The Geology of the Windhoek District in South-West Africa.

(Read 5th November, 1934.)

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(*With permissioin of the South-West African Administration.*)

[Plates X—XIV.]

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A.—Introduction.

In 1931 and 1932 the writer mapped the eastern portion of the Windhoek district, as well as portions of the adjoining districts of Okahandja and Rehoboth. Since the results of these investigations differ considerably from the early pioneer reports of Rimann, who, in 1910 and 1911 mapped the Rehoboth district (Bastardland) and the adjoining portion of the Windhoek district as far north as the southern slopes of the Auas Mountains, they are here presented in their essential features, accompanied by maps on the scale of 1:150,000.

By far the most interesting part of the Windhoek district is its southern portion: the mountainous tract to the south of Windhoek, extending from Lichtenstein and Oamites to beyond the Elephant's River. The rest of the district is almost entirely composed of monotonous biotite-schists, which towards the east disappear beneath the wind-blown sands of the Kalahari basin. Only the maps covering the southern, south-eastern and central parts of the district have therefore been chosen to accompany this paper.

On the whole, the area just referred to presents considerably greater difficuties in the unravelling of the structure of the Fundamental Complex than Western Damaraland, where a detailed stratigraphy has been established. This is partly due to the greater degree of tectonic disturbance in the central portion of South-West Africa (Windhoek and Rehoboth districts) and the constantly high, mostly vertical dips of all sediments south of the Auas Mountains. In addition, variation in petrological facies of several horizons of the Fundamental Complex further helps to complicate matters. The contemporaneous survey of the adjoining (western) portion of the Rehoboth district by W. P. de Kock, therefore, was a most fortunate and valuable circumstance (13).[1]

B.—Morphology.

The region actually mapped represents an area of approximately 4,000 square miles. Windhoek, the capital of South-West Africa, is

[1] The numbers in parenthesis refer to the Index of Literature at the end of this paper.

situated near its western margin. The main railway of the territory runs through the centre of the district in a north-south direction for a distance of about 75 miles.

The Windhoek district embraces the most highly elevated tract of South-West Africa. Windhoek itself lies at an altitude of 1,725 metres (5,320 feet), while the Moltkeblick, the highest peak of the Auas Range, rises to 2,485 metres (7,662 feet) above sea-level. It represents the highest point but one in the entire territory.

The highlands of the Windhoek district may be conveniently divided into three morphological entities:—

(*a*) *The Khomas Highlands.*—(| omas = Nama for mountains) and its eastern continuation: the *Windhoek Highlands.* These represent a highly dissected peneplain, which in the Windhoek area lies at a height of not quite 2,000 metres (±1,930 metres = 5,950 feet). In the west this peneplain is terminated by the Great Escarpment, there being a sheer drop of about 700 metres (2,158 feet) down to the coastal Namib. Also its north-western margin is marked by a drop in altitude down to the bed of the Swakop River, which here by active corrosion has caused the Great Escarpment to recede far back into the interior.

The Kuiseb River has cut into the heart of the Khomas Highlands from the west, making it one of the most highly dissected and inaccessible regions of the whole of South-West Africa.

In the east the Khomas Highlands are terminated by the Otjiseva and Windhoek valleys, which have been cut right across the highlands from the north by two headstreams of the Swakop River. They appear to be mainly due to normal erosion and do not represent a "graben," as formerly supposed (10). East of these valleys the peneplain of the Khomas Highlands is continued by the highly dissected and rugged Eros, Otjihavera and Ovitoto Mountains, which in turn are separated by the deep north-south valley of the main headstream of the Swakop River from the Otjizonjati Mountains, which continue the peneplain with a gradual easterly dip into the Kalahari basin and under the sand-covering of the latter.

The Khomas and Windhoek Highlands are built up almost entirely by a monotonous series of biotite-schists of tremendous thickness (*Khomas Series*). The age of the Khomas peneplain is later than the intrusions of alkali-rocks in the Windhoek-Rehoboth area. It is generally given as late-Cretaceous or early Tertiary and correlated with the Cape-peneplain.

(*b*) *The mountainous tract to the south of Windhoek.*—While the elevated peneplain of the Khomas Highlands proper is continued to the south across the Kuiseb River by a less highly dissected plateau-region, that gradually descends into the Rehoboth depression, to the south of Windhoek it is terminated by a series of very rugged mountain-ranges that rise above the general Khomas peneplain for heights varying between 400 and 600 metres (1,230-1,850 feet). The

summits of these mountain ranges are mostly situated between 2,200 and 2,485 metres, and appear to indicate the remnants of a former, now almost completely denuded peneplain, from which some of the highest peaks (Moltkeblick, 2,485; Grossherzog Friedrichberg, 2,380; and Ruschberg, 2,430 metres) may have projected as "Inselberge."

The most northerly of these ranges are the Auas Mountains immediately to the south of Windhoek. Beginning on the farms Lichtenstein and Bergeck in the region of the Ruschberg and Roonberg (±2,300 metres), the range first trends east-west, but soon turns into a north-south direction. On Regenstein it again turns into the predominant ENE-WSW direction, and continues past the Moltkeblick to Voigtland, where it abruptly terminates on account of the main quartzite-horizon pinching out. Another overlying quartzite-bed, however, a few miles further east again attains a great thickness in the conspicuous Bismarckberg (2,265 metres). The contours of this mountain on its southern and eastern foot appear to be determined by faulting.

While the Auas Mountains are built up by a zone of superimposed quartzite-lenses (Auas quartzites) intercalated in the main body of biotite-schists (Khomas Series), the mountain ranges further south are mainly composed of the main quartzite-horizon (Quartzite Series) at the base of the Damara System. To the latter belong the Billstein (2,250 metres) and Oamitesberg (2,144 metres), part of the Schwarzkopf Mountains (2,214 metres), the Orachab (2,165 metres), Hoher Schein (2,258 metres), Langbein (2,188 metres), and many others. The Schwarzkopf Mountain proper is built up by platy gneiss intrusive into the Damara System.

In the region around Aris and Leutwein, in the very centre of this mountainous tract, the young intrusions of phonolite and trachyte build up several very conspicuous mountains (Schildkrötenberg, 2,192 metres; Huguamis, 2,015 metres).

