Parts of the deposit at GT 6 have been ferruginised, a process that has affected the more aquatic fossils, such as gastropods, by forming nodular overgrowths on them. Site GT 1 yielded small fish vertebrae and many small mammals. The pale green, poorly sorted, coarse sands that overlie the dark green silts are usually devoid of fossils, but at GT 1, near an old pipeline aqueduct, large chelonian scutes were found along with a suid mandible.

Langental

Near Bogenfels, there is a wide north-south valley extending several km inland from the sea, known as Langental (Plate 6). 2.6 km due north of the Bogenfels mining camp and ghost town, there is a patch of fossiliferous sediment covering about 1 km^2. The deposits are less than 2 metres thick and are unconformably overlain in places by a coarse angular gravel cemented by gypsum and calcite, present not only at the main fossil site (as remnants of a formerly more widespread sheet), but also about 1 km north where it crops out as a prominent terrace deposit on the east bank of the valley. Thicker sediments beneath the northern terrace are of Early Miocene age, but have not yielded any fossils.

The Early Miocene deposits consist of mottled green to brown marls and impure sandstones with occasional rounded pebbles of quartz and other rock types. There are two main levels with calcareous nodules of pedogenic origin. The abundance of aquatic molluscs, charophytes, ostracods and frog bones in the deposits suggest fluvial or paludal deposition for part of the deposit, but the mottling and calcareous nodules indicate that the area was subaerially exposed and subjected to pedogenesis.

The palaeosol at Langental is red-brown with mottling comprised of elongated sinuous greenish patches (Plate 7, Fig. 1). The presence of calcareous nodules is consistent with the suggestion that the deposits were affected by pedogenesis in a semi-arid climate. Similar mottled palaeosols with calcrete nodules occur at Grootfontein and Outjo (Plate 7, Fig. 2) in northern Namibia, in *Acacia* and *Mopane* semi-arid woodland respectively. It is possible that the

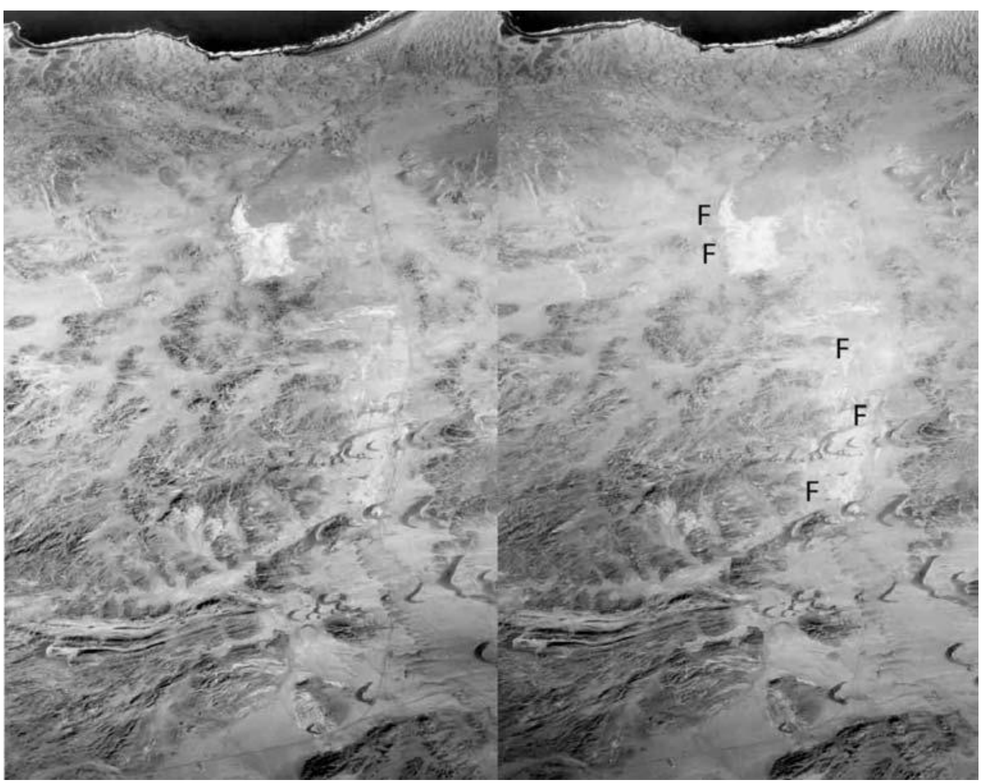


Plate 3. Stereo aerial photographs of the Grillental, northern Sperrgebiet (F= fossil locality)(North is to the right of the page).

