GEOLOGY OF SOUTH WEST ANGOLA, BETWEEN CUNENE AND LUNDA AXIS.

(Read 4th September, 1933.)

By P. F. W. BEETZ.

[PLATE VI.]

[*Geological Map of South West Angola.*]

CONTENTS.

INTRODUCTION.

From June to the beginning of September, 1932, I had the opportunity of carrying out geological investigations in this territory on behalf of the Companhia de Diamantes de Angola (Diamang). As I had the assistance of all persons locally employed and could use the Company's motor service, and had, in addition, the full benefit of the local knowledge of the Company's employees and of all previous research and prospecting work, it was possible to cover a wider area and to get much more information about the geology of this part of Angola than would have been possible if I had had to travel on my own.

About 4,000 miles by motor and 250 miles on foot were made in various trips across the country between the Cunene mouth and Benguella in the west and the "Planalto" of the Chella in the east. More detailed investigations were carried out in the coastal belt between the Cunene and Porto Alexandre. Extensive walking in numerous trips where motor transport failed, more especially towards the Cunene River and further inland, served for the more detailed exploration of the geologically interesting problems of that area. I also visited the Planalto of Mossamedes, *i.e.*, the country around Lubango, Humpata and Huila, and the coastal belt near Chapeu Armado, 100 klm. north of Mossamedes.

It is with a great deal of pleasure that the author acknowledges the valuable assistance rendered to him by the representatives of the Companhia de Diamantes de Angola, especially by the Board of Directors for giving permission to publish the results of these investigations, and to the consulting engineer, Mr. H. T. Dickinson; furthermore, to Mr. J. Hermans, who was in charge of the Company's prospecting work north of the Cunene mouth; from him most valuable information was received, while he always facilitated the very difficult problems of transport with never-tiring personal efforts.

The author would also like to thank Dr. A. L. du Toit for the assistance he has rendered and the criticism he has made of this paper.

Previous Exploration Work.

The area described in the following pages extends from the Cunene mouth in the south-west and Chapeu Armado on the coast 60 miles north of Mossamedes in the north-west, then inland to the Planalto of Mossamedes in the north-east and to the area around the Montenegro Falls in the south-east. Whilst the country around Mossamedes, and between Mossamedes and the Planalto has been visited and described by several explorers, the area further to the south, especially between the Coroca and Cunene, was probably the least known and worse mapped part of Angola before the Diamang started prospecting in 1930.

During the prospecting period numerous sketches of the coastal belt were made by the Company's employees; furthermore, geological and topographical sketches of the inland portion by G. Scoutounoff, a Bulgarian geologist who investigated the interior for base and precious minerals, and topographical sketches of the interior between the Coroca and Cunene by a certain Mr. Adler, a South-West African prospector, were placed at the writer's disposal.

Previously, the country between the Coroca and Cunene had been crossed by a Portuguese medical officer and explorer, J. Pereira do Nascimento;[1] also by an expedition equipped with motor cars trying to find a suitable route for a railway line from Tiger Bay inland to the Cassinga gold district; this expedition succeeded in reaching Otjinjou by motor car after a long and strenuous journey.[2]

Systematic prospecting was done in this area by an expedition sent to southern Angola about ten years ago by the South-West Africa Company of Grootfontein, but no report thereon was published.

[1] "Exploracao geologica e mineralogica no Districte de Mossamedes em 1894-1895," Lisboa, 1898.

[2] Pereira de Souza, F. L.: "Contributions a l'etude Petrographique du sud-ouest d'Angola." *Comptes rendus de l'Academie des Sciences.* T. 162, pp. 692-694, Paris, 1916.

More geological and topographical work has, however, been carried out between Mossamedes and the Planalto 75 miles to the east. Scoutounoff covered this area during his investigations 1931 to 1932, supplementing the most up-to-date previous geological research work of the Dutch geologist and mining engineer, F. J. Faber,[3] a pupil of Molengraaf. Both Scoutounoff and Faber contribute valuable information about the geological problems of the area in question, and I had the opportunity of visiting most of their important critical sections and of fitting their observations in with my own and with the geology of the surrounding areas. The coastal belt of about 50 miles in width between the Cunene mouth and Porto Alexandre was visited by no other geologist before me.

Bebiano [4] has made the most recent and exhaustive contribution to the geology of the whole of Angola; however, in the area between the Cunene mouth and Mossamedes he relies solely on information that he received from others, and his representation of South-Western Angola on his geological map is, therefore, only of schematical value.

Of geological investigations carried out in adjoining areas, of special value are the investigations of J. W. Gregory and P. Choffat and their co-workers in the district of Benguella-Lobito, and of J. Kuntz, C. Krause, J. Gevers and A. Stahl in the Kaokofeld and the northern part of South-West Africa.

Much interesting information about the working of copper mines, about the natives and the life between Mossamedes and Benguella in the early days, can be gathered from the very readable book by the British mining engineer, Monteiro,[5] apparently of Portuguese descent, who for many years lived and worked especially along the coast of Angola. Statham [6] gives a valuable compilation of the animals and plants of the district, but his own observations as given in his book are not reliable and somewhat in reporter style.

L. P. Vageler [7] contributes some valuable observations about the Cunene River and the zone of anorthosite-gabbro rocks in the south-eastern part of the area.

Main Physical and Geological Features.

Special climatic and morphological, besides geological features, characterise the following geographical sub-divisions within the area investigated:—

I. The Serra de Chella in the east.

II. The Lunda Axis (Schwelle) in the north.

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[3] Faber, F. J.: "Bijdrage tot de Geologie van Zuid-Angola." *Proefschrift, Technische Hoogeschool te Delft*, 1926.

[4] Bebiano, J. B.: "Geologia e Riqueza Mineira de Angola," Lisboa, 1923.

[5] Monteiro, J. J.: "Angola and the River Congo." London, 1875, two vols.

[6] Statham, J. C. B.: "Through Angola, a Coming Colony." Edinburgh and London, 1922

[7] Vageler, L. P.: "Beobachtungen in Suedwestangola und im Ambolande, 1920.

III. The Namib peneplain west of the Chella escarpment.
IV. The coastal belt in the west.

I. In the east occurs the Serra da Chella forming a high plateau breaking off abruptly in the west, but with a more gradual slope to the east. The steeper slope corresponds with the Great Escarpment of South Africa. The altitude of the escarpment above the Namib peneplain in the west is over 1,000 metres east of Mossamedes, where it forms the western limit of the well watered and fertile " Planalto de Mossamedes." Towards the south the continuation of this escarpment as preserved east of Mossamedes gradually diminishes in height, but is still 300 to 400 metres high east of the Otjitemi River, where it is called the " Tunda "; it disappears north of the Cunene near Ondambo on the outskirts of the Kalahari. Its continuation to the south is only a feature brought about by denudation, which has in the southern portion destroyed the greater part of the original updoming of the old bent surface, and has left a deeply-cut mountainous belt (referred to hereunder as the " Mountain Belt ") whose highest residuals in the Tschamalindi Mountains are still covered by the same formation as the unbroken Chella further to the north-east. Erosion took place towards the Coroca, whose very extended drainage system had already originated during the Tertiary period, that river having cut its bed straight across the escarpment, which is here 1,700 m. above sea-level, into the margin of the Kalahari basin, so that the plain around the source of the Otjitemi River, one of the main tributaries of the Coroca, stands at less than 1,000 m. above sea-level.

The crest line of the updomed country along the original escarpment turns west-south-west at the sixteenth parallel in a very conspicuous angle, and runs in that direction for over 50 miles before it turns to the south again at the very point where the Coroca bends eastwards. The edge of the escarpment is about 1,700 to 1,900 m. high, east of Mossamedes, which altitude is also reached in the Tjamalindi Mountains, that form a relic of the old Chella escarpment in the Mountain Belt as mentioned above. This Belt does not persist north of the Coroca, where the Namib peneplain is as much as 130 kilometres wide.

The plateau of the Serra da Chella is for the most part covered by fairly horizontal sediments (Chella formation), consisting of grits, sandstones, quartzites, breccias, conglomerates and limestones with intercalated sills and intruded dykes of dolerite. The Chella formation can be correlated with the Otavi and Nama formation of South-West Africa, the Transvaal system of South Africa, the Serie Schisto-Calcaire of the Lower Congo, and the Lower Kundelungu system of Katanga.

Rain water soaking into the Chella plateau becomes stored in the sediments and volcanics of the Chella formation, and numerous strong springs are hence found all along the contact of the Chella formation with the underlying granite or schists, so that the Chella plateau presents features very similar to those of the Waterberg in South-West Africa and in South Africa, and the Kundelungu plateau in Katanga. Many rivers have their source along the Chella escarpment, wherefore boulders and pebbles derived from rocks of the Chella formation are common in the Cretaceous, Tertiary and Pleistocene gravels of the coastal belt.

The rough Mountain Belt is deeply cut into by numerous dry rivers (called " dambas " in Portuguese). Only in the south occur residuals of the Chella or the Otavi formations covering the big massif of the Tjamalindi Mountains, which formation runs from here through the Kaokoveld towards the south-east and is continued as far as Tsumeb in South-West Africa.

Otherwise the underlying schist formations are exposed in the Mountain Belt. Of these the oldest known to me consists of various types of highly metamorphosed acid and basic gneisses with one or two bands of marble and quartzite. The main occurrence of this oldest gneiss formation is in the Namib peneplain and the coastal desert south of Tiger Bay.

The next younger formation occurs over wide areas in the south-western portion of the Mountain Belt and at many places in the Namib peneplain, and consists of well stratified schists containing many thick layers of reddish granulitic gneiss, quartzites, mica-schist, amphibolites, garnet-schists and marbles. Higher levels in this schist formation show a great development of marbles and limestones with interbedded mica- and garnet-schists. Marble layers form over 50 per cent. of the 200-400 metres of beds belonging to this formation as developed in the Ohungokoro (Zebra) Mountains, 50 kilometres to the east of the Cunene mouth. The marble is often of excellent quality. These rocks can be correlated with the similar schist-quartzite-marble formation of the Namib east of Swakopmund in South-West Africa, whose marble beds have been exploited for a long time in the vicinity of Karibib. The latter has been called the " Karibib formation " by the author and more recently the " Damara system " by T. W. Gevers, who has investigated the type sections of this formation in the Chuos Mountains east of Swakopmund.

A third still younger schist formation which seems within the investigated region to be confined to the Mountain Belt, in which it spreads over very extended areas, consists of phyllites, sericitic grits, conglomerates, greyish greenish and reddish quartzites, chloritic schists and thick layers of amphibolites and granulites. The lower beds of this formation are intruded by granites, and the whole formation from top to bottom is invaded by numerous sills, dykes and stocks of altered diabases, diorites and gabbros.

Similar formations are known to occur in many parts of Central and South Africa; for instance, the Karagwe-Ankolean rocks in Uganda, the Kabele system of the Congo, the Chloriteschist and Phyllite formations of South-West Africa, etc. The Sub-Commission of African Geological Surveys,[8] at their first meeting at Kigoma in July, 1931, decided that this system should in the future be referred to as the Muva-Ankole system.

Most of the conspicuous peaks and crests of the ranges in the Mountain Belt are formed by the greyish-white basal quartzites or the very thick layers of hard red granulites of this formation, for instance, the Tjirumbo, the peaks of the Kaokahengombe Mountains (two of them are called Capucette and Lion respectively) and others.

North-east of the Montenegro Falls the Muva-Ankole system is intruded and broken up by enormous gabbro-anorthosite intrusions, which appear as the southern continuation of the gabbro-anorthosite belt known to occur 200 kilometres further to the north-east, north and south of Gambos (Chibemba) on the Planalto de Mossamedes. Its continuation from Gambos to the Cunene was anticipated by other geologists (Faber, Vageler and Pereira de Souza).

Numerous watering places exist in the eastern portion of the Mountain Belt and to the north along the foothills of the escarpment, but only a few in the western portion of the Mountain Belt and on the Namib peneplain. In the former regions such is mostly underground water coming to the surface in the river beds, especially where the latter are crossed by rock bars (Ovipako, Otjissengo, Pediva, Ondambo, Kahama, etc.). Most of these places contain water ranging from brackish to salty. In the western portions of the Mountain Belt and the Namib peneplain, a few places are known where water can be obtained by digging in the river beds (Gariata, Buracco); other places contain water only after rains (Kurupiko); a few represent springs issuing along faults (Kambeno) or along the contact of sedimentary formations with schists (Ujona, Gau or Tjamarindi, Ovikambekambe, Chacuto, Binga), and these springs furnish excellent water. The Kambeno springs are thermal, giving a lukewarm water with the odour of H_2S. Another thermal spring is reported by Nascimento from the foot of the escarpment north of Pediva (Coroca); two others, Kitewe and Montipa, are known from the southern slopes of the Lunda Axis between Mossamedes and Lubango.