The most southerly range are the Nauas Mountains, cut by the Usib River at the spectacular Nauas Pforte. The southern limit of the massive Khomas block is tectonically very complicated and highly faulted. From Wortel eastwards there is a major line of faulting accompanied by many other faults to the north and south (see Maps Plates XI, XII, XIII). While the Nauas Mountains proper and their eastern continuation north of the Farm Wortel are built up by ancient Damara quartzites, a series of transverse faults causes younger Nama quartzites (Dordabis Series) to be brought into line with these ancient rocks. The Nama quartzites, bounded by a great fault on the north, continue the Nauas Mountain range to the east, building up the Hamib Mountains (2,009 metres), Kamtsas Mountains (2,010 metres) and the Grimmrücken near Dordabis. From here onwards the quartzite ridges gradually decrease in height, until they break up into low "Inselberge" rising out of the Kalahari sand, and finally disappear.

To the south and south-east of Dordabis there are numerous similar parallel ridges, composed of Nama quartzites and separated by wide plains deeply covered by wind-blown sand and devoid of outcrops. In the neighbourhood of Dordabis the Nama beds have been cut into narrow slices by a series of faults parallel to the major fault, along which the Nama beds abut against the older rocks. The tendency of these faults, supplemented by transverse faults, is a progressive lowering towards the SE.

A large number of rivers originate in this mountainous tract. Most of them extend through the southern ranges up to the southern slopes of the Auas Mountains: Usib, Wortel, Schaf and Elephant's Rivers. A noteworthy feature is, that all these rivers generally do not follow the contours of the present land surface, and do not flow around the numerous quartzite mountain ranges, but cut across them at right angles to their strike in a series of very impressive gorges. (Nauas-, Wortel-, Hamib- and Schafriver Pforte.) While these gorges generally occur on the site of minor transverse disturbances, it appears certain that the river system still existing to-day is a superimposed and antecedent one and must have originated on the old peneplain still indicated by the heights of the mountain ranges (±2,300 metre-peneplain) long before the formation of the Khomas (±1,900 metre-) peneplain, now being eroded.

This older peneplain is at least pre-Karroo in age. It appears probable, however, that it dates back to pre-Nama times, for de Kock now definitely refers the Gamsberg sediments, which lie undisturbed on this peneplain at a height of 2,300 metres on top of the Gamsberg, some 60 miles to the west, to the basal Nama beds (13).

(*c*) *The Kalahari Basin.*—It has already been stated that the Windhoek Highlands gradually decrease in altitude towards the east, until east of the Otjozonjati Mountains and the Bismarckberg, the ancient rocks composing them disappear under a mantle of wind-blown sand, the eastern margin of the great Kalahari basin. The plain, however, is not yet an absolute one, for a fair number of "Inselberge" are still found rising above it as far east as Omitara. In the south-east the low quartzite ridges of the Nama beds, which already in the Dordabis area are separated by extensive sand-covered plains, continue intermittently into the Gobabis region.

A striking feature resulting from the advance in former times of a thick mantle of wind-blown sand from the east and south-east is the disappearance of a considerable number of rivers of fair size. The White and Black Nossob Rivers, flowing due east from the Windhoek Highlands, keep their channel clear past Gobabis to a point far to the south-east, near the Bechuanaland border. The Seeis River, however, disappears practically completely on Okapanje, after a course of about 50 miles.

Most striking of all is the disappearance of the Elephant's River. Rising on the southern slopes of the Auas Mountains, at an altitude

of 1,950-2,000 metres, it continues as far as Koanus (±1,680 metres) as a well-marked erosion-channel cut into solid rock. From Koanus onwards, it enters the region covered by wind-blown sand, its gradient now is low and it widens out considerably, but still possesses a well-marked bed fringed with Acacia giraffae. On Otjimukona the actual river-bed is a wide, sandy, in part clayey depression, about 1½ Km. in width.

A few miles further south, behind a range of limestone-"inselberge," the river-bed has been more or less completely drowned by wind-blown sand and, when the river comes down in flood, millions of cubic metres of water disappear every year over a distance of a few kilometres. Until this year's excessive rainy season no appreciable quantity of water has been known to reach the Kleepforte—a deep gorge cut by the Elephant's River through two ranges of Nama quartzites (10 miles further south) before the advent of the sand dunes—within the memory of white men. Not only is this the case, but a borehole put down in the Kleepforte gorge in the very river-bed through 117 feet of sand and gravel, down to a depth of 579 feet, less than 15 miles away from where the water disappears, has remained bone dry. Probably the "Karst"—nature of the limestones crossed by the river near its point of disappearance is in part responsible for this extraordinary feature.

The Schaf, Usib and Rehoboth Rivers disappear, though not as abruptly, much further south. While it was formerly thought that the Schaf River drainage leads into the Fish River, it is now held that the Uriab River represents its continuation and that formerly it therefore drained into the Auob River.

C.—The Fundamental Complex.

Rimann, in his pioneer reports on the geology of Bastardland (1 and 2), divided the Fundamental Complex, called "Primary Formation" by him, into three groups. an upper *Marble Series*, a middle *Quartzite Series*, and a lower *Schist Series*. In addition, he separated a supposedly younger group of phyllites and quartzites from the Fundamental Complex under the term "Phyllite Formation." The investigations of the writer in the Windhoek district and of de Kock in the Western Rehoboth district, however, have shown that this classification is untenable.

It has been found that the Phyllite Formation does not really exist, except in the very complicated region around the Schaf River, in the Tsatsachas area, where a younger group of sediments has been proved to be interfolded with the Damara System. It comprises, however, also conglomerates and limestones in addition to phyllites and quartzites.

Further, it has been shown that the great bulk of schistose rocks form the upper division of the Fundamental Complex in this region, and that Rimann's lower Schist Series should be separated from

the Damara System as an older division. While a well-marked unconformity in actual contact is not to be seen except at a few isolated points, massive conglomerates have been found to occur at the base of the Quartzite Series, the pebbles of which, moreover, have to a large extent been derived from the underlying rocks. In addition, in the Hoheworte area, for instance, the members of this lower group, which comprise quartzites, graphitic schists and limestones, possess strikes different from those of the massive quartzites and limestones (Damara System) surrounding them.