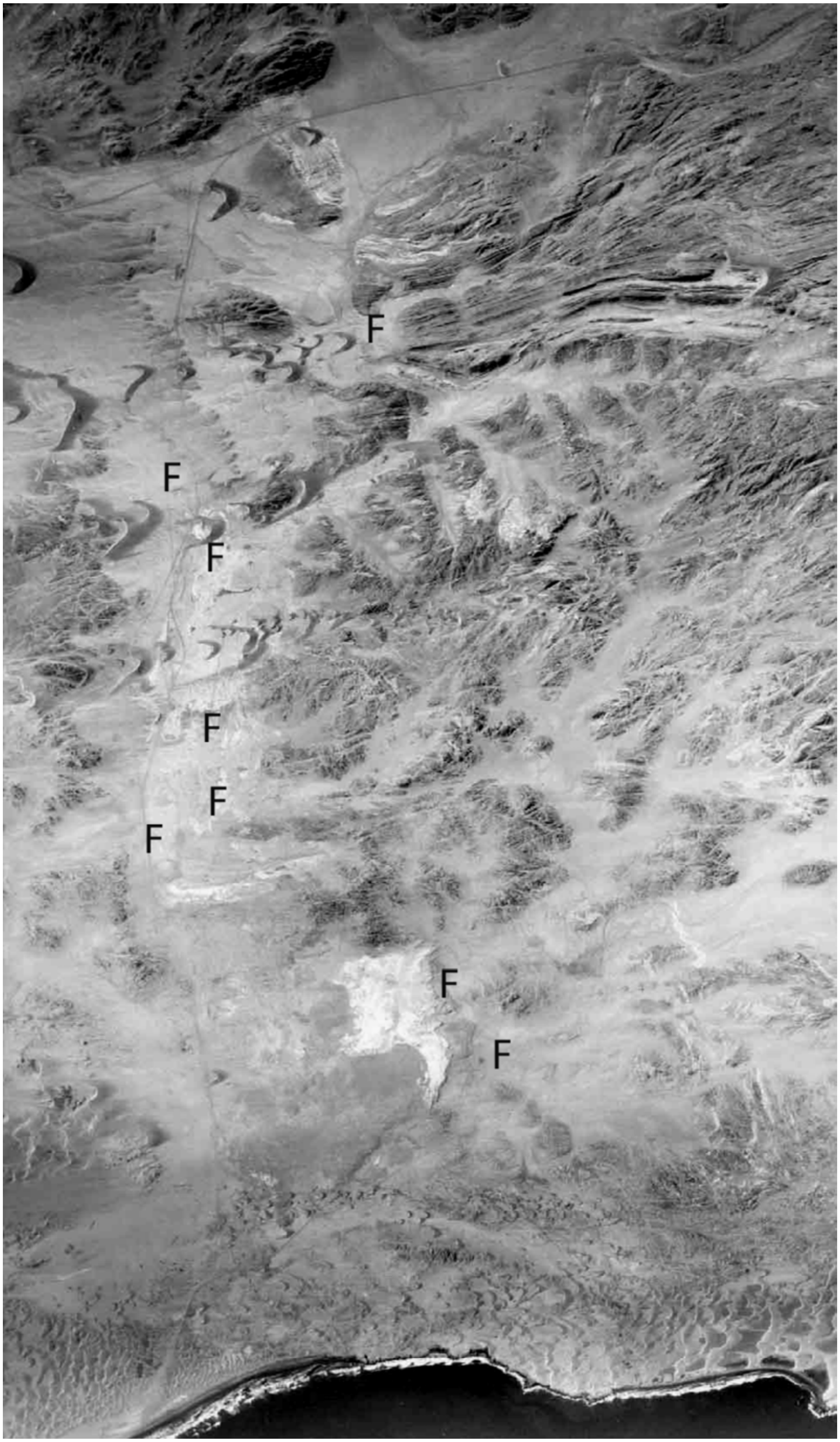


Plate 4. Aerial photograph of the Grillental area, northern Sperrgebiet (F= fossil locality) (North is towards left of page).

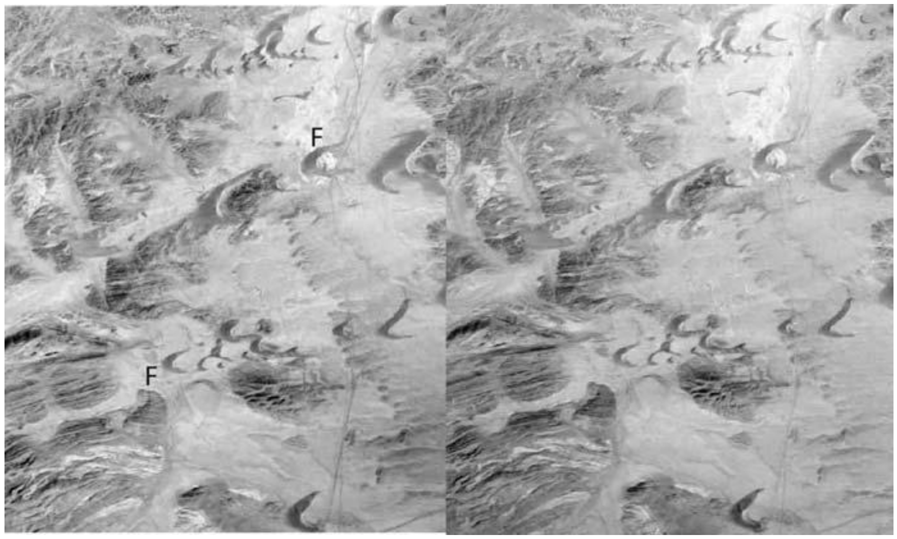


Plate 5. Stereo aerial photographs of locality GT 6 (top right) and GT Carriere (bottom left), Grillental, northern Sperrgebiet (F= fossil locality)(North is towards the left of the page).