II. The Lunda Axis or Rise (Schwelle) runs from west to east from the coast inland, north of the Mossamedes-Lubango railway line. It is marked geologically by a projection towards the west of the Chella granites, and by the disappearance of the Chella formation on the Planalto north of Vila Ariaga and Lubango. No proper escarpment occurs on the axis, as the hard table formation of the Chella is missing, the slope of the country on it being more gradual. The country along the Lunda Axis generally surmounts that to the north and south of it, and this higher country is cut up by erosion into numerous granite hills within the limits of the investigated area. The Namib peneplain, although still in existence, is much narrower on the

[8] *Proceedings of the First Meeting of African Geological Surveys.* South Equatorial Section, p. 12. Published: Institut Geologique de l'Universite Louvain, 1932.

Lunda swell than further to the south. The belt of Cretaceous and Tertiary beds in the coastal desert gets narrower north of Mossamedes, until between Lucira and Cape St. Maria the coastal formation disappears altogether and gneiss and granite form the shore.

The rocks of the Lunda Axis consist almost solely of Chella granite and gneisses within the investigated area, fringed in the west by a narrow band of schist and by Cretaceous and Tertiary beds. Further to the east the Lunda Swell forms the watershed between the Congo and the Kalahari basins; crystalline rocks—granite, gneisses and schists—occur on this important African divide and extend far into the interior. Many other facts besides those mentioned above prove that the Lunda Axis is not only a geographical feature, *i.e.*, a higher strip of country comprising a watershed, but that it existed since pre-Cambrian times, and during later geological periods exerted an influence on the geological history of enormous areas both to north and south of it.

It may be mentioned that at its northern slope, south of Benguella, or—more closely—south of Dombe Grande, a sudden change takes place in the geological structure of the country. As the Cretaceous beds rise slowly towards the Lunda Axis, the schists, whose strike is north-south east of the Cretaceous formation near Benguella, turn abruptly into an east-west direction and all the younger formations north of this line running parallel thereto, whilst east-west faults are to be observed in that area.[9]

Along the southern slope of the Lunda Swell within the area of my investigations, between Mossamedes and Lubango, the old schists (Damara system) are running east-west, *i.e.*, parallel to that rise. Where the Chella granite ascends towards the north, numerous isolated portions of the older Damara system are still preserved as "roof pendants" partially enveloped by the granite.

Furthermore, the lower beds of the Chella (Otavi) formation change their facies when followed towards the Lunda Axis. Whilst in the southern Kaokoveld hardly any basal beds (grits or conglomerates) and quartzites occur between the dolomite and the underlying rocks, such coarser and siliceous strata increase in thickness progressively towards the north, *i.e.*, towards the Lunda Axis, becoming over 600 metres thick east of Mossamedes. A parallel to this change of facies can be found in the thickening of the Black Reef Series towards the north-east (Rhodesian schist dome) in the Drakensbergen between Carolina and Haenertsburg. A similar change of facies is known to occur within the Lower Kundelungu Series of Katanga.

III. The Namib peneplain is a remarkably level strip of country lying below and to the west of the escarpment, and continues from the Cunene in the south to a point east of Chapeu Armado 100 kilo-

[9] Velez Mouta, I. S. T., and Alexandre Borges: "Sur le Cretace du Litoral de l'Angola," *Compte Rendus XIV Congres Geologique International*, 1926.

metres north of Mossamedes. Its altitude is between 400 and 500 metres in the larger eastern portion, but the peneplain slopes slightly in its smaller western portion towards a monocline in the west, which marks the former Cretaceous and Tertiary coast line.

The escarpment or else the Mountain Belt forms the eastern limit of the peneplain, which is surprisingly abrupt; only a few isolated hills or lines of hills rising above the otherwise uniform plain. Its width varies considerably; between the Cunene and Coroca it is about 50 kilometres wide, of which 15 kilometres in the west stands at between 200 and 400 metres, and 35 kilometres in the east at between 400 and 500 metres. Where the escarpment turns eastwards along the Coroca, the peneplain widens to about 100 to 120 kilometres and continues at that width from the Coroca towards the north to the southern limit of the Lunda Axis, *i.e.*, to the hilly country along the Mossamedes-Lubango railway line. North of this railway its width is not known to me, but the peneplain is well developed along the road between Pedra Grande and Chapeu Armado at about 400 metres, sloping to 300 metres towards the monocline of the old coast line, which—at Chapeu Armado—is situated at a distance of only a few kilometres back from the present shore.

This peneplain has been recognised by most of the previous observers, although some of them (Vageler, Jessen and Gregory) regard Western Angola as being built up in several distinct steps rising from the coast to the Planalto of the interior.

Jessen [10] mentions as many as five steps between Loanda and the Lunda Axis at altitudes of 300-400 m., at 900-1,000 m., at 1,200-1,300 m., at 1,600 m., and 1,700-1,900 m., and reports that he found five steps also in Southern Angola, although there are differences in their extent and altitude in the southern area as compared with those further to the north. Within the area investigated by the author, Jessen only measured the altitudes along one section, *i.e.*, along the road and railway line from Mossamedes to Lubango, that is to say, in an area which is situated on the southern slope of the Lunda Axis. No steps exist in the area investigated by the author between the Namib peneplain at 400-500 m. and the Planalto (1,700-1,900 m). Jessen particularly mentions the absolutely level character of the floor of his step at 300 to 400 m. altitude between Loanda and Benguella, such probably corresponding with the Namib peneplain of our area.

Vageler [11] is also of the opinion that Southern Angola between the Kalahari and the coast is built up in a step-like manner, but he leaves the question open as to how many of these steps exist (*loc. cit.*, p. 181); again he apparently confines his "Stufenland" to the

[10] Jessen, Prof. Dr. O.: "Berichte ueber seine Forschungsreise nach Angola." *Mittl. Geogr. Ges. Muenchen.* 1. Bericht 1931, 2 und 3, Bericht Bd. XXV, 1932.

[11] Vageler, Dr. P.: "Beobachtungen in Sudwestangola und im Ambolande." *Ges. f. Erdk.* (17. ix 1919) 1920, pp. 179-193.

Planalto and its immediate neighbourhood, whilst he calls all country further west the "Kuestenvorland." This latter, according to Vageler, begins in the east at an average altitude of 450 to 500 m. and slopes gradually towards the west, *i.e.*, to the coastal cliff of Mossamedes, which is about 40 m. above sea-level.

It may be repeated that one of the main features of the peneplain as observed by the author between the Lunda Axis and the Cunene, is the fact that for the greater part it keeps at a level at between 400 and 500 metres, that it ends abruptly against the steep escarpment in the east and slopes gradually towards the monocline in the west, which forms the old Tertiary and Cretaceous coast line, the slope dropping from 400 to 150-200 m. in the south (Tiger Bay, Milungu, Vimpongos), or from 400 to 300 m. in the north (Chapeu Armado).

Faber,[12] who crossed the Namib peneplain on several trips between the Coroca and the railway line, is more explicit in his description of the Namib peneplain. He calls it the "Schiervlakte" between coastal belt and Serra da Chella, and described it as an almost level country traversed by shallow, sandy, dry river beds; the surface is covered by a layer of sand with isolated granite hills sticking out of their own debris. Sometimes swarms of hills give parts of the peneplain a hilly appearance, although none of these hills exceeds 300 ft. in altitude. Through weathering, local denudation and sedimentation, all inequalities of the surface have been removed, and that is how, according to Faber, the large peneplain of the Namib originated. He also mentions that this peneplain rises gradually from 250 up to 550 m. above sea-level, beginning 2 to 20 kilometres back from the coast.

According to Faber, a marine transgression of the sea took place probably in the Eocene, reaching as far as the Chella, and the origin of the Namib peneplain is ascribed by him as partly due to this transgression.

According to my investigations, the level character of the Namib peneplain between Chapeu Armado and the Cunene is due to two factors:—

(1) To the existence of an old pre-Cretaceous peneplain which is preserved in many portions of this area, which corresponds with the pre-Cretaceous peneplain as known in the Namib of South-West Africa and in other parts of South Africa, but does not show the same type of weathering (*i.e.*, silicification, deeply penetrating leaching of rocks, etc.) as in South Africa, so that it has probably been formed under different climatic conditions. In Southern Angola this peneplain has been deeply cut into by numerous Cretaceous and Tertiary rivers.

[12] Faber, F. J.: "Bijdrage tot de Geologie van Zuid-Angola (Afrika) Delft," 1926.

(2) To the infilling, up to the peneplain level, of these Cretaceous and Tertiary valleys by shifting dune sands entering Angola from the Kaokoveld previous to the existence of the Cunene River.

In the Cretaceous and Tertiary epochs the dunes entered Southern Angola, and their remains are to be found as dune sandstones filling in all valleys of the old land surface; a thickness of over 150 m. having been observed on the banks of the Cunene River and in gullies leading down to that river from the unbroken Namib peneplain, although a thickness of 200 to 300 metres is probable in places. A similar arid or desert infilling of valleys and depressions by dune sand, gravels and local debris took place in the Cretaceous and Tertiary periods in South-West Africa and Namaqualand.

The Cunene cuts through these dune sandstones, which proves that this river originated at a later period than these Tertiary sandstones, *i.e.*, in the Pleistocene period. This, together with the juvenile character of the Lower Cunene with its numerous rapids, cataracts and gorges, confirms the idea held by many eminent geologists that the present lower course of the Cunene must be quite young, as there exist many indications that its previous course was directed towards the Etosha Pan in South-West Africa.

Water is very scarce in the Namib peneplain, permanent water places being confined to the beds of the bigger rivers like the Cunene, Coroca, Bero and Giraul. Other watering places where the supply is stored up behind bars and in holes in granite after rainfall are numerous and are known as "cacimbas." Practically the whole of the Namib peneplain is under arid, and its western section under extremely arid climatic conditions with or without very scanty vegetation, worse indeed than the Namib of South-West Africa. Desert comprises the coastal belt and great parts of the Namib peneplain, stretching from the Cunene to Chapeu Armado, its width being 75 klm. in the south and about 10 klm. near Chapeu Armado.

Rocks occurring on the Namib peneplain are granite, gneisses, the schists of the Damara system and the terrestrial sandstones, gravels and cemented debris of the Cretaceous, Tertiary and Pleistocene periods. Furthermore, shifting dune sand covers a large area between the Coroca and Cunene.

IV. The coastal belt is the strip of country along the coast, which is partly or entirely covered by Cretaceous, Tertiary or Pleistocene marine deposits.

The character of the coastal belt respectively south or north of Tiger Bay is different. South of Tiger Bay it rises gradually from sea-level up to about 30 metres above high-water mark. Here the old cliff coast, which bounds the coastal peneplain in the east, is very marked south-east of Tiger Bay along the western slope of Morro Vermelho, where it is 50 to 75 metres high, but it is much lower and partly hidden by dune sand further to the south. The marine peneplain of the coastal belt is from 3 to 5 kilometres broad, west and south-west of Morro Vermelho, but widens to about 10 kilometres north of the Cunene mouth.

North of Tiger Bay, for about 80 kilometres, the shifting dunes come close to the coast, hiding all geological features.

About 20 kilometres south of Porto Alexandre the western boundary of the dunes turns inland to the north-east, leaving free from sand a triangular area which is covered by more or less horizontal sandstones, marls, gravels and limestones of the Tertiary coastal formation, which attains several hundred metres in thickness. This desolate area between the dunes, coast and the Coroca is swept by heavy sandstorms during a great part of the year, and shows as vegetation only a few shrubs; it is called "Medos" by local people, the meaning of the word being "be afraid."

The coastal Tertiary formation runs from here along the coast towards the north and is replaced at a point 50 kilometres north of Mossamedes by Cretaceous beds, and that formation is continued in a narrow belt to the north so far as Lucira Bay, where the gneiss and granite of the Lunda Axis comes to the coast. Whilst a continuous belt of Tertiary or Cretaceous beds is lacking south of Tiger Bay, where gneiss prevails at the surface, this belt is 50 kilometres wide east of Porto Alexandre and 32 kilometres wide east of Mossamedes. Where the Cretaceous formation begins south of Rio Piambo, the belt of coastal formations is not more than 10 kilometres wide, and is even narrower close to Chapeu Armado, where—at one place—the distance between the coast and the granite is only 2 kilometres.

On account of the generally horizontal bedding of these young formations, plateaux predominate in the coastal belt, and table-like mountains (Mesas) have originated through erosion and denudation, giving the landscape an appearance quite different from that of the gneiss country between Tiger Bay and the Cunene.