The rocks in question therefore form one or more older groups, which may conveniently be grouped together under the term *Abbabis System*, the latter name being derived from Western Damaraland, where an older group of sedimentary and igneous rocks was found to underlie the Damara System uncomformably. In the western Rehoboth district de Kock separated two divisions: The *Duruchaus Series*, consisting mainly of schistose and quartzitic rocks with impure limestones, and the *Marienhof Quartzites*, intensely hard grey to greyish-blue fine-grained quartzites, frequently the main constituent of the pebbles in the basal conglomerates of the *Quartzite Series* and in the *Tillite Horizon* of the overlying Damara System (13 and 9). These rocks extend into the Windhoek district in the area of the Billstein, west of Bergland (Map Plate XI). Similar rocks were also found to occur in the Hoheworte area, where, however, they exhibit a greater petrological variety (*Hohewarte Series*).

The succession of sedimentary beds within the Fundamental Complex was therefore found to resemble closely that of Western Damaraland, already described by the present writer. Several differences, however, are met with, which will be dealt with in a later chapter.

In broad outline the succession is as follows:—

			Approx. thickness.
Damara System.	*Khomas Series*	Upper Schist group	±16,000 metres.
		Auas Quartzites	0 - ±7,000 metres.
		Lower Schist group	±7,000 - 8,000 metres.
	Marble Series with Tillite-Horizon		0 - ±2,000 metres.
	Quartzite Series with Basal Conglomerate		>500 - <3,000 metres.
	Unconformity.		

Abbabis System: Duruchaus (Hohewarte) Series; Marienhof Quartzites; Gauchab Series.

I. *Abbabis System.*

(*a*) *Duruchaus Series.*—Rocks belonging to this group extend from Duruchaus in the Rehoboth district into the south-western corner of the mapped area, where they are found along the southern slopes of the Billstein and Oamitesberg.

The predominant constituent rocks in this region are: Soft biotite-schists, biotite-amphibole-schists, light-coloured muscovite-sericite-

biotite-schists and phyllites, with which occur pale-reddish, fine-grained sericitic quartzites and narrow beds of impure limestones. In places a bed of soft, white talcose and sericitic marble is very characteristic.

These rocks are generally heavily invaded by gneisses and granites on an extensive scale. Mixed rocks are therefore very abundant. Their base has nowhere been identified and it is impossible to state the order of succession within the group.

(*b*) *Hohewarte Series.*—Similar rocks are found over a limited area around Hohewarte, 40 kilometres to the south-east of Windhoek, in the upper reaches of the Elephant's and Schaf Rivers, where, however, they exhibit a greater petrological variety. This region is a very complicated and highly disturbed one. Dips are predominantly vertical, or nearly so, and faulting appears to have taken place on an extensive scale. In addition, the rocks are surrounded on nearly all sides by contacts with intrusive gneissose granite. It has not been possible, therefore, to work out the succession of these beds in detail. It was also impossible to ascertain definitely to which group the quartzites building up several conspicuous hills south of the Bismarckberg should be assigned. Their contacts appear to be mostly faulted. They possess no outstanding petrological characteristics and may therefore be part of the Hohewarte Series, within which narrower bands of similar quartzites occur, or part of the very massive Damara quartzites, which are well developed in this area (Map Plate X). The nature of the southern and south-eastern boundary of these rocks, where they adjoin rocks of the Damara System, is also doubtful. It is likely that a strike-fault of considerable throw occurs in this region, but the position of some of the biotite-schists, amphibolites and biotite-quartzites, as well as talcose and actinolitic marbles, that occur below the basal Damara quartzites, remains somewhat uncertain. Most probably, however, they belong to the older group. On Brack, some ten miles further south, at only a single locality, however, similar rocks were seen to underlie Damara quartzites unconformably.

The rocks belonging to this group in the Hohewarte region include: Abundant grey graphitic schists and phyllites with intercalated narrow beds of coarse grey marble; impure cherty limestones and sericitic quartzites; widely distributed dark amphibolites and amphibole-schists with abundant layers of itabirite, including an iron-ore layer of high grade magnetite- and specularite-rock with intercalated highly ferruginous layers of amphibole-skarn (total thickness ±600 metres); contorted biotite-schists, often garnetiferous; lenses of reddish felspathic quartzite; a massive layer of tremolitic and actinolitic, highly altered limestone with veins of galena and chalcopyrite (thickness ±500 metres), narrower bands of talc- and calc-silicate rock (altered limestones) and a great variety of migmatites and mixed rocks.

The graphitic schists and phyllites present the same appearance as similar rocks in the Damara System and the very much later Bastard Series. Some types contain abundant sericite.

The total thickness of the individual bands of iron-ore is over 100 metres. They are exposed over a length of 4 Km. The admixture of quartz-grains is very variable, a large proportion being high grade iron-ores of Bessemer type.

(*c*) *Gauchab Series.*—Under this term are grouped together a series of rocks consisting mainly of massive talc and serpentine, as well as green, scaly chlorite-schists, dark amphibolites and amphibole-schists. They do not have a wide distribution and are found below the Damara Quartzites on Rietfontein, where they build up the massive pyramid of the Gauchab Mountain (2,186 metres) and several other minor hills in the surroundings of Onnams. In addition, talc and serpentine build up the Omieve and Owiwaju Mountains, two prominent "Inselberge" in the sand-covered area between the Black and White Nossob Rivers, north-east of Otjihaenena.

At the great Gauchab Mountain the talc occurs in three massive layers of a total thickness of 25 metres, separated by narrow layers of dark amphibolite and platy biotite-gneiss. It is mostly of the white variety, but pale-greenish types also occur, as well as spotted varieties, the spots being due to scales of chlorite. Occasionally plates of pennine, up to 5 cm. long, are quite common within the talc. Some cavernous varieties exhibit remnants of calcite in considerable abundance. Magnetite occurs in small octahedra, but is not common.