Early Miocene climatic regime at Langental was semi-arid with summer rainfall.

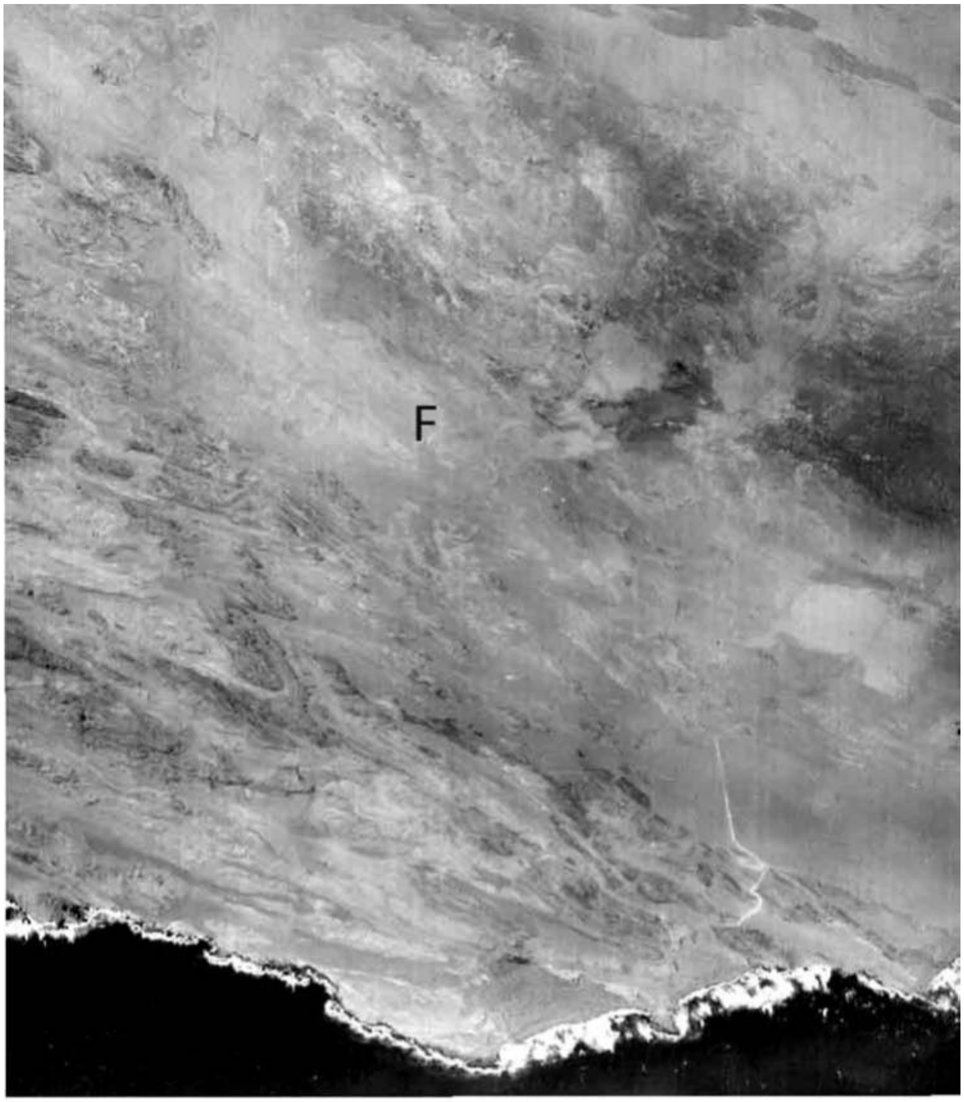
Glastal

Below the wind eroded scarp at Kalkrücken there are deposits of Early Miocene marls with calcareous nodules, sands and conglomerate deposited in a low valley cut into bedrock (Plate 8). These deposits lie about 0.5 km to the west of Kalkrücken as one descends the road towards Bogenfels. In these deposits there are well developed calcareous nodule horizons of pedogenic origin, very similar in morphology to nodules that typify extant soils near Grootfontein, Otavi Mountains, Namibia. The nodules are light pink with darker veins of calcite, and they occasionally contain terrestrial gastropods, frog bones, rodent jaws and chelonian scutes. The marls and sands are a few metres thick, and are unconformably overlain by a thin horizon of coarse conglomerate with chelonian scutes and several metre thick aeolianites of Late Miocene age. The latter are themselves overlain by a second thin horizon of coarse conglomerate. Finally, there is a well developed calcrete level developed on aeolianite, particularly well developed at the *Trigonephrus* site (Pickford and Senut, 2000).