The disappearance of the coastal formations south of the 16th Parallel north of Tiger Bay coincides in the interior with the bending of the escarpment towards the W.S.W. as described above, which fact provides further proof of this bending of the escarpment being a main structural feature of the investigated area. All along the West African coast, from Capetown to Tiger Bay, the direction of the unbroken coast line is consistently from S.S.E. to N.N.W. Again from Tiger Bay to the north, *i.e.*, north from the 16th Parallel on which the escarpment protrudes 75 klm. to the west, its direction changes to north and even to N.N.E. for hundreds of kilometres, and the distribution of the coastal Tertiary and Cretaceous formations shows that during those geological periods the sea trespassed upon the continent even further to the east than the present receding coast line does, forming an enormous ancient bay, interrupted only for a short distance by the pre-Cambrian Lunda ridge and reaching 200 kilometres inland again in the Loanda embayment beyond.

From Tiger Bay southwards, the escarpment keeps its distance from the sea of only 75 kilometres or less, right through the Kaokoveld so far as the Ugab River, where the 1,000 metre contour line again recedes for about 100 kilometres towards the east along the northern limit of the gneiss " swell " east of Swakopmund,[13] from which the escarpment is also missing.

The marine peneplain is narrow south of Tiger Bay, and no development of Tertiary or Cretaceous beds of any thickness is known to occur between here and south of the Pomona area in South-West Africa, where the Wittpuetz " trough valley " gave the Cretaceous and Tertiary sea another opportunity of invading the continent.

The plateaux of the coastal formations north of Tiger Bay end abruptly towards the west in a coastal cliff, which has an average altitude of about 40 metres and is continuous for hundreds of kilometres, to beyond Loanda. This feature has played an important part in the distribution of the shifting dunes.

The Kaokoveld dunes, which to-day are moving from south to north in a belt 50 kilometres wide south-east of the Cunene mouth, end abruptly at the south bank of the Cunene in a steep slope of 50 to 150 metres in altitude. The vegetation at the south bank is often submerged by sand gliding down these slopes. On the other hand, the strong current of the juvenile lower Cunene easily transports all this sand into the sea. It is then thrown on to the beach north of the Cunene mouth, transported inland by the winds and concentrated in a compact belt of shifting dunes, which increase in width towards the north covering enormous areas between Tiger Bay and the Coroca. This belt of dunes is cut off again by the Coroca River, which, although a dry river for most of the year, comes down in flood frequently enough to wash all the new sand into the sea. North of the mouth of the Coroca begins the high coastal cliff of Tertiary beds, which is continuous for hundreds of kilometres, and there is no possibility of a new belt of dunes being formed, although desert conditions prevail for 100 kilometres north of Mossamedes *i.e.*, as far as Chapeu Armado.

The coastal cliff north of Porto Alexandre is capped by young Tertiary and Pleistocene marine deposits, which indicates that the coast has been rising during recent times. This is confirmed by the fact that all rivers along this part of the Angola coast are engaged in cutting deep canyons into the coastal belt, whereas their beds are shallow and sandy across the Namib peneplain. In the coastal belt, here and also to the north, erosion is dominant, and the various rivers, from the Coroca to the Caporollo, have deposited scarcely any gravel recently. In all the gravelly deposits (terrestrial or marine) existing along the rivers or otherwise in the coastal belt, the pebbles have been transported from the interior to the coast by Tertiary or

[13] Stahl, Alfred: "Die Grundzuege der Schollentektonik Sudwestafrikas Zeits. d. D.G.G." Bd. 79. 3/4, 1927, p. 64.

Cretaceous rivers. The eastern limit of the coastal belt is formed either by an old coastal cliff or a monocline, as described below.

STRATIGRAPHICAL SCHEME.—CLASSIFICATION AND DESCRIPTION OF ROCKS.

I. *Table of Formations.*

From top to bottom this is as follows:—

Recent Alluvial and Eluvial:

Soils, sands of shifting and fixed dunes, debris on slopes and eluvial on plains, fanglomerates, gravels; marine beaches, sands and lagoon silts.

Pleistocene:

Superficial limestone silicified in places and cemented sand and debris. Lower marine beaches between the Cunene and Tiger Bay, Chapeu Armado, etc.

Unconformity.

Upper Tertiary (Miocene to Pliocene):

(*a*) Marine—sandstones, marls, limestones and gravels from the Medos, south-east of Porto Alexandre, to Rio Piambi, north of Mossamedes, and at Chapeu Armado; higher beaches and residuals of green sandstones in depressions in gneiss between Tiger Bay and the Cunene.

(*b*) Terrestrial—arid infillings of valleys composed of sandstones and river gravels.

Unconformity.

Lower Tertiary (Eocene to Oligocene):

Marine sandstones, marls, limestones and gravels between Milungu, east of Porto Alexandre and Rio Piambo, north of Mossamedes. Terrestrial gravels and sandstones.

Unconformity.

Cretaceous:

Senonian—

Intrusion of dykes and pouring out of lava sheets; nepheline basalt and felspar basalt of Chapeu Armado, south Nicolau and Dombe Grande; limburgites, bostonites, etc., between Tiger Bay and the Cunene. Porous fossiliferous red grits—probably calcareous originally—underlying sheets of basalt north and south of Chapeu Armado, and underlain by a basal conglomerate containing boulders derived from the Chella formation.

Unconformity.

Turonian (?)—

Argillaceous grits and sandstones, mostly of a vivid red colour and thin layers and veins of gypsum; many irregular lenses of coarse gravel of local rocks with many sub-angular boulders.

Disconformity (?).

Albian (?)—

Greyish-white, loose sandstones with cross-bedding, greenish marls and clays with bituminous layers, irregular layers and lenses of sandy limestones and a thick layer of white dense limestone (with cavities) weathering with a black crust, layers of fanglomerates at the base and lenses of gravels intercalated in the sandstones.

Unconformity.

Jurassic:

Andesitic and trachytic lavas east and north-east of Mossamedes; dolerites in dykes and stocks along the escarpment.

Unconformity.

Cambrian to Silurian (?) Chella Formation:

Limestones with chert, limestone breccias. Quartzites, shales, sandstones, grits and silicified lower limestone. Conglomerates, breccias and grits of the Tunda and Chella escarpments, and tillite of Tjamarindi Mountains.

Intrusions: sills, dykes and sheets of melaphyre.

Slight Unconformity.

Algonkian—Upper Konkip Formation:

Red, slightly-cemented sandstones and shales, grits and basal conglomerate.

Unconformity.

Algonkian—Lower Konkip Formation:

Intrusion of diabase, diorite, gabbro, pyroxenite. Intrusion of the anorthosite-gabbro suite between Chibia and Montenegro Falls. Sericitic and chloritic slates and sericitic grits.

Unconformity.

Huronian (?)—Muva-Ankole System:

(From top to bottom).

Intrusion of metamorphosed diabases in sheets and dykes. Intrusion or effusion of acid and basic lavas now preserved as metamorphosed red massive granulites (200 metres) and dark greyish-green amphibolites with intercalated sericitic (micaceous) slates. Greyish-white quartzitic slates, and green chloritic slates; chloritic and mica schists, quartzites and amphibolites intruded by Chella granite. Massive, splintery, white quartzites and conglomerates (20-50 metres) forming crests of mountains around Ojona.

Intrusion of the Chella granite during the period of sedimentation of the Muva-Ankole System.

Unconformity.

Archaen:

Damara System—

Thick layers of marble (–200 m.) garnet and biotite schists, quartzites. Well stratified gneissose quartzites, granulites, mica schists, garnet schists, amphibolites, etc.

Unconformity.

Pre-Damara Gneiss—

Non-stratified acid and basic-gneiss, amphibolites, one or two marble layers, augengneiss.

II. *The Pre-Damara Gneiss.*

This forms the country rock over large areas of the Namib peneplain between the Cunene, Coroca and the Lunda Axis, and along the coast between Morro Vermelho and the Cunene. Furthermore, it occurs within the Mountain Belt in an anticline along the Kahama valley north-west of Montenegro Falls, which anticline seems to be bounded by faults; another gneiss anticline occurs west of the Tjamalindi Mountains.

It is difficult or impossible to say from a rock specimen alone whether it has been taken from the pre-Damara gneiss, the Damara system or certain rocks belonging to the Muva-Ankole system. However, in the field there are marked differences in their modes of occurrence. The pre-Damara gneiss is not stratified like the rocks of the Damara and the Muva-Ankole systems, and is much more intruded—mostly in lit-par-lit fashion—by basic and acid igneous rocks than that of the other systems. Furthermore, the strike of the old gneiss is persistently around true north along the coast, as well as further inland, whilst the general strike of the two other rock systems is N. 30° W. The unconformity between Gneiss and Damara system could be followed up in the field some 30 kilometres east of Morro Vermelho. Gneissose rocks also occur in the two other systems, where they are invaded by the Chella granite and by the anorthosite-gabbro complex; in the field there is no lit-par-lit intrusion in such cases, but the rocks are broken up into breccias with the fragments floating in, or in process of absorption by the enveloping granite or anorthosite.

Between the Coroca and the Lunda Axis, amphibolites and biotite gneisses predominate, intruded by numerous veins of aplite, pegmatite and granite. Furthermore, dozens of large basic dykes are very conspicuous within this area, such being often over 10 metres wide and running for many kilometres straight across country, weathering into steep ridges; most of them run from north to south, others have a more north-westerly direction. Their character is variable, and it is probable that not all of them belong to the same period of intrusion; some of them belong to the gneiss formation. Souza [14] mentions kersantites, diorites and quartz diorites; Faber [15] describes the dyke

[14] Souza, F. L. P. de: "Contributions a l'etude Petrographique du Sud-ouest de l'Angola." *Comptes rendus d'Academie des Sc.* Tome. 162, pp. 692-694, Paris, 1916.

[15] Faber, F. J.: "Bijdrage tot de Geologie van Zuid-Angola (Afrika) Delft," 1926.

of Vila Ariaga as quartz-diorite-porphyrite, and dykes between Chacuto and Cahinde as olivine-dolerite. The latter seems to be absolutely fresh and may even belong to the Karroo dolerites, as described below. The Vila Ariaga dyke does not cross the Chella formation and probably belongs to the intrusions of the Muva-Ankole system or to the Konkip formation. Scoutounoff [16] mentions diabases, dioritic and gabbroid rocks and fine-grained greenstones.

In the belt of gneissose rocks in South-West Africa, also in the Conception Bay and Spencer Bay areas, the occurrence of similar types of dyke rocks has been observed, and these have been described as diabases, diorites, dolerite, etc. In the Spencer Bay area most of the dolerites are the deep-seated equivalents of the Konkip volcanics, which have been correlated with the lavas of the Ventersdorp system, and the same probably applies to most of the basic dykes of our area, especially as most of them have a comparatively fresh doleritic appearance. To settle this problem it would be necessary to carry out a special investigation of all the dykes.

Biotite-gneisses with aplitic veins have been observed between Gariata River and Tiger Bay; reddish mylonitic gneisses occur on the north-eastern slopes and east of Morro Vermelho, also on the coast west of this hill. Going southwards along the coast from Morro Vermelho to the Cunene one meets first " Zebra-gneiss," *i.e.*, biotite gneisses intruded lit-par-lit by aplitic and pegmatitic material often showing " eye " structure, that is to say, more or less rounded quartz-felspar aggregates; isolated lenses of greenish marble and lime-silicate hornfels with much garnet and other silicate minerals are quite common in the zebra-gneiss. An area of several square miles composed of very compact " augengneiss " showing felspar-quartz eyes up to several inches across in a brownish matrix occurs half-way between Morro Vermelho and the Cunene. This probably represents a highly metamorphosed porphyritic granite. Large pegmatite dykes, some of them containing rose quartz and others having graphic structure, occur several kilometres north-east of the Cunene mouth.

Remarkable is the occurrence of a marble band which is 20 to 40 metres thick and runs north-south, with only minor disturbances, for about 40 kilometres from Morro Vermelho to the Cunene at a distance of about 10 kilometres from the coast. This marble is partly silicified and contains many impurities; occasionally quartzites and garnetiferous mica schists are connected with it, especially at its southern end. East of Morro Vermelho the band is broken up into fragments floating in the gneiss and metamorphosed into lime-silicate hornfels.

The gneiss in the corner between the dunes north-east of Tiger Bay is mostly a dark basic variety traversed by amphibolitic dykes, probably kersantites.