The chlorite-schists are rather different from the chloritic schists so common in the Damara System, which generally contain fair proportions of biotite and quartz and are invariably fine-grained. These rocks, on the other hand, are for the most part coarse aggregates of scaly chlorite of green colour, occasionally, *e.g.*, at the Owiwaju Mountain, showing numerous bronze-red spots. Everywhere the rock is full of crystals of magnetite. Some are crowded with small scales of silvery talc. Other varieties contain sphaerules consisting of radial scales of pennine. Clinozoisite is generally present.

The serpentine rocks are mostly dirty-green in colour with grey-violet patches. Occasionally narrow veinlets of the fibrous variety are seen in cross-fibre form. Nearly everywhere the rock is studded with bright metallic grains of magnetite, sometimes with a diameter of over 1 cm. Chemical tests show the magnetite to possess a considerable content of chromium, and under the microscope the grains of magnetite occasionally exhibit a core or outer margin of chromite. The rock weathers with the production of a dirty-yellow cavernous crust, and at the Owiwaju Mountain it is veined by innumerable intersecting stringers of opal.

At the Gauchab Mountain the serpentine rocks attain a preserved thickness of ±250 metres. Their association with hornblendites suggests their derivation from ancient basic intrusions older than the gneisses and granites of this region.

II. *Pre-Damara Gneiss and Granite.*

In Western Damaraland the sedimentary and volcanic components of the Abbabis System have been invaded by a great profusion of pre-Damara gneisses and gneissose granites. Among the latter a plagioclase-granite is very conspicuous. In the Windhoek district no rocks of similar age have been found *in situ*. That pre-Damara gneisses and granites, however, must have existed also in this region, is shown by the presence of pebbles of reddish, only slightly gneissose granite, in part porphyritic, and reddish pegmatite in the basal conglomerate of the Damara quartzites and in the tillite-horizon. They are nowhere very abundant, however, the bulk of the pebbles being derived from the Marienhof quartzites, now outcropping 40-50 miles to the south-west in the western Rehoboth district.

III. *Damara System.*

Rocks belonging to this system by far predominate not only in the Windhoek district, but in the whole of Central South-West Africa. Together with the old granites intruded into them they make up more than 95 per cent. of the rock-floor of what formerly was known as Damaraland.

The total thickness of the components of the Damara System must be an enormous one. On a conservative estimate it must be in the neighbourhood of about 30,000 metres in the Windhoek district. It is interesting to note that similar enormous thicknesses have been reported for ancient archaean sedimentary systems from other parts of the earth, *e.g.*, for the Grenville Series of North America.

(*a*) *Quartzite Series.*—As in Western Damaraland (7, 8) the base of the system is formed by a massive quartzite-horizon, referred to as the *Quartzite Series*, which at numerous places includes a well-developed basal conglomerate. At the Billstein and Wolfberg, west of Bergland (Map Plate XI), the latter, together with conglomeratic arkoses, possesses a thickness of several hundred metres. The rocks in question are here light in colour and highly sheared and sericitic. Towards the Oamitesberg these basal conglomerates decrease in thickness and are overlain by a thick lens of reddish felspathic quartzites, which here and there contain pebbly layers.

Owing to a thick mantle of scree-deposits the junction of the conglomerates with the underlying Duruchaus beds is nowhere exposed. In this area the quartzite horizon includes thick (up to 1,000 metres) intercalations of highly garnetiferous quartz-muscovite-schists and sericitic quartz-phyllites.

Excellent exposures of the basal conglomerate also occur in the Schwarzkopf Mountains, where they attain a thickness of 40 metres. The pebbles are closely packed and consist mainly of quartz and greyish quartzite (Marienhof). In addition, pebbles of reddish gneiss, reddish, slightly gneissose, porphyritic granite and reddish pegmatite are to be found. Fragments of dark biotite- and amphibole-schists from the underlying Duruchaus beds are also met with. The conglomerates are overlain by reddish, highly felspathic cavernous quartzites.

At the Hoher Schein and Langbein Mountain, in the neighbourhood of Rietfontein, the lower quartzites are reddish, rich in felspar and well bedded. The grain is generally fine, but narrow coarse and conglomeratic layers also occur. Knots (biotite and magnetite) in the rock are common. The quartzites are here underlain by the large granite-mass of Rietfontein with an intrusive contact.

The upper portion of the Quartzite Series, which in this region has a total thickness of about 3,000 metres, exhibits very different features. It is platy and flaggy, in some layers almost laminated, of white colour, very fine-grained, less felspathic, but rich in sericite.

In the mountains west of the Poort, through which the road to Dordabis passes, just south of the Schaf River on Brack (Map Plate XII), conglomerates are again well developed. They are here underlain by a thickness of 40-50 metres of reddish felspathic quartzites, dipping 25° to the south. These quartzites are in turn directly underlain by dark amphibole- and biotite-schists, veined by pegmatites and dipping 50-60 to the south. These features strongly suggest an unconformity at this point, there being no indications of thrust-movements.

On Hohenau, north of the Humansberg, this massive quartzite-horizon appears to pinch out completely. Another quartzite-lens is here developed in a slightly higher horizon, but soon disappears under wind-blown sand east of the Elephant's River.

Where there are continuous exposures from the Quartzite to the overlying Marble Series, as in the Billstein-Oamites area, there is generally a transition zone, in which fine-grained sericitic quartzites alternate with in part very quartzose biotite- and amphibole-schists. In this region lenses of fine-grained sericitic quartzites are to be found right through the Marble Series as high up as the basal schists of the Khomas Series.

It has already been stated that the Quartzite Series builds up most of the high mountains in the area to the south of Windhoek.

(*b*) *Marble Series.*—In the interior highlands of the Windhoek, Rehoboth and Okahandja districts the Marble Series is not nearly as strongly developed as in Western Damaraland, *e.g.*, in the Karibib and Omaruru districts. In the latter regions it builds up high mountain ranges, and as a morphological factor frequently eclipses

the Quartzite Series. But also in this latter area great variations in thickness and number of individual marble bands are common, and the latter in several places are absent altogether.

In the Windhoek district the Marble Series is particularly feebly developed in the south-western area, north of the Billstein and Oamitesberg. Here the main marble layer is represented by a lens of talcose, altered limestone intercalated between biotite- and amphibole-schists and amphibolites. Its maximum thickness is about 120 meters. It pinches out in the west and is cut off by a fault in the east. Near Kamtsoas it contains insignificant deposits of Cu- and Pb-ores. Above this layer several more lenses of less altered crystalline limestone, together with lenses of sericitic quartzites, are found intercalated throughout a thickness of about 2,000 metres of biotite- and amphibole-schists and para-amphibolites. One of these marble bands attains a thickness of 150 metres.