Strauchpfütz Carbonate

The three layers of carbonate rock at Strauchpfütz (Pickford and Senut, 2000) were thought to be Pleistocene, but a reassessment of the deposits in 2003 revealed that they are most probably of Early Miocene age. The deposits overlie basement rocks, each carbonate horizon being interbedded with mottled green-brown (sometime brick-red) silts, often with carbonate nodules of pedogenic origin (Plate 7, Fig. 4, Plate 9). Fossils found in the uppermost carbonate horizon consist of freshwater gastropods similar to those found at Langental, Grillental and Chalcedon Tafelberg. The outcrops form a prominent feature in the landscape, being clearly visible in aerial photographs (Plate 9), covering an area about 1 km east-west by about 3/4 km north-south.

A section at the eastern end of the outcrop (27° 29'58.2"S : 15°30'16.1"E) consists of 26 metres of marls, limestones and conglomerate. The basement surface is undulating, so in some areas, especially to the west, the thickness is greater, and the sediments pinch out altogether to the northeast of the measured profile. The base of the succession comprises 8 m of white limestone, the base of which is nodular, with the nodules lying in green-brown marly silt and sand, not dissimilar to the Early Miocene deposits at Langental, a few km to the northwest. Overlying the white limestone is 2 m of hard yellow brown limestone that forms a low cliff. The top of this layer is white and it forms an extensive outcrop exposed by the action of the wind. This resistant horizon forms a prominent platform in the topography, and is overlain by about 10 metres of green-brown silt and sand with two main layers of whitish limestone, but not forming such extensive steps in the topography. These limestones also have nodular bases, and are interpreted to be pedogenic in origin. Above the uppermost limestones, there is a further 3 m of green-brown marls with calcareous nodules, which are themselves overlain by a 1 m layer of very coarse conglomerate with phonolite pebbles and boulders that forms an extensive terrace covering several square km to the north. In places this conglomerate contains reworked blocks of calcrete, indicating the existence of a major unconformity between the calcrete event and the conglomerate. Finally, a placage of indurated aeolianite occurs



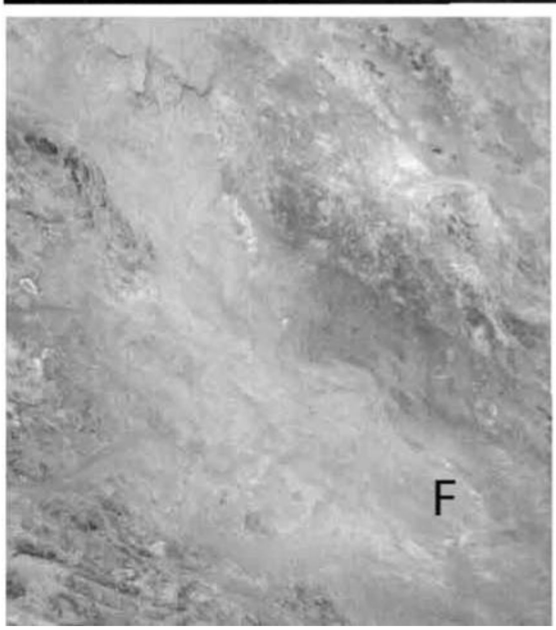


Plate 6. Aerial photographs of the Langental area, central Sperrgebiet. Top: general view, bottom: detail of main fossil area (F= Fossil site) (North is to the left of the page).

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Plate 7. Palaeosols (including calcretes) in Namibia.
Figure 1. Horizontal surface of palaeosol at Langental fossil site.
Figure 2. Subvertical section through palaeosol at Langental fossil site.
Figure 3. Subvertical section through palaeosol at Outjo, northern Namibia.
Figure 4. Palaeocalcrete at Strauchpfütz, Central Sperrgebiet.
Figure 5. Calcrete near Grootfontein, *Acacia* woodland, northern Namibia.
Figure 6. Calcrete near Outjo, *Mopane* woodland, northern Namibia.