The gneiss anticline north-west of Montenegro Falls shows basic (dioritic) gneiss near the Cunene; further to the north zebra-gneiss

[16] Scoutounoff, G. F.: Several Reports, 1932. Not published.

with garnet-mica schists and amphibolite, and in the upper Kahama valley gneiss granite with a body of pyroxenite. In this area I came across several "Buck Reefs," *i.e.*, zones of crushed, flinty rocks, which show the faulted nature of this anticline.

III. *Damara System.*

Rocks belonging to this system form a strip of about 20 kilometres wide, running from Otjinungwa on the Cunene (opposite the mouth of the Marien River of the Kaokoveld) in a north-north-westerly direction, disappearing in the dunes south-west of Mount Zangaia. Where they vanish the dune sand is coloured red and black by garnets and magnetite derived from the destruction of these schists. Probably connected with this occurrence are the rocks cropping out below the Chella formation in the O'Nethu Valley in the southern Tjamalindi Mountains, where Scoutounoff reports the occurrence of layers of limestone in the gneiss.

Another strip of rock—20 kilometres wide—occurs east of Mossamedes running east-west and forming the southern limit of the Chella granites of the Lunda Axis. The beds of this strip turn to the north, following the eastern limit of the coastal formation, and forming a band of varying width between it and the Chella granite for about 100 kilometres northwards.

The rocks of the Damara system consist in their presumed lower portion of well-stratified gneissose quartzites, granulites, mica-schists, garnetiferous-schists and amphibolites; a higher horizon contains thick layers of marble, besides garnetiferous and biotite schists, quartzites and other schists. In a sequence of over 200 metres of such beds in the Ohungokoro (Zebra) Mountains, 45 kilometres east of the Cunene mouth, over 50 per cent. consisted of thick marble layers.

The marbles are mostly of high quality and often free from impurities, and occur in layers several metres in thickness. They compare very well with the marbles of Karibib in South-West Africa, which have been exploited for years, though unsuccessfully, despite the high quality of the marble, on account of the excessive costs due to high wages and transport charges. The exploitation of the marbles between the Cunene and Coroca would be impracticable, as costs of transport would be still higher. The marbles south of the railway line, Mossamedes-Lubango, are exploited at several places and burnt in lime-kilns for local use. These marbles occur in very disturbed position, and contain too many impurities (silica and antinolite, pyrites) to be fitted for building purposes or export.

The marble horizon between the Coroca and the Cunene contains in places limestones which show to the naked eye hardly any crystallinity, and may be mistaken for limestones of the Chella formation; I found them interbedded with garnet- and mica-schitsts.

Apparently connected with water stored in those marbles is the supply of the so-called Cacimba at the north-eastern shore of Tiger

Bay, 35 kilometres north of the settlement; here water occurs in the sand close to the shore, although there is no indication of any river bed nearby, but a hill of about 300 metres altitude, consisting of limestone, is close behind it in the dunes to the east.

Numerous watering places with brackish supplies derived from the marble horizon occur on the eastern slopes of the marble hills of the Ohungokoro Mountains in the Salt River and the Damba da Viboras, where plenty of game is still to be found, especially zebras, oryx antelope, springbok, koodoo, lions and a few rhinos.

Faber [17] mentions the marble used for the lime-kiln at the Dos Irmaus east of Mossamedes as being coarsely crystalline and containing garnet, crystals of pyrites and wollastonite, and being associated with quartzites. He also described the rocks from the hills east of Cambonge as being traversed by aplitic dykes and consisting of quartzite and marble, the latter often silicified or containing nodules of diopside and greenish or brownish garnet. The same kind of garnet occurs in the marble of the Lulea hills.

Scoutounoff describes silicification of the marbles along numerous veins, 0·20 to 0·50 metres thick, traversing it in all directions. These veins are sometimes mineralised; certain of them carry some copper ores, and gold occurs in many places around the marble hills south of the railway line, but never shows payable values. Silicification, as well as mineralisation, is confined to the vicinity of the Chella granite. Furthermore, mica (muscovite) schists, quartzites, grits and amphibolites are mentioned to occur in connection with the marble beds; the amphibolite at Mount Eimba contains lenses of marble.

IV. *The Muva-Ankole System of South-Western Angola.*

The strata correlated with this great central African system comprise beds belonging apparently to two distinct formations:—

(1) An older and very thick series of sediments beginning with sheared conglomerates and white splintery quartzites, followed by quartzites, amphibolites and granulites, with intercalated sericitic and chloritic schists; and

(2) An apparently younger group of less metamorphosed greenish phyllitic or sericitic clay-slates, with occasional lenses of limestone and dolomite, and bands of schistose grit.

The main (Chella) granite of Angola has been intruded into the first-named, though not, so far as is yet known, into the second. Both are cut by basic intrusions, but those invading the older group have suffered much metamorphism, and have been converted into amphibolites and granulites, whereas those cutting the younger are much less altered, and are diabases and dolerites. Their mutual relations and correlation with the Konkip formation of South-West Africa will be dealt with more fully below.

[17] Faber, F. J.: *Loc. cit.*, p. 46.

A similar twofold stratigraphical succession is represented in the Namib in South-West Africa, as described from south of Luderitz by Kaiser [18] and from north of Aus by the author,[19] the problems raised being the same as those reported from the type-region situated south and west of Lake Victoria in Central Africa.

It was impossible for me in the time at my disposal to separate these two divisions in the field in Southern Angola, and to define the character of their contact line more exactly. It will suffice to point out that this problem exists, and would have to be considered in any further investigations of these or similar occurrences.

A further very interesting point is the intrusion of the Anorthosite-Gabbro suite, which occupies large areas in the south-eastern portion of the attached map. These are younger than the granulites of the Muva-Ankole system, but are in part metamorphosed, no evidence, however, being found to show that they are younger than the Chella system. They probably correspond with the intrusions of the Sinclair Series or the Ventersdorp system. They seem to represent the deep-seated equivalents of those volcanics, and with their hypersthene content, to grade over into the charnockite rocks described by Tyrrell [20] (p. 539) and by Lacroix [21] from Liberia and the Ivory Coast (p. 540).

The rocks of the Muva-Ankole system of South Western Angola may be grouped in the following order:—

Sediments.		*Igneous Rocks.*
Middle Konkip Formation (Sinclair Series of S.W. Africa, or Ventersdorp Series of S. Africa).		Anorthosite-Gabbro suite. Diabase, Pyroxenite. Diabase in dykes and sills.
Lower Konkip Formation (Kunjas Series of S.W.A.).	Sericitic clay-slates and sericitic grits; lenses of limestone.	
	Unconformity.	
Muva-Ankole System. (Chloritschiefer Formation of S.W.A.)	Quartzites, sericitic and chloritic schists, gneissose conglomerates and quartzites.	Acid and basic lavas and intrusions, metamorphosed to granulites and amphibolites. Chella granite, corresponding approx. with the Salem granite of S.W.A.
	Unconformity.	

[18] Kaiser, Erich: "Die Diamantenwueste Suedwestafrikas," Berlin, 1926. Bd. I., p. 88.

[19] Beetz, W.: "The Konkip Formation on the Borders of Namib Desert. North of Aus." *Trans. Geol. Soc. of S.A.*, 25, 1922. pp. 23-40.

[20] Tyrrell, G. W.: "A Contribution to the Geology of Benguella, Based on a Rock Collection made by Prof. J. W. Gregory." *Trans. Roy. Soc. Edin.*, Vol. LI, Part III, 1915.

[21] Lacroix, A.: "Charnockite of the Ivory Coast." *Comptes rendus CL.* (1910), p. 20.

Damara System.

The Muva-Ankole system of South-Western Angola—with the exception of the Anorthosite-Gabbro suite—is confined to the Mountain Belt between the Cunene, Coroca and Gariata Rivers. In the east it disappears below the Chella escarpment; it crosses the Cunene into the Kaokoveld in a narrow band west and east of the Montenegro Falls. It forms several synclines and anticlines, which run N.N.W.-E.S.E., *i.e.*, in the same direction as the beds of the Damara system west of the Gariata River.

The basal beds, *i.e.*, white quartzites and conglomerates, have been found only in the south-western portion of the Mountain Belt, north and north-west of the Tjamalindi Mountains. Along the Gariata River the basal beds are covered by alluvials; in the north they are intruded and metamorphosed into the condition of gneiss by the Chella granite; in the east they are hidden below the Chella formation, and in the south-east they are broken up by the enormous anorthosite-gabbro bodies.

Eruptive breccias are found at the Coroca, where the granite has intruded the Muva-Ankole system, and in the south-east, where that formation has been broken up by the anorthosite-gabbro intrusions. In the latter case the very resistant massive red granulites are affected, and east of the Montenegro Falls one can see patches of red granulites as large as 500 metres across enveloped by white anorthosite. Where invaded by granite or anorthosite-gabbro, the beds often exhibit a gneissose structure. The mica-schists, which form the lower portion of the Muva-Ankole system along the Coroca granite contact, fall within the aureole of contact metamorphism of this granite. The metamorphism caused by the numerous basic intrusions of the Middle Konkip formation, *i.e.*, dykes and sills of less metamorphosed diabase, diorite and gabbro, has been less intense, only " hornfels " and " garbenschiefer " resulting.

Overlying the basal beds are green sericitic and chloritic schists, probably mostly amphibolites of very fine grain; then follow greyish-white quartzitic slates of over 100 metres thickness, overlain by green chloritic slates, and then massive dark green to black amphibolites and impure quartzites. One of these dark massive rocks was investigated under the microscope; it represents a true fine-grained amphibolite, consisting of over 50 per cent. green amphibole, 40 per cent. felspar (mostly albite) and 10 per cent. quartz; the structure is " homeoblastic, granoblastic, parallel."

The highest beds of this schist formation consist of very massive, fine-grained red rocks about 200 metres thick, which were taken in the field by Scoutounoff and myself to be quartzites, but which under the microscope proved to be granulites. They contain more felspar than quartz; fairly large plates of felspar (mostly microperthite with less labradorite and microcline) are set in a fine-grained quartz felspar matrix resulting from the crushing of quartz and part of the felspar. A typical mortar structure is developed. No biotite is present, but sericite is found filling numerous parallel clefts together with iron ore, partly limonite, but mostly scales of hematite, which give the rock its red appearance.

The succession and the types of rocks met with in this formation resemble closely those of certain beds observed west of the Albatross, about 10 to 20 kilometres south of Luderitz in South-West Africa. For comparison, the following table is given:—

From top to bottom.

South-Western Angola.	*South-West Africa, south of Luderitz.*
Ca 200 m. granulites.	140 m. granulites in the upper portion with intercalated amphibolites.
? amphibolites and chloritic slates.	6·80 m. sandy greyish-white quartzitic slates with many flattened pebbles.
Ca 100 m. greyish-white quartzitic slates.	94·00 m. greyish-white quartzitic slates.
(? amphibolites) chloritic and sericitic slates.	37·00 m. amphibolites and chloritic slates.
20-40 m. splintery white quartzites and quartzitic gneissose conglomerates with small quartz pebbles.	11·00 m. gneissose conglomerates with flattened small quartz pebbles, sericitic, chloritic schists.

Unconformity.

Archaen Schist Formation.	Schist Formation (Archaen).

The less metamorphosed sericitic clay slates and sericitic grits which have been correlated with the similar Lower Konkip formation of South-West Africa, cover large areas east of the Gariata River along the main road; also at the lower Muende River and south of Otjissengo in the east, where lenses of limestone were observed by Scoutounoff and myself. The thickness of these beds must be over 100 metres. The slates are crossed by numerous quartz veins, as in South-West Africa. The slates and grits are easily destroyed by weathering, an action facilitated by their splitting mostly along two planes, *i.e.*, along the bedding and along a schistosity crossing the latter at right angles, thus producing "slate pencils." The same twofold cleavage has affected as well the lower folded Chella formation along the western slopes of the Tjamalindi, but is not met with in the eastern part of these mountains, nor along the present Chella escarpment east of Otjitemi River, which was not subjected to folding.

Basic intrusions ascribed to the Konkip system occur throughout the Muva-Ankole system, and in places even exceed the sedimentary material, though in the conspicuous massive red granulites they are comparatively scarce.

V. *Rocks Intrusive into the Damara and Muva-Ankole Systems.*

These intrusions belong to two periods. First came that of the Chella granite (Salem granite) and certain basic intrusions connected therewith, while it is likely that the very thick layers of metamorphosed acid and basic lavas (*i.e.*, granulites and amphibolites) of the lower Muva-Ankole system are in part the effusive equivalents of the above-mentioned acid and basic intrusions. Secondly came the intrusion of certain less altered basic rocks, diabase, diorite and gabbro, in sheets, dykes and stocks throughout the Muva-Ankole system, and the majority of the dykes and batholiths intruded into the gneiss and granite between the Coroca and the Lunda Axis. Furthermore, the author attributes to this period the anorthosite-gabbro bodies in the south-east and certain pyroxenites met with in the upper Kahama Valley north-west of the Montenegro Falls.