Near Bergland limestones are already more conspicuous, but highly disturbed and folded in an intricate way. They here also include talcose, highly metamorphic rocks, but the bulk are bluish-grey in colour, rather fine-grained and less altered, though needles of tremolite and actinolite, as well as porphyroblasts of talc and chlorite are very common. In places the limestones are very siliceous and cherty. The horizon here also comprises dark graphitic schists and phyllites, as well as brownish fine-grained quartzites, frequently exhibiting numerous small cubes of limonite pseudomorph after pyrite. North-east of Aub the limestones include a fine-grained black variety.

While at Bergland the carbonate-rocks preponderate over the interbedded graphitic schists and phyllites, only a few kilometres further east, in the area of Nabitsaus, they entirely recede against the latter, pebbly biotite-schists and metamorphosed marls, which here represent the tillite-horizon. The graphitic rocks are frequently full of grains of limonite pseudomorphs after pyrite, and were evidently deposited under stagnant conditions.

This feature, *i.e.*, the almost complete passage of the marble-horizon into a graphitic facies greatly complicates the stratigraphic orientation and great care has to be exercised in deductions based on single isolated traverses.

De Kock has found very similar conditions in the adjoining Rehoboth district. In this connection it is of interest to note, that also the limestones of the Marble Series in Western Damaraland and the Omaruru and Otjiwarongo districts contain graphite disseminated in the form of small flakes or larger masses.

The predominantly graphitic facies continues eastwards as far as the Schaf River, from where onwards limestones again undergo a stronger development. Between this river and the Elephant's River on Koanus, Hohenau and Waldburg coarse bluish-grey and white

marbles, so common in Western Damaraland, are again much in evidence, and on Koanus form a band 1-1½ kilometre wide. The actual thickness, however, is here at least duplicated by folding.

The fairly massive limestone-band near Wortel, faulted down against the quartzites of the Nauas Range, contains cherty layers, which under the microscope occasionally exhibit ovoid structures suggestive of silicified oolites.

Of special interest is the development of the Marble Series along the Schaf River on Elisenhöhe, Stolzenfeld and Tsatsachas. The intercalated limestones frequently present a very youthful, only slightly altered appearance, but highly metamorphic biotite- and amphibole-schists, as well as para-amphibolites occur interbedded with them. The following section from the base upwards is here exposed:—

Quartzite Series: Reddish quartzites of the Elisenhöhe Mountain.

Marble Series: Two narrow bands of marble, the lower one somewhat talcose, separated by layers of graphitic phyllites and reddish fine-grained quartzites.
- Green amphibole-schists and dark biotite-schists of great thickness.
- Iron-ore horizon with amphibole-skarn.
- Biotite- and graphite-schists.
- Reddish-brown fine-grained quartzite.
- Graphitic phyllites and biotite-schists.
- Massive band of mainly bluish-grey, but also reddish crystalline limestone with small needles of actinolite.
- Biotite- and sericite-schists.
- Pebbly phyllitic quartzites.

Further south, around Koas and Hatsamas, conditions become very complicated, due to tectonic disturbances, universal high dips and the interfolding of a younger post-granite group of rocks (Bastard Series), also comprising quartzites, conglomerates, graphitic phyllites and apparently also limestones. It was found impossible to assign some of the rocks of this region to their stratigraphic horizon with any degree of certainty, and a final settlement of the stratigraphy of this locality is not claimed.

Itabirite.—Of special importance are extensive deposits of iron ores in this horizon on Elisenhöhe and Tsatsachas, a few miles west of the Schaf River.

They attain their greatest thickness on Tsatsachas, where two layers separated by a distance of 800-1,000 metres are to be found. The lower horizon is exposed over a distance of 2 kilometres, when it disappears under a covering of sand. It consists of a large number of bands of itabirite varying in thickness from a few metres to 45 metres, and separated by highly ferruginous amphibole- (Hornblende-) skarn and subordinate biotite-schists. The dip of the rocks is

high, varying from 60° to vertical. It is mostly directed to the north-east. The total thickness of all bands of high-grade iron ore is about 100-110 metres.

The upper horizon is similar, but does not appear to be quite as thick. It continues from Tsatsachas into Elisenhöhe over a distance of 7 kilometres. It gradually decreases in thickness in this direction, and near the Schaf River on Elisenhöhe is only a few metres wide.

The iron ore is mostly platy, but only a part is banded and in the nature of typical itabirite. The banded varieties, consisting of almost pure layers of magnetite or specularite and less high-grade layers containing a varying admixture of quartz grains, are frequently contorted. Very frequently the entire plates consist almost exclusively of iron oxide.

Two varieties of ore are to be distinguished: (1) A high-grade ore exhibiting a dull surface on new fractures and composed predominantly, frequently almost exclusively, of magnetite; (2) generally also high-grade ore possessing a bright lustre and containing numerous scales of specularite in addition to magnetite, or the former almost alone.

Analyses of specimens of both types gave the following results:—

	(1)	(2)
$Fe_2O_3 + FeO$	78·54%	86·98%
Fe	54·93%	60·83%
SiO_2	20·92%	12·61%
MnO	0·0%	0·0%
P_2O_5	0·0%	0·0%

The ores are therefore of Bessemer type, poor in phosphorus.

(*c*) *Tillite Horizon.*—In Western Damaraland, along the north-western margin of the great Khomas syncline, the Chuos Tillite occupies a definite horizon between the Quartzite Series and the overlying Marble Series, but the occurrence of a great thickness of varved rocks at the Larger Heinrich, right through the very attenuated Marble Horizon into the lower portion of the Khomas Schists, shows that glacial conditions in other regions continued for a considerable period. The tillite-horizon in Western Damaraland, moreover, is marked by well-developed rocks of morainic nature of very variable thickness and, in a number of places, by varved rocks overlying them (8).