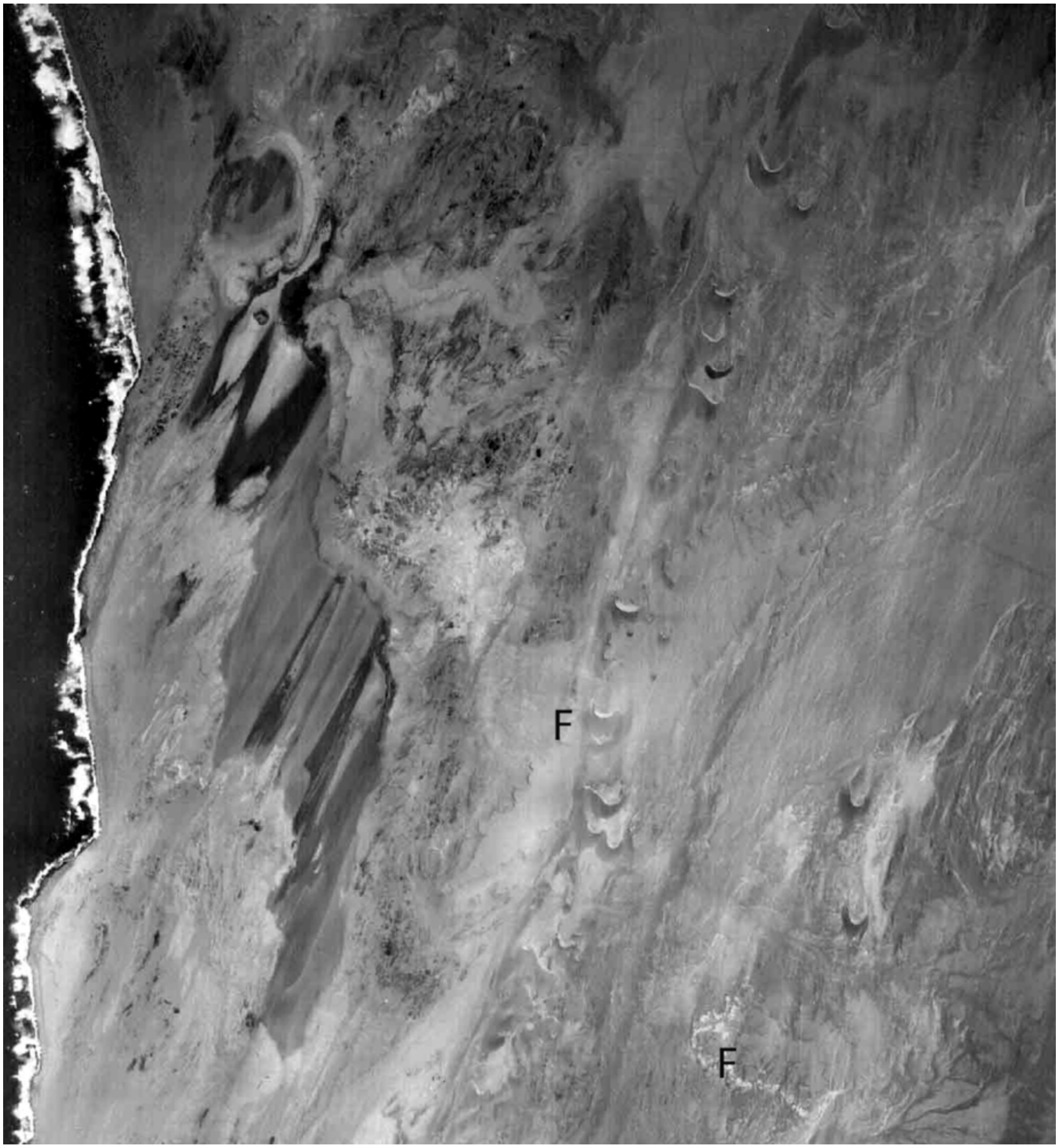

Plate 8. Aerial photograph of the Kalkrücken - Strauchpfütz area, central Sperrgebiet. (F= fossil locality) (North is to the top of the page).

unconformably on the top of the extensive limestone bench, and this is identical to aeolianites that crop out at Kalkrücken, about 2 km to the northwest.

This succession is interpreted as a series of four superposed calcretes, the second one being the most mature, the lowermost and upper two horizons being quite mature and the marls with calcareous nodules being at a relatively immature stage of pedogenic development. The capping conglomerate is of unknown age, but apparently predates aeolianite deposition in the area. A similar conglomerate occurs on top of the Early Miocene sediments at Glastal dated by the presence of an Early Miocene rhinoceros in it (Guérin, 2003), above which lie the Kalkrücken aeolianites, which at this locality incorporate some of the coarse boulders in the base of the aeolianites. A single egg shell fragment in the Kalkrücken aeolianite is thought to be of *Diamantornis laini* on account of the very smooth shell, with what is interpreted to be widely spaced pore complexes (the fragment is small and has no pores preserved, and if it belonged to any of the other known species of fossil ostriches (Pickford and Senut, 2000), at least one pore complex would be expected to be present). If this identification is correct then the aeolianites at Kalkrücken are Late Miocene in age. Part of the aeolianite succession has