(*a*) *The Chella Granite.*

Certain granites of the Mountain Belt are surrounded by gneisses, which gradually pass outwards into the well-stratified gneisses of the Damara system or into the quartzites and mica-schists of the lower Muva-Ankole system. These gneisses form metamorphic aureoles around the granite bodies. Again, there is a difference in the habit of their intrusion into the Damara and the Muva-Ankole systems respectively. The aureole around the granite batholith of Kurupiko, south-west of Tjamalindi, begins with dioritic rocks, which are the result of magmatic differentiation; then follows a gradual transition into gneissose dioritic schists and at last into the well stratified gneisses of the Damara system. In the case of the Muva-Ankole system, the contact consists of an eruptive breccia, and the adjoining lower beds of this system are metamorphosed into mica schists.

Whilst in small bodies and close to its contact with the older rocks, the Chella granite has a gneissose character, it appears quite fresh and little altered at a greater distance from those contacts. It covers enormous areas, especially on the Lunda Axis and along the escarpment; it also occurs towards the interior on the outskirts of the Kalahari, east of the escarpment.

The type is mostly a normal biotite-granite of coarser or finer grain; certain varieties contain amphibole, as reported by Bebiano,[22] at the foot of the escarpment, north of Chacuto, and from many other places between Mossamedes and Cassinga. Faber [23] mentions zircon in biotite granite of Morro Antonio east of Capangombe. Tyrrell [24] describes various types of Chella granite east of Benguella, and mentions the association of granodiorites.

[22] Bebiano, J. B.: "Geologia e Riqueza Mineira de Angola." Lisboa, 1923, p. 148.

[23] Faber, F. J.: *Loc. cit.*, p. 55.

[24] Tyrrell, G. W.: "A Contribution to the Petrography of Benguella." *Trans. Roy. Soc. Edin.* Vol. LI., Part III. No. 14, 1916, p. 546.

The Chella granite is non-porphyritic, and is the chief acid intrusive in the schist formation of South-Western Angola. The corresponding "Hauptgranit" of South-West Africa, from Conception Bay to the Kaokoveld, is the porphyritic "Salem granite," a grey porphyritic biotite granite, with tabular phenocrysts of orthoclase and sometimes microcline. These phenocrysts usually exhibit flow structure, *i.e.*, a parallel orientation, which is usually strictly parallel to the strike of the schist and granite contact. The Salem granite shows the greatest conformability to the tectonic structure of the invaded sediments, forming concordant bodies of the nature of phacoliths. It shows its porphyritic structure even in veins of less than an inch thick, and the large orthoclase phenocrysts are well preserved even in mixed rocks, *i.e.*, in case of rocks assimilated by the granitic magma. A similar porphyritic granite has been found in the investigated area only once, forming the highest elevation of the Morro Vermelho south-east of Tiger Bay and intruded into the surrounding schists, and showing all these characteristics of the Salem granite in an excellent manner. The occurrence is the more remarkable, since no further one could be found in South-Western Angola, although this is the most common granite in the Namib, south of the Cunene.

Under the microscope the Morro Vermelho granite shows mortar structure; it contains much quartz, partly broken, partly in large grains with undulating extinction; some rounded grains are enclosed in felspar. The orthoclase occurs in large plates, is mostly kaolinised and often exhibits a faint microcline "gitter" structure; some fresher microperthite; a little oligoclase with fine albite-twinning; a few large flakes of greenish-black biotite with strong pleochroism to light greenish yellow; and ilmenite, mostly thoroughly weathered to leucoxene.

A dark dyke cutting the granite is a hypidiomorphic, fine-grained rock showing an aplitic structure, but with a tendency to parallel arrangement of the felspar laths; no quartz could be seen. Of the felspars a few are labradorite in irregular plates exhibiting fine twin structure; the bulk of the felspar is oligoclase-andesine of irregular outlines; then there exist many more rectangular plates of orthoclase surrounded by a shell of plagioclase. Biotite is practically the only femic mineral, and forms about a third of the total rock; it is partly altered to chlorite. The ilmenite is mostly surrounded by leucoxene. Apatite occurs in a few large grains, but also in many fine needles. No amphibole or pyroxene could be observed. The rock may be called a kersantite, or, better, a tonalite-aplite.

The Salem type represented in the Morro Vermelho is intrusive in gneisses and in a dark metamorphosed diorite or quartz diorite, which covers a large area around this hill, but must not be confused with the large body of much younger basic and ultrabasic rocks (peridotites, limburgites, etc.) in the coastal plain west of Morro Vermelho.

(*b*) *The Anorthosite-Gabbro Suite.*

The occurrence of such intrusions covering large areas east of the Planalto, south of Chibia, has been mentioned by several authors; its continuation towards the Cunene has been anticipated by others, but not investigated. The bending of these intrusions towards the west, *i.e.*, towards the granite of Etampa-Viqueros in the north and towards the Montenegro Falls in the south makes them occupy an arc concave to the west. Similarly shaped anorthosite occurrences are mentioned from the Bergen district of Norway.[25]

Vageler [26] mentions that the ranges bordering the Kalahari are mostly formed by anorthosite-gabbro types, including very coarse-grained varieties containing much garnet in the centre of the bodies near Xillengues (*i.e.*, about on the 16th Parallel), becoming fine-grained towards their contacts, where they become free of felspar. Furthermore, there occur large lenses of ilmenite-magnetite in the centre of the intrusions containing millions of tons of ore. Hills formed by them have a north-south orientation. The associated dykes traversing the surrounding formation have the character of diabase.

Vageler was of the opinion that these types represent the plutonic equivalents of the lavas of the Kaoko formation (Karroo), which form sheets many hundred metres in thickness in the Kaokoveld of South-West Africa. The quartzitic rock of the Table Mountain, on which the Portuguese Post Gambos is built, was recognised by Vageler as chalcedonic sandstone belonging to the Cretaceous or Tertiary, corresponding with the Botletle Beds of the Kalahari. It might be mentioned that Vageler was thoroughly acquainted with these characteristic rocks from his extended trips through the Kalahari, but that Faber's [27] description of them, as belonging to the Chella quartzites and as being metamorphosed at their contact with the gabbro, is certainly a mistake.

Souza's [28] account of these rocks is of importance, and is here translated: "From Nionga up to Tehitunguira gabbros are developed traversed by veins of granulite and aplite with vermiculated quartz. At the contact with the granite there crops out a quartz-norite, then anorthosites, a gabbro-norite, and in Amuti a quartz-norite. The granite continues for 12 kilometres nearly to the east of the fort of Quipongo, but includes outcrops of troctolite and hypersthene-diabase. Then in an easterly direction to the Cunene, one finds more or less basic rocks, diabase, olivine-diabase, quartz-diabase, augite-porphyrite, associated with acid types: rhyolites, rocks carrying quartz, epidote

[25] Daly, R. A.: "Igneous Rocks and Their Origin." 1st Ed., New York, 1914, p. 332.

[26] Vageler, P.: "Beobachtungen in Suedwestangola und im Ambolande." *Verh. Ges. f. Erdk.* (17. IX. 1919), 1920, pp. 179-193.

[27] Faber, F. J.: *Loc. cit.*, p. 79.

[28] Souza, F. L. Pereira de: "Contributions a l'etude Petrographique du Sued-ouest de l'Angola." *Comptes rendus d'Academie des Sc.* Tome. 162, Seance du 1 Mai, Paris, 1916, p. 692.

and prehnite, etc. Going from Chibia towards Gambos, that is to say, in a south to south-east direction, one finds beyond the granite and at 5 kilometres from Serradores a great extent of gabbros with olivine and biotite (troctolite) and anorthosite. The labradorite of these rocks is generally saussuritised and calcified. These gabbros are traversed by veins of granulite and pegmatite, and before reaching Gambos, between Cachanga and Cantiates, by an alkali-syenite containing albitised orthoclase (microperthite), zircon and an amphibole close to hastingsite. The same syenite is again met with more to the west near Pocollo. The gabbro continues to the south until Chabiqua. It is associated between Jucundja and Otjinjou with an alkali-granite containing orthoclase mottled by albite (microperthite), riebekite and ilmenite."

This account is based on rock specimens collected by others, and I could not locate on any map some of the sites mentioned by Souza. His petrographical descriptions are, however, in agreement with those from specimens collected by me at the Cunene.

Faber [29] investigated the anorthosite-gabbro complex between Chibia and Gambos. He mentions olivine-gabbro, granophyre, anorthosite and biotite-olivine-norite. He does not agree with Souza that the labradorite of the gabbro is saussuritised, nor that much calcite has been formed by the weathering of the felspar. Again describing the granophyre, Faber mentions that the quartz shows undulatory extinction and that needles of apparently secondary amphibole occur, which facts certainly show metamorphic influences.

The anorthosite-gabbro body crosses the Cunene upstream of the Montenegro Falls, the general trend of the frequent banding being N. 70° E. It was followed by the author for about 20 kilometres up the river, and extends south-westwards into the Kaokoveld for at least 10 kilometres.

The predominant rock along the Cunene is anorthosite of snow white to rosy colour. Gabbro forms only narrow bands on both sides of the anorthositic centre. Where the massive red granulites of the Muva-Ankole system have been broken up by the anorthosite group, acid types of syenitic and granitic character appear in two narrow strips parallel to the strike of these granulites, but diagonal to the anorthosite massif. The many "floating reefs" of red granulite included in the anorthosite body, and the direction of such granitic bands suggest that these acid kinds are hybrid rocks, originating through assimilation of the siliceous granulites by the anorthosite magma, the microscopic investigation showing that they should be grouped with the "mangerites" of Rosenbusch.[30] Like them they contain as the dominant felspar a microperthite, besides microline and oligoclase-andesine, also some orthoclase and microperthitic-microcline; quartz occurs in grains with irregular outlines and undulatory

[29] Faber, F. J.: *Loc. cit.*, p. 77.

[30] Rosenbusch, H.: "Mikroskopische Physiographie der Massigen Gesteine II." Bd. 1. Halfte 4. Auflage 1907, p. 358.

extinction. The femic minerals are mostly altered to chlorite often dotted with crystals of magnetite, but relics of fresher pyroxenite show that monoclinic as well as rhombic pyroxene is present, while some of the rhombic pyroxene displays the pleochroism of hypersthene. Grains of leucoxene represent weathered ilmenite; there are also large aggregates of crystals of magnetite. Two grains of orthite were observed in a rock slide from the mangerite 5 kilometres upstream of Montenegro Falls; they show no cleavage, but a pronounced pleochroism from dark brown to lighter brown and high interference colours.[31] Furthermore, a vivid green felspar (amazon stone) has been found in a pegmatitic dyke in the same mangerite occurrence, and in places abundant brown garnet.

The mangerites show the influence of dynamo-metamorphism, the quartz and some felspar being partly crushed and secondary minerals like chlorite, sericite, epidote and zoisite having been formed. The "granite alcaline" and "syenite alcaline," with their microperthite, as described by Souza, belong apparently to the mangerites also.

The anorthosites show fewer indications of crushing, though the felspars are commonly epidotised with the formation of fresh epidote and microcline. They are hypidiomorphic rocks of coarse grain consisting entirely of felspar, mostly labradorite, also bytownite, which seems to be more kaolinised than the labradorite. Narrow veins traverse the rocks filled with labradorite, and in one case with a colourless mineral with high interference colours and straight extinction—probably scapolite.

The gabbros are mostly of coarse grain, though fine-grained types also occur. The predominant felspar is labradorite; bytownite and anorthite are also abundant. Biotite occurs in small scales intergrown with the pyroxenes, as also does the scanty olivine. Monoclinic and rhombic pyroxenes occur in almost equal amounts. Large irregularly shaped areas of monoclinic pyroxene consist of diallage mostly intergrown with ilmenite; almost all rhombic pyroxene is hypersthene with pronounced pleochroism, only a few patches of enstatite and bronzite having been observed. The ore is magnetite in large grains and small crystals. Some of these gabbros or norites are quite fresh, others show signs of crushing and alteration. Mixed rocks of gneissose character occur along contacts with the granulites, amphibolites and phyllites of the Muva-Ankole system.