In the Windhoek and Rehoboth districts, on the other hand, the tillite-horizon is indicated in the main by pebbly phyllites, limestones and altered marls forming part of the Marble Series, and also by banded pebbly biotite-schists immediately overlying the latter and belonging to the lowest horizon of the Khomas Series.

The pebbles are erratic in distribution and size, and to a large extent facetted in typical fashion. They are very abundant in many

localities and distributed over a wide area in the Windhoek and Rehoboth districts along the southern margin of the Khomas syncline.

The features presented by the tillite-horizon in this region have already been described by W. de Kock and the writer in a paper: "The Chuos Tillite in the Rehoboth and Windhoek Districts, S.W.A. (*Trans. Geol. Soc. S.A.*, Vol. 35, 1932), to which the reader is referred (9).

(*d*) *Khomas Series.*—This series comprises the great bulk of the schistose rocks of the Damara System and makes up by far the greatest portion of the latter. Its total thickness must approximate 25,000 metres.

In Western Damaraland its full thickness is seldom preserved, and the Khomas Series there consists of an endless succession of mainly biotite-schists with intercalated biotite-quartzites and a few marble bands.

In the Windhoek district there occurs another well-developed quartzite-horizon (*Auas Quartzites*) in the lower portion of this schist-series, dividing it into a *lower* and *upper schist-group* separated by the *Auas Quartzites*.

1. *Lower Schist-group.*

This group can best be studied in the area north of the Oamites Mountain and the Billstein, on the farms Oamites, Krumneck, Lichtenstein and Haigamas. It consists essentially of generally garnetiferous biotite- and biotite-muscovite-schists, frequently quartzose, and grading into biotite-quartzites. In their lower portion lenses of reddish, fine-grained sericitic quartzite and greyish marble are not infrequent. The tillite-horizon extends into this group in the form of pebbly, banded and frequently contorted biotite-schists, which in places grade into pebbly biotite-sandstones.

In the upper portion of this group several narrow lenses of marble are to be found, *e.g.*, at Goas, on Lichtenstein, and near Leutwein Station, where a single band of marble obtains a thickness of 10 metres.

In the area between Krumneck and Leutwein, and in the surroundings of the gneiss-massif to south of the Auas Mountains, the schistose rocks of this group have been felspathised to a considerable extent and often grade into injection-gneisses. The felspar is mainly orthoclase and microcline.

In the uppermost portion of this group, below the first Auas quartzite (Ruschberg quartzite) there is a great development of dark greenish-black amphibolites and amphibole-schists, associated with which occur garnet-biotite-muscovite-chlorite-schists, as well as graphite-schists.

2. *Auas Quartzites.*

This quartzite-horizon consists of a number of lenses of fine-grained, sericitic, non-conglomeratic quartzite of white, yellowish or

grey colour when fresh. Deep red tints are not met with. The felspar-content is generally low and often practically absent. The quartzites are well bedded and often flaggy. They are separated by schistose rocks, in which, contrary to the rest of the Khomas Series, biotite-schists are not conspicuous and strongly recede against amphibolites, amphibole- and garnet-schists, as well as graphitic schists and phyllites. Intercalated with these schistose rocks occur mostly narrow bands of crystalline limestone in several horizons and one zone of itabirite.

The following combined section through the Auas Mountains, from south to north, illustrates the composition of this horizon:—

Approx. Thickness in Metres.		
±7,000–8,000	...	*Lower Khomas Schists.*—Biotite-schists, amphibolites, amphibole-garnet-schists and graphite-schists, with one or more narrow lenses of fine-grained quartzite and limestone.
0–1,000	...	*Ruschberg Quartzite.* — Fine-grained sericitic quartzite.
300–400	...	Dark para-amphibolites and amphibole-schists with subordinate biotite-schists, in the west with one marble-band (thickness, 25-30 metres), in the east (Voigtland) with two marble-bands (thickness, 25 and 80 metres).
0–1,800	...	*Moltkeblick Quartzite.*
23	...	Amphibolites, amphibole-, graphite- and biotite-schists with narrow lenses of quartzite.
3–4	...	Itabirite (Magnetite and Specularite).
20	...	Amphibole-, graphite- and biotite-schists.
2	...	Reddish and yellowish, ferruginous and cherty limestone.
3	...	Amphibole-, graphite- and biotite-schists.
2–3	...	Yellowish-white crystalline limestone.
8–10	...	Amphibole-, graphite- and biotite-schists.
4–5	...	Greyish-blue crystalline limestone with chert.
0–400	...	*Grossherzog Friedrichberg Quartzite.*
600	...	Para-amphibolites, amphibole-, graphite- and biotite-schists.
1½–2	...	Yellowish crystalline limestone.

3–4	...	Para-amphibolites with two narrow bands of limestone.
250–300	...	Dark para-amphibolites and amphibole-schists with small lenses of sericitic quartzite and intrusive sills of black ortho-amphibolite.
1½–2	...	Dark black crystalline limestone.
400	...	Amphibole-schists, etc., with lenses of quartzite.
40	...	Intrusive sill of coarse ortho-amphibolite.
300	...	Quartzitic muscovite-schists, quartzose biotite-schists, etc., with lenses of sericitic quartzite.
150–200	...	*Aredaragas Quartzite.*

Upper Khomas Schists.

2,000	...	Mainly garnetiferous biotite- and biotite-muscovite schists with six major lenses of quartzite from 10-50 metres thick and a few very narrow bands (0-0·3 metres) of limestone.
14,000	...	Main body of Khomas Schists, mainly garnetiferous biotite-schists and biotite-quartzites.

From the Moltkeblick quartzites upwards the above section refers to thicknesses observed between the Moltkeblick and Klein Windhoek. Towards the east, on Voigtland and at the Bismarckberg, several of the marble-bands swell out to considerably greater thickness (80 metres).

The thickness of the four main quartzite-layers, named after prominent mountains built up by them, varies within wide limits. They are all in the nature of lenses. Beginning in the west, north of the Hakos Mountains near the Kuiseb River, the Auas quartzite-horizon is at first inconspicuous, but traceable as a low escarpment as far as Lichtenstein, where several superimposed quartzite-lenses swell out to great thickness to form the beginning of the Auas Mountains. From here onwards they alternate in morphological importance, now the one forming the highest peaks, now the other.