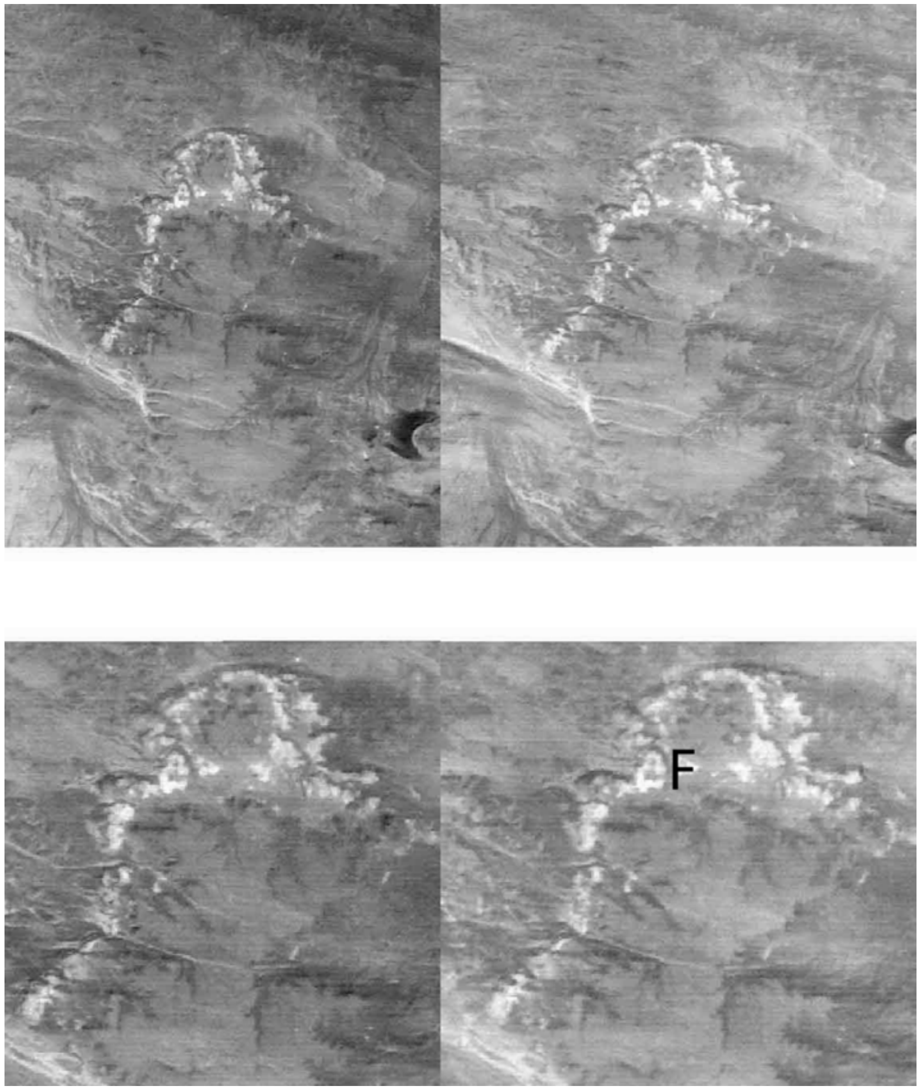

Plate 9. Stereo aerial photographs of the Strauchpfütz area, central Sperrgebiet (F= fossil gastropod locality) (North is to the right of the page).

been reworked by fluvial activity, or has fluvial intercalations, and it is capped by a very coarse conglomerate, not unlike the one that occurs at the base of the aeolian succession and above the Early Miocene sediments.

Thus, the Strauchpfütz carbonates and marls with calcareous nodules are demonstrably earlier than the Kalkrücken aeolianites, and the similarity of the non-carbonate sediments in the succession to those that crop out in the Glastal and at Langental invites correlation. It is thus not unreasonable to consider these deposits to be Early Miocene, but the only way to be sure of this would be to recover mammals from them.

Chalcedon Tafelberg

Chalcedon Tafelberg is a crater filling which has been dolomitised and silicified (Plate 10). The sediments are fine grained and the fossils that occur in the deposits are exclusively freshwater forms such as algae and gastropods. Lock and Marsh (1981) reported that the deposits have been intruded by "limburgite", but in fact they lie unconformably on top of an eroded plug of lava which has a thick soil profile developed on it, upon which repose the dolomites and silicified deposits. The soil has also been partly silicified in irregular patches. Thus the sediments are younger than the "limburgite" and not older than it. The gastropods are similar to material from Grillental known to be Early Miocene on the basis of associated mammals. Thus the Chalcedon Tafelberg sediments are most likely to be Early Miocene, though there is no direct evidence for this, as the gastropods are not sensitive age indicators. Stocken (1978) considered the deposits to be younger than Middle Miocene on the grounds that the underlying "monchiquite" intrusion is of this age.