Two other bodies of igneous rocks within the area investigated probably belong to the same period of intrusion as the above. The one is a fairly large mass of pyroxenite or hornblendite in the upper Kahama Tal, north of Montenegro Falls; it consists mainly of green hornblende and diallage in equal amounts, with a smaller proportion of hypersthene and enstatite and olivine. The hornblende occurs

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[31] Rosenbusch, H.: *Loc. cit.*, p. 358 mentions the occurrence of orthite in acid types of this group from Norway.

partly in large plates with irregular outlines, partly in crystals; parallel strips of dusty inclusions characterise the hornblende. Pyroxenites and hornblendites are associated with most of the anorthosite-gabbro intrusions elsewhere, and the described pyroxenite is very similar to certain types of pyroxenites investigated by the author south of Luderitz in S.W.A., where they are also connected with gabbros, periodotites and hornblendites, and are attributable to the same period of intrusion as the Angola anorthosites.

An interesting gabbro or olivine-norite has been found by the author 17 kilometres east of the Cunene mouth. It is, however, very fresh, and may possibly be connected with the Mesozoic Karroo intrusions, as described later. On the other hand, its large hypersthene content suggests a closer connection with the anorthosite complex. The texture is ophitic, the spaces between the broad prisms of labradorite being occupied by pyroxene and olivine mainly; that is to say, by large diallages and fairly abundant hypersthenes, partly in irregular areas, partly enclosing the olivine poikilitically. Fine reaction rims are present, those around the olivine consisting of radial enstatite, those around the hypersthene of biotite, or else of enstatite and iron ores. The biotite is often intergrown with the other femic minerals.

Furthermore, all the partially altered basic rocks intruded into the gneiss and the beds of the Muva-Ankole system as dykes, sheets and bodies, can be attributed to the period of intrusion of the Konkip formation (Ventersdorp system of South Africa), *i.e.*, to the same period as the anorthosite-gabbro masses. They consist mostly of diabasic and dolerite types. It can even be assumed that they were directly connected with the anorthosite-gabbro magma and that they represent the hypabyssal facies thereof. Daly [32] regards the anorthosite sills of the Thunder Bay district, Ontario, as differentiations from a diabasic magma.

The rock of the large dyke of Otjissengo is a true diabase with ophitic structure without signs of crushing, but contains much sericitised labradorite and some oligoclase and partly uralitised diopside, secondary fibrous hornblende and ilmenite. The labradorite occurs in large phenocrysts and radially arranged aggregates of laths.

The features of the anorthosite-gabbro bodies of South-Western Angola conform well with the peculiarities to be observed in other anorthosite occurrences. The Angola rocks form a very large body, 200 kilometres long and 25 kilometres wide, covering 5,000 square kilometres, or nearly 2,000 square miles in extent, comparing well with the largest masses of Northern America and Scandinavia. Its age is pre-Cambrian, though seemingly younger than most of the latter (see Daly, *loc. cit.*, p. 322). A pseudo-stratification is developed in these Angola intrusions by mineral banding and by layers of acid or basic types. Masses of iron ores occur in the anorthosite-gabbro of Angola as elsewhere, and, furthermore, according to Souza, alkaline

[32] Daly, R. A.: "Igneous Rocks and Their Origin." 1st Ed., 1914, p. 325.

types are connected with it, though the writer did not come across any of the latter along the Cunene River east of the Montenegro Falls.

In one respect the Angola occurrence seems to differ in its southern portion from its normal habit, namely, in the way in which it breaks discordantly across the beds of the Muva-Ankole system almost at right angles, instead of running concordantly as in most of the laccolithic bodies elsewhere. (See Daly, *loc. cit.*, p. 328.)

VI. *The Konkip Formation.*

The Konkip formation has been described in South-West Africa [33] as consisting of three series of rocks, which are separated from each other and from the underlying and overlying formation by unconformities. The lower or Kunjas Series comprises conglomerates, clay slates and limestones, the middle or Sinclair Series is composed almost entirely of basic and acid rocks, and is correlated with the Ventersdorp system of South Africa, and the upper or Auborus Series represents terrestrial deposits of an arid climate with thick layers of conglomerates, red grits, red sandstones or quartzites and red shales.

The less metamorphosed green sericitic clay slates and sericitic grits of the Mountain Belt between the Cunene and Coroca have been correlated with the similar rocks of the Kunjas Series, and the anorthosite-gabbro-volcanics and the partly metamorphosed diabases, etc., intrusive into the gneiss and the Muva-Ankole system of this area, with the dominantly igneous Sinclair Series of S.W.A. and the Ventersdorp system.

In South-West Africa the conglomerates, red grits, quartzites, sandstones and shales of the Upper Konkip formation (Auborus Series) show no metamorphism and only a slight unconformity with the overlying Nama system, at the base of which a tillite is known to be present locally. It is highly probable, therefore, that the similar red grits, quartzites, sandstones, shales and conglomerates occurring in places between the schists below and the tillite above in the Tjamalindi Mountains, and as a fairly continuous band at the base of the Chella formation along the escarpment between Ondambo and Lubango, belong to the Upper Konkip. No beds ascribable to this formation have been found in the northern and western slopes of the Tjamalindi Mountains, where the tillite rests directly on gneiss. At Ovikambekambe a band of red shales a few metres thick is intercalated between the tillite and schists, while a few kilometers further to the south I found red grits and sandstones together with the red shales, the whole formation being not more than 10 metres thick.

East of the Otjitemi River, between Ondambo and Pediva, this formation is considerably thicker, *i.e.*, over 50 metres, and is interposed between the schists of the Muva-Ankole system and the basal breccias or conglomerates of the Chella formation. Here it is apparently conformable with the overlying Chella beds, but the

[33] Beetz, W.: "The Konkip Formation on the Borders of the Namib Desert, North of Aus." *Trans. Geol. Soc. of S.A.* XXV, 1933, pp. 23-40.

absence of these older beds elsewhere, their rapidly varying thickness and their covering of conglomerate or tillite in the Tjamalindi Mountains, would suggest that an unconformity really exists between them and the Chella formation.

The occurrence of the group in question along the escarpment has greatly puzzled previous investigators. Bebiano,[34] de Souza [35] and Scoutounoff [36] attributed the beds below and above the Chella conglomerate to two different formations, though the latter admitted that they seemed to be completely conformable. Faber [37] found no unconformities within the Chella formation as mentioned by Bebiano and Souza; he ascribed the often non-horizontal attitude of the beds to faulting, and came to the conclusion that all the strata covering the Planalto belonged to one—the Chella system.

No basal conglomerate of the Upper Konkip formation was observed by Scoutounoff or Faber. The author, however, found that the basal conglomerate of this formation is often missing, and is, when present (Ovipako and in the folded Chella formation north of Mucongo), only a few decimetres thick, consisting of small quartz pebbles with a grey or red sandy matrix, although grits at the base, or else overlying the conglomerate, and consisting of coarse grains of quartz and felspar in a slightly cemented matrix of red sand, gradually changing into coarse red sandstones towards the top, are occasionally 5 to 10 metres thick. The dominant strata are sandstones, quartzites and shales that are deep red and much softer and less consistent than the overlying beds of the Chella formation. Ripple marks and sun cracks are quite common on the bedding planes. This, together with their deep red colour and sandy to gritty character, indicates that they represent terrestrial deposits formed under an arid or desert climate just like the corresponding Auborus Series of South-West Africa. The disconformity between this group and the Chella formation, and the absence of metamorphism constitute additional evidence for their correlation with the Auborus Series.

It is interesting to note that Faber (*loc. cit.*, p. 75) observed dykes of quartz-porphyry cutting these beds south of Lubango.

VII. *The Chella Formation.*

This is mostly horizontal or only slightly tilted in the east, where it covers the Chella and Tunda plateaux, but is folded in the west. The transition from the table-like to the folded state is well developed in the western slopes of the Tjamalindi Mountains. Furthermore, the folded beds have been observed in several isolated occurrences north-

[34] Bebiano, J. B.: "Subsidios Para o Estudo Geologico e Mineiro da Provincia de Angola." *Boletim da Agencia Geral das Colonias.* Anv. II, Fevereiro de 1926, No. 8, Lisboa.

[35] Souza, Pereira de: "Contributions a l'Etude Petrographique du Sud-ouest d'Angola." *Comptes Rendus d'Academie des Sciences.* Tome. 162, pp. 692-694, Paris, 1916.

[36] Scoutounoff, G.: Report 8, 1931. Not published.

[37] Faber, F. J.: *Loc. cit.*, pp. 69-71.

east of Mossamedes. Faulting and monoclinal structures have also affected it on the Chella plateau.

That the Chella formation formerly extended farther west than the present escarpment is proved by large outliers of this formation on the top of certain table mountains (Maluco near Vila Ariaga, Tjamalindi Mountains) to the west of the escarpment, and by the large outliers of such folded strata north-east of Mossamedes. The main period of such denudation was not very remote, and probably coincided or started with the progressive uplift of the region since the Cretaceous, as all the old Tertiary rivers are crowded with boulders derived from the Chella formation. The faults and the monoclinal structure affecting this formation are to be connected with the upheaval of the escarpment. On the other hand, the folding of the Chella formation in a north-south direction towards the west is much older, and, like the coastal folded Nama of South-West Africa and further south, may belong either to the period of folding of the Cape ranges (early Triassic) or to one still earlier. The sheets of melaphyre occurring in the Chella formation were poured out previous to the folding, as they have shared in it.

These movements apparently preceded the breaking up of Gondwanaland, thus defining the line of subsequent separation, or as du Toit [38] puts it: "Gondwanaland had gradually become weakened by the development of certain trough-like features across it, that were bordered by belts in which the otherwise horizontal strata had been thrown into folds, and it was along these zones of wrinkling of the earth's crust that the separation of the several segments seems to have actually taken place."

The basal beds are formed by conglomerates or breccias, when the overlying beds are quartzites, or by tillite, which is then overlain either by quartzites (Ojona, Kambeno) or by phyllitic slates. The lateral change from quartzites to slates above the tillite has been observed in South-West Africa as well, and is connected apparently with the glacial activity which took place close to the coast line which existed during that period.[39]

The tillite has been found in Angola so far only at the base of the Chella formation in the Tjamalindi Mountains. Where folded in the western portion of these mountains (Ojona, Kambeno) it is highly sericitic and shows a schistosity, but is massive and compact where not so affected (Ovikambekambe, O'Nethu Valley and along the Cunene upstream of O'Nethu). It is 50 to 100 metres thick and shows all the peculiarities of corresponding glacial deposits known in South-West Africa and elsewhere. It consists of a shaly to sandy or even gritty matrix, through which inclusions of various rocks are

[38] du Toit, A. L.: "The Evolution of the S.A. Coast Line." *S.A. Geogr. Journal*, December, 1922, p. 2.

[39] Beetz, W.: "Ueber Glacialschichten an der Basis der Nama und Konkipformation in der Namib Suedwestafrikas." *Neu. Jahr. f. Min.* B.B. 56. Abt. B. pp. 437-481, 1926.

scattered without any definite arrangement. No stratification can be observed, and—seen from a distance—the massive unsheared rock looks like granite. The inclusions are either angular, sub-angular or rounded; they are of various sizes, boulders and blocks of over one metre across having been observed, whilst the smaller ones form a gradual transition to the finer grained or slaty matrix. The ratio of inclusions to matrix differs greatly, whilst in places larger boulders are only found at intervals of several metres, one finds in other places the rock to be packed to such a degree with angular or rounded inclusions as to give it the appearance of a breccia or conglomerate, in which case the matrix often becomes fairly coarse.

Scoutounoff observed the tillite horizon along the O'Nethu and Cunene valley, but did not recognise it as glacial, nor did he realise the identity of the corresponding rocks, where they are folded along the western slopes of the Tjamalindi, which he describes as gneiss. Nevertheless, his account of the undisturbed tillite of the O'Nethu valley is illuminating, and may be quoted as giving the viewpoint of an independent observer, who was not aware of the morainic nature of the material in question: "The gritty conglomerate crops out all along the O'Nethu River on both sides, to 5-6 kilometres from the Cunene to disappear beneath the red quartzites. It is a rock indicating an excessively rapid transgression. It is for the most part a breccia composed of inclusions of very unequal sizes. It is not rare to meet blocks of granite and diabase up to one cubic metre, together with little grains of coarse sand. The pebbles are of sandstone, granite, diabase, quartz; rounded ones are mixed with angular ones, the whole cemented by a coarse sandy material." [40]

The discovery of the tillite in Angola is an important link in the correlation of the older South and Central African formations. Very thick layers of tillite form the base of the Nama system in large areas of South-West Africa,[41] which the author has correlated with that at the base of the Serie Schisto-Calcaire of the Lower Congo and in the Kundelungu system of Katanga,[42] pointing out the probability that it would also be found in the Kaokoveld and in Angola. At the first meeting of the African Geological Surveys (South Equatorial Section) at Kigoma in 1931,[43] it was stated by Dr. J. Lombard that the "Katanga system, which includes the whole schisto-calcaire of the Congo basin, contains rocks that are most evidently of Transvaal-Nama age," and Dr. D. M. Davidson described the lower part of the Katanga system, which rests unconformably upon the Muva system, as exposed in Northern Rhodesia in the Lower and Upper Roan

[40] Scoutounoff, G.: Report 14, 1932. Not published.