On Voigtland, for instance, the Moltkeblick quartzite pinches out completely over a few miles, while in its stead the next higher horizon, the Grossherzog Friedrichberg Quartzite, after having been inconspicuous from the Auas Pass eastwards, rapidly swells out to great thickness, building up the Bismarckberg. From here eastwards all four horizons gradually dwindle away again and are finally lost altogether.

Above the uppermost main quartzite-lens (Aredaragas) the quartzites still persist in the form of irregular lenses, forming well-marked ridges as far north as Klein Windhoek, through a thickness of approximately 2,000 metres.

3. *Upper Schist Group.*

The lower portion of this group has already been described in the preceding section. With the exception of the quartzite lenses near its base, it consists of an endless succession of mostly garnetiferous and quartzose biotite-schists, which are traversed by innumerable narrow quartz-veins. North of Windhoek the schists in many layers become progressively more quartzose and frequently grade into weather-resisting biotite-quartzites, which build up the rugged Eros and Otjihavera Mountains. They persist as far north as the contact with the large granite-massif of Hereroland near Okahandja. In the marginal portion they frequently grade into staurolite-schists.

To the west these schistose rocks continue through the Khomas Highlands, which they build up exclusively, to beyond the great escarpment and far into the Namib Desert.

In addition to the predominating garnetiferous biotite- and biotite-muscovite-chlorite-schists and biotite-quartzites, this group includes generally very subordinate intercalations of muscovite-, sericite-, chlorite-, amphibole-, amphibole-biotite-, graphite-, staurolite-garnet- and cyanite-schists. Para-amphibolites are common in the neighbourhood of the marble-bands in the lowest portion of this group.

IV. *Post-Damara, Pre-Bastard Eruptive Rocks.*

In contrast to most other regions of Central South-West Africa, intrusive rocks do not take up large areas of the Windhoek District. Only the gneiss-Massif south of the Auas Mountains and the granite body between the White Nossob and the Seeis River in the east possess appreciable dimensions.

In addition to granitic rocks, small lens-shaped bodies of ortho-amphibolite exhibit a fair distribution.

(*a*) *Ortho-amphibolite.*—Reuning on his map of Central South-West Africa indicates a continuous layer of amphibolite in the Khomas schists extending from the Gorob Mine in the Namib Desert as far east as Windhoek. This horizon, however, can be followed still further east as far as Otjihase and Ongeama. It consists of numerous lenticular bodies of amphibolite occurring intermittently in more or less the same line of strike over a width of 3-4 kilometres. A few miles west of Windhoek, along the Hochfels Road, one such lens attains a thickness of 40 metres. The dip and strike generally coincides with that of the intruded schists. Associated with these rocks there occurs on the ridge just south of the Windhoek sewerage farm a porous, reddish-weathering chlorite-serpentine-rock, utilised by the municipality as road material.

Also in the Auas Mountains, particularly in the surroundings of the Auas Pass, several lenticular intrusions of amphibolitic rocks are to be found. They are also very common as xenoliths in the gneiss-massif south of the Auas Mountains. They are thus older than the gneiss and granite of post-Damara age.

Petrologically the rocks represent *hornblendites* with a varying admixture of basic plagioclase and quartz in some specimens. Apatite and titanite are found as accessories. In some varieties zoisite, epidote and serpentine are to be found in fair quantity. Frequently part of the hornblende is changed to pennine.

At least part of the rocks probably represent ancient saussuritised and uralitised gabbro or coarse-grained diabase.

(*b*) *The Gneiss-Massif South of the Auas Mountains* is approximately 50 kilometres long and 25 kilometres wide. It consists predominantly of platy *biotite-gneiss and biotite-muscovite-gneiss.*

In the eastern portion of the massif on Voigtland, Hohewarte Waldburg, etc., the most common rock is a light-grey biotite-gneiss, the foliation of which is not always very marked. In composition it resembles the granite along the banks of the Seeis River further east and probably represents a somewhat more highly stressed body of the same magma. Its main constituents are microcline, orthoclase and quartz. Biotite is always present, but not always in quantity. Muscovite is generally also seen and sometimes preponderates over biotite. Augen of coarse microline, surrounded by a kataclastic aggregate of microcline, orthoclase and quartz, are common and probably represent deformed phenocrysts.

The massif is crowded with xenoliths of amphibolite and biotite-schist and the greater part of the rock, particularly in its western and marginal portions, really represents migmatites and injection-gneisses. It has already been stated, that the enveloping schists have to a large extent been felspathised to a considerable degree, and at the margin there is generally a gradual passage from the former to the latter with no sharp boundary. These mixed gneisses, most typically developed in the western portion of the massif, are generally very platy and highly foliated.

Plagioclose is quite subordinate in these rocks, but microperthite more common.

In the marginal portions of the massif and particularly well developed on Voigtland and Paulinenhof a rock composed almost entirely of muscovite is widely distributed. It probably represents a metamorphosed muscovite-greisen. In accordance therewith and the frequent albitisation of the felspar in greisenised pegmatite or granite, the felspar in this rock frequently shows a preponderance of albite over potash-felspars.

The foliation of the gneiss coincides with the tectonic structure of the enveloping sediments or large xenoliths of the latter.

Within this platy, grey biotite- and biotite-muscovite-gneiss there is to be found at several localities a reddish gneiss, frequently porphyritic and always coarser in grain. It evidently represents a later phase of the intrusive cycle. The rock is markedly gneissose and the original phenocrysts have been deformed into " Augen."

The rock suggests a deformed phase of the widely distributed

Kobus or Salem granite. Very frequent in this reddish gneiss are aplitic varieties containing lenses of coarse orthoclase, quartz and microperthite in a fine-grained kataclastic matrix of the same minerals.

The summit of the Krantzneus Mountain near Gocheganas is built up by a platy, reddish muscovite-gneiss.

On Aris, Waldeck and Gocheganas the grey biotite-gneiss is traversed by numerous large bodies of reddish pegmatite, which weather out of the softer gneiss to form conspicuous hills and wall-like ridges. They are very coarse-grained and rich in muscovite. Their strike and dip generally conforms to the foliation of the gneiss and the corresponding tectonic directions of the enveloping sedimentary frame.