The lower slopes of Chalcedon Tafelberg on the

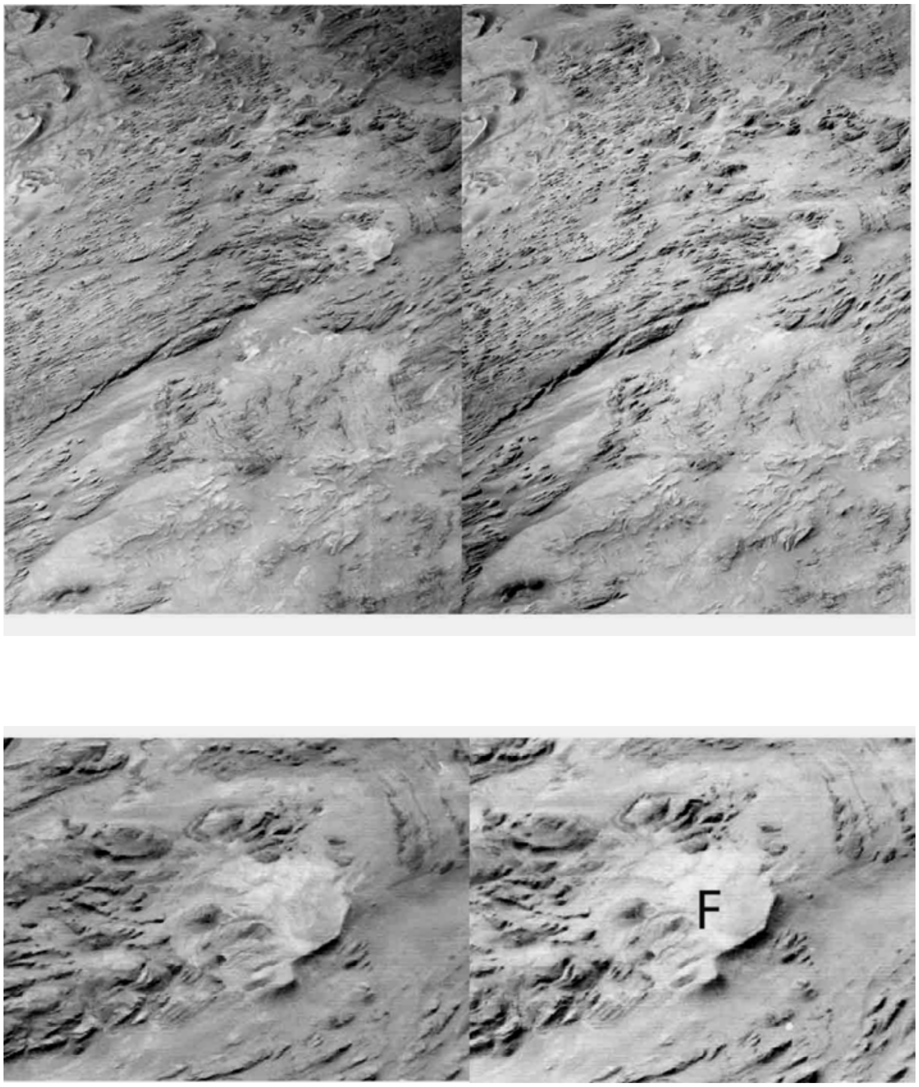

Plate 10. Stereo aerial photographs of the Chalcedon Tafelberg, northern Sperrgebiet (top: general view; bottom: detail of the tafelberg) (F= fossil gastropod locality) (North is towards the top of the page).

north and west side are covered unconformably by calcified aeolianite which extends upwards towards the top of the hill, where it reposes discordantly on the crater fill. These aeolianites contain terrestrial gastropods (Wenz, 1926) and are probably of Pleistocene age but nothing diagnostic of age was found in them. The crater facies contains abundant fossils of freshwater gastropods and algal filaments.

Sediment colour in the Grillental-Elisabethfeld sector

There is a strong contrast in sediment colour between the red basal deposits at Elisabethfeld and the green ones in Grillental and at Fiskus, as well as the upper parts of the Elisabethfeld succession. The mammals from these sites suggest that Elisabethfeld is older than either Fiskus or Grillental, and this is borne out by the fact that green sediments overlie the red basal deposits at Elisabethfeld.

The red deposits owe their colouration to the fact that the iron is in the oxidised (ferric) state, and it is only immediately around bones and teeth at Elisabethfeld that the sediments are green (with ferrous oxides). At Fiskus and Grillental in contrast, all the iron in the deposits is in the reduced condition, and no red deposits occur.

It is not known whether the redox potential in the region was related to atmospheric factors (temperature, humidity), or to depositional ones (availability of organic material or other reasons), but the fact that the base of the succession at Elisabethfeld is red, and the upper part green suggests that oxidation-reduction conditions changed over time, from relatively oxygen-rich to relatively oxygen-poor.

Table 1. Biochronological and biogeographic relations between Namibian and East African Early Miocene mammalian faunas

Namibian Early Miocene Mammalian Fauna	Localities in East Africa where the same species occurs
Myohyrax oswaldi	Napak, Karungu, Rusinga
Protypotheroides beetzi	Unknown outside Namibia
Metapterodon kaiseri	Unknown outside Namibia, but closely related to *M. zadoki*
Metapterodon stromeri	Unknown outside Namibia
Austrolagomys inexpectatus	Rusinga, but closely related to *Austrolagomys minor*
Protenrec sp.	Songhor, Koru, Rusinga
Amphechinus sp.	Songhor, Koru, Rusinga, Napak
Parapedetes namaquensis	Unknown outside Namibia
Propedetes sp.	Unknown outside Namibia
Bathyergoides neotertiarius	Unknown outside Namibia. East African fossils attributed to this species belong to a different family of Rodents (Mein and Pickford, this vol.)
Neosciuromys africanus	Unknown outside Namibia
Neosciuromys fractus	Unknown outside Namibia
Phiomyoides humilis	Unknown outside Namibia
Apodecter stromeri	Unknown outside Namibia
Phiomys andrewsi	Songhor
Diamantomys luederitzi	Songhor, Koru, Napak, Rusinga, Kipsaraman
Pomonomys dubius	Unknown outside Namibia
Protarsomys sp.	Rusinga
Gomphotherium	Widespread
Eozygodon morotoensis	Moroto, Meswa, Lothidok
Prohyrax tertiarius	Unknown outside Namibia
Afrohyrax namibensis	*Afrohyrax championi* at Rusinga, Moruorot, and Kipsaraman
Brachypotherium heinzelini	Widespread
Brachyodus depereti	Unknown in E. Africa, but closely related species at Meswa, Rusinga
Brachyodus aequatorialis	Napak, Rusinga, Karungu, Moruorot
Diamantohyus africanus	Rusinga, Karungu, Napak, Moruorot
Nguruwe namibensis	Unknown, but larger species at Napak, Songhor, Koru
Dorcatherium songhorensis	Songhor, Koru, Napak
Propalaeoryx austroafricanus	Unknown outside Namibia
Sperrgebietomeryx wardi	Unknown outside Namibia
Namibiomeryx senuti	Unknown outside Namibia