[41] Beetz, W.: *Loc. cit.*, 1926.

[42] Beetz, W.: "Ueber das wahrscheinlich Altkambrische oder Jungproterozoische Alter der Glazialschichten an der Basis des Kundelungu Systems von Katanga und am Untern Kongo." *Neu. Jahr. f. Min.* BB. 61, Abt. 61, pp. 61-82, 1923

[43] *Proceedings First Meeting of Afric. Geo. Surveys* (S. Equa. Section), Kigoma, July, 1931.

Groups. The basal conglomerate (*i.e.*, tillite) of the Kundelungu Series had been traced into Northern Rhodesia, and was known to pass eastwards underneath the dolomites near Broken Hill. These dolomites must, therefore, be correlated with the Lower Kundelungu.

Traced along the Chella escarpment between Ondambo and Lubango the character of the basal beds changes considerably. In the south, between Ondambo and Otjissengo, basal breccias predominate, representing cemented debris consisting of fragments of the underlying schists in a matrix of red sand. Going north from Otjissengo the material becomes more and more rounded, and at Mount Herau, east of Pediva (confluence of the Otjitemi River with the Coroca), true conglomerates occur with well rounded pebbles of quartz and of different kinds of schists. These conglomerates are found all along the escarpment further to the north as far as Lubango, and have also been discovered in the folded beds north-east of Mossamedes. Overlying the basal beds are coarse quartzites and quartzitic grits, finer grained quartzites, and in places towards the north silicified limestones. The latter are often in layers broken up and recemented, thus representing intraformational brecciated silicified limestones, which shows that they were deposited in shallow water. In places the limestones of this horizon are only partly silicified, and in the folded belt north-east of Mossamedes still retain a high lime content. A similar calcareous horizon within the basal beds of the corresponding Nama system occurs also in South-West Africa along the coast, south of Luderitz, and has been described as the " Unterer Dolomit." [44]

The bulk of the Chella formation is formed by quartzites, red or grey sandstones, and indurated shales which overlie the basal beds. This division is about 150-200 metres thick in the Tjamalindi Mountains, and at least 400 metres, probably 600 metres, along the escarpment east of Mossamedes.

The highest beds of the Chella formation, as preserved in outliers from the Planalto de Mossamedes to the Tjamarindi Mountains near the Cunene, are limestones with chert bands. Faber [45] describes from Chivinguiro sandy limestone, marl, sandy dolomite and oolitic dolomite. The limestone of this horizon was burnt in a lime-kiln about 12 kilometres south-west of Humpata, but this has been abandoned apparently on account of the high silica (chert) content. Other lime-kilns met with in areas covered by this formation are using instead the Pleistocene calcareous tufa contained in some caves in the limestone formation, which often contains bones and teeth of zebras and antelopes.

In the upper portion of the quartzite horizon, or right between the limestone and quartzites, one often finds basic sills, the thickness of which increases towards the south where—east of Ovipaka—two sheets have been observed—separated by quartzites—with a combined

[44] Beetz, W.: Die Konkip und die Nama Formation; in E. Kaiser Die Diamantenwueste Suedwestafrikas," Berlin, 1926, p. 107.

[45] Faber, F. J.: *Loc. cit.*, p. 72.

thickness of from 50 to 100 metres. The upper one is a fresh ophitic olivine-free dolerite consisting of laths of felspar (labradorite), often filled with epidote and zoisite, and of pyroxenes. Monoclinic pyroxene (diopside) predominates, filling the interstices between the laths of felspar; some enstatite occurs with interpositions of ilmenite, while diallage has also been observed. Ilmenite in large irregular grains is mostly weathered to leucoxene.

The rock collected from the lower sheet is not so fresh, its pyroxene being partly uralitised. It is so rich in monoclinic pyroxene and poor in labradorite as to approach a pyroxenite. The scanty rhombic pyroxene and probably also diallage are disintegrated to such a degree that they can only be identified by their fibrous structure and the inter-positions of ilmenite. Small scales of biotite are present. The sheets often exhibit a columnar structure. They must be placed between the more altered basic rocks of the Konkip formation and the fresh Karroo dolerites. Faber (*loc. cit.*, p. 74) calls them dolerites, but did not investigate them under the microscope; he observed near Chivinguiro on the Planalto sheets as well as dykes cutting the quartzites of the Chella formation. Those basic intrusive sheets that have been folded in with the Chella formation are much more altered than those which are undisturbed.

It was pointed out that the thickness of the quartzites decreases towards the south, *i.e.*, away from the Lunda Axis. Across the Cunene there is a further decrease in thickness until in the southern Kaokoveld the dolomites with intercalated shales rest with marked unconformity almost directly upon the schists.[46] Furthermore, the thickness of the dolomites increases considerably towards the south, being as much as 3,000 metres in the Otavi Mountains of South-West Africa.[47]. A thickening of the dolomites towards the south is also reported from Katanga (Faber, *loc.cit.*, p. 93). These facts suggest that during the deposition of the Chella formation there existed a deep west-east geosyncline stretching from the Kaokoveld to Otavi and further to the east, but towards the north its floor rose in the direction of the Lunda ridge. A similar trough must have existed north of that axis, for the sandy sediments of the Bembe system in that region are gradually replaced by the argillaceous and calcareous deposits of the Serie Schisto-Calcaire of the Lower Congo. Therefore, the Lunda Axis must already have been in existence in pre-Chella times, that is to say, if the tillite be taken as the equivalent of the South Australian Sturtian tillite—in the late pre-Cambrian.[48]

[46] Kuntz, J.: "Die Geologischen Verhaeltnisse des Kaokofeldes." *Ztsch. d. D.G.G.* Bd. 64, No. 7, 1912, pp. 308-309.
[47] Schneiderhoehn, H.: "Abh. d. Senckenbergischen Naturforsch. Ges.", 1921, Bd. 37, H. 3 p. 220.
[48] Beetz, W.: "Ueber Glacialschichten an der Basis der Nama und Konkipformation in der Namib, S.W.A." *Neues Jahr. f. Min.* BB 56, Abt. B. 1926, p. 469.

Analogous is the thickening from 50 to 2,500 feet of the arenaceous Black Reef Series between the Witwatersrand and the Drakensbergen north of Pilgrims Rest, that is to say, towards the Rhodesian shield;[49] also can be mentioned the lateral passage from the calcareous argillaceous Nama beds into the arenaceous-argillaceous Zwartmodder beds with elimination of the limestone (Schwarzkalk) when traced towards the gneiss-granite shield stretching from Namaqualand to Gordonia, as observed by du Toit [50] between Holoog and Upington, south of the Kharas Mountains in South-West Africa.

My reasons for correlating the Chella formation with the Otavi and Nama of South-West Africa, the Serie Schisto-Calcaire of the Lower Congo and the Kundelungu system of Katanga can be summarised as follows:—

(1) The existence of the very thick basal tillite in the Tjamalindi Mountains. Thick layers of tillite have been found at the base of corresponding formations in South-West Africa, Katanga and the Lower Congo.
(2) The existence of the threefold grouping of conglomerates, quartzites and limestones in the Chella formation.
(3) The unconformity below the basal conglomerates or the tillite.
(4) The occurrence of folded Chella beds in the west.
(5) The unbroken belt made by this formation from the Tjamalindi Mountains through the Kaokoveld to Otavi.
(6) In Angola and in Katanga the facies in the Chella and the Kundulungu formation each changes from arenaceous to argillaceous-calcareous as it is traced southwards—away from the Lunda Axis and from the Kundelungu Plateau respectively.

VIII. *Karroo Intrusions and Cretaceous Volcanics.*

It has been explained that the Namib peneplain is abruptly bounded in the east by the great escarpment of the Planalto or the Mountain Belt, and that its western limit is set by a monocline which marks the former Cretaceous and Tertiary coast line. The original line of the escarpment—the present being due to backward erosion—can also be conceived as a monocline, so that the comparatively level Namib peneplain is bounded on both sides by monoclinal structures.

Along both monoclines occur younger fresh-looking intrusive and effusive rocks, connected apparently with the updoming of the escarpment and the bending down of the old coastal monoclines. These movements of the crust coincided with those that affected the whole of South Africa, and have been responsible for its present main surface features. It is known that that period of unrest started in the Triassic and continued right through the Cretaceous and Tertiary

[49] du Toit, A. L.: "Geology of South Africa," p. 85.
[50] du Toit, A. L.: "Geology of South Africa," pp. 118-119.

into the Pleistocene, and it is my opinion that there were correspondences in the volcanicity, starting with the outpouring of the Karroo lavas, continued by Cretaceous basalts and by intrusion of alkaline rocks and ultrabasic pipe rocks, and signalled to-day by thermal springs.[51]

It is not often that the exact age of the intrusion of such young volcanics can be made out, but the investigated area gives two clues thereon. Firstly, the volcanics of Chapeu Armado are intrusive into certain beds, which farther north have been recognised as being Cretaceous—Middle or Lower Albian—while certain basaltic lavas at Chapeu Armado overlie, and at San Nicolau are intercalated between fossiliferous beds of Senonian age.[52] Secondly, certain andesitic lavas east of Mossamedes underlie Eocene beds and have furnished pebbles to Eocene conglomerates, while similar lavas have been found to underlie Lower Cretaceous beds in the Loanda embayment, and can hence be regarded as Jurassic or as equivalents of the Karroo lavas of the Kaokoveld and Basutoland.[53] The association of young volcanics with the Cretaceous or Tertiary coast line has also been observed by Bebiano.

The dolerites are fresh looking rocks occurring in plugs and dykes, consisting of broad laths of felspar (labradorite and bytownite) —often darkened by magnetite dust like the felspars of the gabbros— the pyroxene is mostly monoclinic augite, but enstatite and hypersthene also occur quite frequently disintegrated to chlorite and sericite. Set in the pyroxene are a few irregular grains of olivine peculiarly darkened by magnetite dust, but otherwise quite fresh. Iron ore is abundant. The structure is ophitic.

It is interesting to note that Tyrrell[54] describes very similar rocks from west of Lepi along the Lobito railway as "coarse-grained ophitic olivine dolerite, consisting of a plexus of broad laths of labradorite in ophitic relations with irregular plates of brown augite. There is also some anhedral olivine, magnetite blackened," etc. "Their geological relations suggest that they are the youngest set of igneous rocks in the region." He furthermore describes "augitites" in connection with the dolerites.

I am inclined to ascribe them to a more remote epoch, *i.e.*, to the Karroo dolerites, although certain features, such as the rather high content of olivine, are not typical of the latter. However, the chlorite replacement of rhombic pyroxenes and the occasional bending or the fibres of the pyroxene point to a degree of alteration which has not been observed in certain, probably Cretaceous, ultrabasic and alkaline rocks.

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[51] Beetz, W.: Discussion on Dr. W. Gevers's paper: "The Hot Springs of Windhoek, S.W.A." *Proceedings Geol. Soc. S.A.*, for 1932, p. xl.

[52] Borges, V. Mouta et A.: "Sur le Cretace du Littoral de l'Angola." *Comptes Rendus XIVe Congres Geol. International*, 1926, p. 17.

[53] Bebiano, J. B.: *Loc. cit.*, p. 184.

[54] Tyrrell, G. W.: *Loc. cit.*, p. 558.

One of the plugs occurring not far from the Gariata River contains a fairly coarse olivine-norite with abundant olivine commonly enclosed by a shell of pyroxene, sometimes in poikilitic fashion; the pyroxene is either hypersthene or bronzite, but there may be some augite as well. A very little biotite is attached to iron ore. The felspar is labradorite in broad laths. The texture is allotriomorphic to hypidiomorphic.

The volcanics east and north-east of Mossamedes have been described as andesites and trachytes by Faber [55] and de Souza.[56] They are dark red brown or greyish-green porphyritic rocks, the felspar phenocrysts often weathered out, leaving cavities; in other places a true amygdaloidal structure occurs, the amygdales filled by calcite and chalcedony and at Catrona by heulandite as well, as described by Faber (*loc. cit.*, p. 29). It is interesting to note that Monteiro [57] has mentioned from this region "basalt, containing in places small quantities of doubly refracting calcspar and heulandite."

Under the microscope one sees in a fine-grained matrix phenocrysts of felspar consisting of plagioclase, sanidine and microcline; quartz is abundant, according to Faber, in needles and in veins, and probably not primary. Again the author observed quite abundant and apparently primary quartz in one of his rock slides; furthermore, in the matrix occur many laths or rectangular crystals of orthoclase with a shell of plagioclase and large prisms of apatite. Some iron ore and chloritic alterations occur.

The andesitic lava occurs in several flows, some of them fairly horizontal, others steeply inclined; red tuffs are connected with them near Vimpongos and Macala. Faber estimates the thickness of the lava flows at Posto Giraul to be at least 200 metres.

Of apparently younger age than the dolerites and andesites are the ultrabasic and alkaline intrusions between Tiger Bay and the Cunene mouth, and the basaltic rocks of Chapeu Armado.

The former, mainly ultrabasic, are confined to a narrow belt along the coast between the Cunene and Tiger Bay. The centre of these intrusions is situated on the coastal peneplain west and north of Morro Vermelho. A large intrusive body of six kilometres long and 2 kilometres wide, consisting mainly of dunite and pyroxenite, exists here. This plutonic mass is accompanied by numerous dykes of varied composition. Besides limburgites there occur syenite-porphyries, tinguaites and bostonites, while de Souza, examining specimens, recorded dunite and dykes of limburgite and monchiquite. He commented on the intime association of alkaline and calc-alkaline types, and suggested that the diamonds found more to the south near the coast may have come from ultrabasic rocks like those in South Africa.

[55] Faber, F. J.: *Loc. cit.*, p. 27-29.

[56] Souza, F. L. P. de: "Contributions a l'Etude Petrographique du Sud-ouest de l'Angola." *Comptes Rendus*. Tome. 162, pp. 692-694, Paris, 1916.

[57] Monteiro, J. J.: "Angola and River Congo." London, 1875, Vol. II, p. 220.

It is important to note that kimberlite dykes were actually found in the Kaokoveld south of the Cunene mouth as far back as 1910, and there is every reason for believing that they also occur with the ultra-basic dykes between Tiger Bay and the Cunene. Diamonds have actually been found in beaches of this area, and have probably been derived from such kimberlites. The diamonds recovered were, however, few and small, and no payable deposit has yet been located in even the highly concentrated beach shingles. The few grains of platinum found during prospecting in beach deposits west of Morro Vermelho have probably been derived from the underlying dunite, in which it must occur in such minute quantities as to be of no economic value. A more detailed description of the igneous rocks in question will be published later.

The basaltic rocks of Chapeu Armado occur both as a dyke forming the crest of the Chapeu Armado hill, and as extensive lava flows covering certain Cretaceous beds along the coast. Other basaltic dykes probably occur west of the Chapeu Armado hill, but are covered by sediments of the Miocene marine transgression, being present as derived pebbles in the Miocene beaches on the western slopes of the hill. Dykes are reported to occur further to the south, while Faber (*loc. cit.*, p. 30) discovered a small basalt pipe only a few metres across in granite in the valley of the Rio Piambo between Chapeu Armado and Mucongo.

The Chapeu Armado dykes are alkaline; the matrix being formed by nepheline packed with needles of greenish augite. The phenocrysts are mostly titanaugite, some large ones being beautifully fresh in the boulders occurring in the Miocene beach. Faber did not find any olivine, and, therefore, describes this basalt as a nephelinite, though the author found so many small olivine crystals in one of his rock slides as to indicate the existence of true nepheline-basalt as well.

Quite different petrologically are the lava flows, so that a connection between the Chapeu Armado dyke and lava flows is improbable. The lava is a normal olivine-basalt consisting of laths of felspar, mostly showing flow structure, and a few small crystals of augite, olivine and iron ore set in a ground mass of fresh, greyish-green glass. The texture is hyalopilitic.

Here again it seems that alkaline rocks occur side by side with calc-alkaline types like those south of Tiger Bay.

IX. *Cretaceous and Tertiary Formations.*

Only a short description of the sediments of the coastal formations and the problems connected therewith will be given; more details will be published later.

The coastal belt of marine Cretaceous, and further to the south, of Tertiary sediments is only 2 kilometres wide at Chapeu Armado, 32 kilometres at Mossamedes and over 50 kilometres at Porto Alexandre, south of which place the formation must end abruptly where the escarpment bends towards the west along the 16th Parallel. Thence, *i.e.*, from Tiger Bay to the Cunene, the marine Tertiary beds are represented as fossiliferous sandstone, marl and conglomerate filling holes in the gneiss peneplain below beach deposits, and occur, furthermore, as gravels in raised beaches standing at between 20 and 30 metres above sea-level.

Cretaceous beds occur only north and north-east of Mossamedes; the road from Mossamedes to Muquequete-Mucongo crosses certain white sandstones which are similar to those of the lowest Cretaceous at Chapeu Armado. The Miocene transgression has cut its way to the foot of these sandstone hills south of Muquequete.

Good sections through Cretaceous beds were investigated along the Damba Grande, *i.e.*, the dry river running down to the bay of Chapeu Armado. (Damba Grande must not be mistaken for Dombe Grande, a place 60-70 kilometres south of Benguella, whence Choffat described many Cretaceous fossils). Here the lowest Cretaceous beds seem to be unfossiliferous; they are dipping partly at angles of over 20 degrees towards the west, and show also a slight folding. They consist mostly of greyish-white loose sandstones with cross-bedding and irregular calcareous portions often extending down in veins into the underlying sandstone very much as a superficial limestone does; interbedded are lenses of coarse unstratified conglomerates and breccias, the inclusions being sometimes rounded, sometimes angular, but all of local origin. Of similar nature is the basal bed. All these strata may be of terrestrial origin. Overlying the basal bed is a thick layer of white dense limestone full of cavities and weathering with a black crust, so that from a distance it was mistaken by the author for a basalt. No fossils were found in this limestone. It may have been a bituminous variety like similar black limestones occurring farther north, for on a certain horizon occur greenish marls and clays with bituminous layers like those characterising certain sediments east of Loanda and between Loanda and Benguella, which have been described as Albian by Gregory and others.

Higher up in this series along the Damba Grande there is a fairly sudden change to vivid red argillaceous grits and sandstones with thin layers and veins of gypsum, also irregular lenses of coarse gravel derived from local rocks, many of the boulders being subangular.

No unconformity was observed between these red beds and the underlying white sandstones. Sediments of similar character, which are probably Turonian, have been described by Mouta and Borges [58] from the Benguella district as "groupe des gres et des calcaires oolithiques a Acteonella achietui et Nerinea Capelloi," but are separated by unconformities from the Albian and the Senonian.

Then follows unconformably at the Damba Grande a conglomerate which for the first time contains boulders derived from the Chella formation, showing that erosion had succeeded in cutting backwards into the interior plateau. The conglomerate passes gradually into a

[58] Mouta, V., and Borges, A.: "Sur le Cretace du Littoral de l'Angola." *Comptes Rendus XIVe Congres Geol. International*, 1926, Madrid, 1928, p. 15.

coarse fossiliferous, porous, red grit, which was probably calcareous originally, while this grit is overlain by a sheet of basalt, which is continuous for many miles along the coast, towards the south as well as towards the north. Similar beds have been described by Mouta[59] and Borges from San Nicolau, 25 kilometres farther to the north, as "Formation a Rondaireia Forbesiana et Rondaireia Drui" being Senonian in age.

While the earlier Cretaceous was characterised by upheaval during the Albian and Cenomanian, the later Cretaceous was marked out by folding and faulting in Angola just as in the coastal region of South Africa.[60]

Then followed, probably in the early Eocene, a marine transgression that cut across the westerly dipping Cretaceous and extended in the investigated area farther inland than any other Crestaceous or Tertiary marine invasion. It is just possible that Cretaceous beds exist between Mossamedes and Porto Alexandre, hidden beneath the thick covering of Eocene beds, which form the bulk of the coastal formation around Mossamedes, being in turn concealed by only a comparatively thin top layer of Miocene and younger marine sediments. Every river cuts through this Miocene top layer into the Eocene beds, which also appear along the cliff coast north and south of Mossamedes.

There was great river activity during the early Tertiary, probably because of upheaval and unstability, the resulting boulders being brought down to the sea and distributed along the shore in beaches and marine gravels. The mouth of one such river must have lain near the present canyon of the Giraul, 25 kilometres east of Mossamedes, where a gravel cone up to 200 metres thick occurs, and has been described as the "Politiepost-conglomeraat" by Faber (*loc. cit.*, p. 19). Extensive marine gravels up to 10 metres thick occur along the Coroca 50 kilometres east of Porto Alexandre. The highest Eocene marine beaches east of Mossamedes attain a height of about 250 metres, those east of Porto Alexandre of about 150 metres above sea-level, whereas certain, probably Eocene, sediments east of Chapeu Armado reach an altitude of over 300 metres. The bending of the surface near the coast along a north-south axis took place subsequently.

Eocene fossils have been described by Boehm[61] and Priem.[62] Boehm investigated those collected by Faber and found at Vimpongos, 25 kilometres east of Mossamedes: "*Cardita planicosta*" Lm. and "*Turritella (Haustator) imbricataria*" Lm. both represented in the Eocene of the Paris basin, while from limestones near Posta Giraul, he mentions a new species: "*Mactra (Stiphomactra) welwitschi*"

[59] Mouta, V., and Borges, A.: *Loc. cit.*, p. 16.

[60] du Toit, A. L.: "Geology of South Africa," p. 319.

[61] Boehm, Johannes: "Eocaene und Miocaene Versteinerungen aus Angola," D.G.G. 81, 9, 1929.

[62] Priem, F.: "Poissons Tertiaires des Possessions Afriquaines du Portugal." *Communicacaes da Servico Geol. de Portugal*, Bd. VII, pp. 74-79, Lisbon, 1907-1909.

n.sp. which resembles *Barymactra Dernburgi* from the Middle Eocene of Bogenfels, in South-West Africa. A rolled fragment of "*Nautilus*" —probably Eocene—is mentioned from the vicinity of Mossamedes, where many fossils occur, worn down to the state of pebbles through the destruction of the Eocene beds during the Miocene marine transgression.

Priem describes fish-teeth from between klm. 18·5 and 18·6 on the Mossamedes-Lubango railway line as: *Pristis; Odontaspis cuspidata; Odontaspis elegans; Lamna macrota; Otodus obliquus* and *Sphiraenodus*, all characterising the Eocene.

The Oligocene is not known in the area investigated. The next feature is another marine transgression at the beginning of the Miocene; this did not reach quite as far inland as that of Eocene times, and often shows a distinct parallelism to the present coast line, protruding farther inland where a bay exists to-day (Chapeu Armado, Mossamedes, Porto Alexandre). The monoclinal bending of the surface in a north-south direction between Chapeu Armado and Tiger Bay must already have taken place before the Miocene, as the main extent of this formation, reaching as much as 25 kilometres inland, is in the south, where the whole Medos area and the cliff coast from top to sea-level is formed by it; but at Mossamedes only the top layer of the cliff is Miocene, while at Chapeu Armado the Miocene only represents an enlarged bay reaching to the foot of the Chapeu Armado hill, the cliff being Cretaceous from bottom to top. The unconformity below the Miocene has been observed by the author at Chapeu Armadc as well as around Mossamedes.

Fossils from eight sites around Mossamedes were collected by an engineer Rego Lima [63] and investigated by Berkeley Cotter who considered them to be of Miocene age. Boehm [64] described oysters collected by Faber between Mossamedes and Catrona as *Crassostrea gingensis* (Schloth.) *Ostrea lamellosa* Brocchi var. *boblayi* Desh., which oysters are known from the Lower Miocene of the Vienna basin.

A subsequent rise of the coast line to about 40 metres above sea-level occurred during the Pleistocene period, resulting in the development of the coastal cliff from Porto Alexandre northwards, and in the erosion of river canyons in the emerging coastal strata.

Pleistocene and Tertiary, probably even Cretaceous, terrestrial deposits occur over extended areas on the Namib peneplain, but their exact age cannot be determined, as fossils have not yet been discovered in them. The gravel runs, and sandstones of this area, which reach a thickness of over 200 metres, were probably formed during periods of river activity and arid infilling that correspond with those laid down in Namaqualand and the South-Western Namib in the Cretaceous and Tertiary periods.

[63] Rego Lima, J. R., Berkeley Cotter, J. C. A., and de Souza, F. L. P. de: "Alguns Trechos do Relatorio do Engenheiro Rego Lima Sobre a Sua Missao as Minas de Cassinga 1898, Reunidos, Completadose Publicados Postumamente Pelo Capitao Pereira de Souza." *Revista de Engenheiria Militar* 16, pp. 289-291, 1911.

[64] Boehm, J.: *Loc. cit.*, p. 455.