Biochronology

The fossil mammal assemblages from all the fluvio-paludal localities in the region are basically similar to each other, but there are slight differences in frequency of certain species at different sites, and some lineages tend to be smaller at Elisabethfeld and Grillental than at Langental, suggesting that Langental is slightly younger than the others. Elisabethfeld has yielded abundant remains of pedetids (spring hares) yet they are extremely rare at Langental. The suoid *Diamantohyus* is common at Langental and rare at Elisabethfeld and Grillental. The rodent *Diamantomys* appears to be more common at Elisabethfeld than at Langental. These differences could be related to ecological variation, but there might be some contribution from chronological differences. For instance, *Diamantomys* assemblages from the various sites are slightly different in size, possibly reflecting differences in geological age. The same applies to *Nguruwe namibensis*. There can be no doubt however, that all of them are of Early Miocene age, nothing in the available samples suggesting anything of Middle Miocene affinities. In other words, none of the mammals found at Arrisdrift which is of basal Middle Miocene age occur in the northern and central Sperrgebiet. On the contrary, all the species that are common to Namibia and East Africa suggest that these sites are about 20 - 18 Ma.

Table 1 provides a detailed comparison of the Namibian faunas to those of East Africa. Clearly, the Namibian deposits correlate most closely with Faunal Sets P0 and P1 of East Africa (Pickford, 1981), the core faunas of which occur at Meswa Bridge (ca 21 Ma) and Songhor (19-20 Ma). There are some taxa common to Faunal Set 2 (core fauna Rusinga, 18 Ma), but there are fewer of these than are shared with Faunal Sets 0 and 1.

Conclusions

The most richly fossiliferous deposits of the Northern Sperrgebiet accumulated in pre-Miocene valleys incised into the Namib Unconformity Surface. When sea level rose during the Early Miocene, transient sediment that would normally have been flushed out to sea, was back-ponded, and formed linear deposits of clay, silt, sands and minor conglomerates. Fossils accumulated in various facies, the richest being paludal and floodplain sediments, sometimes overprinted by pedogenic alteration, including calcrete pedogenesis. The latter suggests a semi-arid, woodland setting with less than 750 mm rainfall per annum, falling mainly in the summer months. This is borne out by the faunal studies which include pipid frogs, the harvester termite (*Hodotermes*) represented by its bioconstructions, and the overall aspect of the mammalian fauna.

Other fossiliferous deposits of the region accumulated in crater settings, but the fossil record is poor and limited to invertebrates and plants.

Biochronology, based on mammals, indicates that all the deposits are Early Miocene, with Elisabethfeld being the oldest of the sites, followed in age by Grillental, Fiskus and Langental. Chalcedon Tafelberg is possibly Middle Miocene.

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References

Beetz, W. 1926. Die Tertiärablagerungen der Küstennamib. *In:* E. Kaiser (ed.) *Die Diamantenwüste Südwest-Afrikas*, **2**, 1-54, Berlin, Reimer.

Corbett, I. 1989. *The Sedimentology of Diamondiferous Deflation Deposits within the Sperrgebiet, Namibia*. PhD Thesis, Univ. Cape Town, 430 pp.

Greenman, L. 1966. *The Geology of Area 2615C Lüderitz, South West Africa*. MSc Thesis, University of Cape Town, 117 pp.

Greenman, L. 1970. The Elizabeth Bay Formation, Lüderitz, and its bearing on the genesis of dolomite. *Trans. Geol. Soc. S. Afr.,* **73**, 115-121.

Lock, B. and Marsh, J. 1981. Tertiary phonolite volcanism in the Klinghardt Mountains of South West Africa/Namibia. *Trans. Geol. Soc. S. Afr.*, **84**, 1-6.

Pickford, M. 1981. Preliminary Miocene Mammalian biostratigraphy for Western Kenya. *J. Hum. Evol.,* **10**, 73-97.

Pickford, M. and Senut, B. 2000. Geology and Palaeobiology of the Namib Desert, Southwestern Africa. *Mem. Geol. Surv. Namibia*, **18**, 1-155.

Stocken, C.G. 1978. A review of the later Mesozoic and Cenozoic deposits of the Sperrgebiet. *Unpub. Rept The Consolidated Diamond Mines of South West Africa (Pty) Ltd Geol. Dept*. 1-33 and 1-4.