The same type of pegmatite is found to vein also the porphyritic granite on Rietfontein. These pegmatities are no doubt associated with the closing phases of the cycle of intrusion.

In the region of the Usib River, around Aub and Kudis to the south of this massif, there are numerous large bodies of white pegmatitic quartz, which probably belong to the same period of igneous activity.

(*c*) *The Granite-Massif Between the White Nossob and Seeis River.*—This body of granite is lens-shaped and phacolithic in nature, all parallel textures conforming to the structural features of the enveloping schists. Its length is 38-40 kilometres, its maximum width 18 kilometres.

The rock consists of a very uniform, light-greyish *biotite-muscovite granite* of medium to fine-grain. The texture is generally uniformly granoblastic, occasionally slightly porphyritic with small felspar-insets. It is veined by numerous pegmatites composed of white or reddish felspar, quartz, abundant muscovite and common red garnet. The felspar of the granite is orthoclase, microcline and microperthite. Acid plagioclase is quite subordinate. On Voigtskirch and Frauenstein a marginal, highly muscovitic facies is very conspicuous. Over a width of several hundred metres the rock is very rich in muscovite and at the same time platy. The actual margin itself is again formed by biotitic migmatites.

(*d*) *Hornblende-Granite.*—On Krumhuk, at the base of the great Krumhuk Mountain, there are to be found in muscovite-biotite gneiss and rocks of the Damara System lenses and small bodies of a reddish *hornblende-granite*. By the addition of biotite these rocks pass into *hornblende-biotite-granite*.

(*e*) *Red Porphyritic Biotite-Granite.* (Kobus, viz. Salem Granite.) In western Damaraland a grey, generally coarse, porphyritic biotite-granite with numerous phenocrysts of microcline and soda-orthoclase is widely represented. Gürich named it Salem-Granite.

In the great granite area of the Rehoboth region in the interior a very similar type occurs, which only differs from typical Salem granite by the usually red colour of its felspars and the common

occurrence of epidote. De Kock (13) named it *Kobus* granite, in the neighbourhood of which place it is widely represented.

In the Windhoek district this type of granite occurs at three localities: A large massif, 18 kilometres long and 12 kilometres wide, on Rietfontein and Tew; a smaller body, 9 kilometres long and 3½ kilometres wide, west of Stinkwater on the Schaf River; and a very small patch in the north-western corner of Hohenau.

The Rietfontein granite is red in colour, very coarse-grained with numerous large phenocrysts of salmon-coloured microcline. Biotite is always present, but frequently altered into chlorite. Near the farm-house the granite is pale reddish-grey in colour, also coarse in grain, but only slightly porphyritic.

Along the northern margin of the massif, between Tew and Brack, the large felspar-phenocrysts are frequently slightly deformed and the whole rock somewhat gneissose.

This granite is intrusive into the platy biotite-gneiss, with which in places it has formed migmatites by lit-par-lit intrusion.

In the granite near Stinkwater epidote is more common, the microcline has been extensively altered into sericite and the biotite to a large extent chloritised.

In a shaft put down to investigate the Cu-Pb occurrence at Hohewarte, a dark reddish-grey biotite-granite of medium to fine grain has been exposed. Microcline and orthoclase constitute its felspar; microperthite is also present, acid plagioclase only sparingly. Epidote is common and biotite has partly been altered into pennine.

D.—Bastard Series.

It has already been stated that in the area immediately to the south of Windhoek and in the north-western Rehoboth district, the sediments referred by Rimann to his " Phyllite Formation " (2) were found to be conformably interbedded with the rocks of the Damara System. In the vicinity of the Schaf River, however, around Koas, Hatsamas, Stinkwater and Blaukrantz, a definitely younger group of sediments was ascertained to be interfolded with the Damara System.

Krenkel (6) introduced the term " Bastard System " for Rimann's " Phyllite Formation," and this term may conveniently be retained for this younger group of sediments. Its distribution, however, appears to be very limited.

The area in question is exceedingly complex. It is traversed by numerous faults, and in addition nearly all rocks concerned have been so completely interfolded that it is well-nigh impossible to ascertain the true stratigraphic relationship of some rocks. Dips are predominantly vertical. On this account the mapping of this area has been carried out on petrological lines, and only, where there is definite evidence of an unconformity, have separate designations been employed.

Between Stinkwater on the Schaf River and Langbein-Blaukrantz to the west there is a small area underlain by a very coarse, porphyritic

granite of reddish-grey colour that has already been described in the previous chapter. Its margins are generally sand covered, but at the north-western foot of the high quartzite-ridge between Stinkwater and Hatsamas, a sedimentary contact is well exposed. On the highly weathered, steeply dipping granite surface there repose coarse conglomerates and arkoses, which at their base frequently exhibit large and small blocks of granite. This coarse basal block-arkose passes upwards into phyllitic conglomerates full of small quartzite-pebbles and these in turn into reddish compact quartzites. Towards the west the latter rapidly pinch out, but the basal conglomerate can be followed westwards into the neighbourhood of the Blaukrantz Mountain. In this region the conglomerates appear to be followed by phyllitic rocks, which contain finely crystalline limestones of bluish-black, grey and white colour. The mountain itself is built up by a lens of vertically dipping bluish-brown quartzites. Above this there follow highly graphitic phyllites.

It is highly probable that the yellowish-brown fine-grained quartzites, so abundant in this area, and also the finely crystalline limestones, that build up the Lübbert Mountain on Koas and a number of hills further east, also belong to this younger group of sediments. The limestones exhibit a great variety of colour, greyish-blue, white, pink and yellow being the most common tints. No dolomitic varieties were met with.

It appears, from the above description, that in this area there is definite evidence of a group of sediments younger than the Kobus or Salem Granite, which itself is intrusive into the older rocks of the Damara System. It also appears that the stratigraphical succession and petrological nature of this group is far more varied than was supposed by Rimann. Beyond this, however, the precise stratigraphy of this area is to some extent still uncertain, and, owing to inherent difficulties, will probably never be completely solved.

E.—Kudis Series.

While the rocks of the Bastard Series appear to be completely interfolded with those of the Damara System, a further group of younger sediments has been found to overlie the Damara System with a well-marked unconformity. It is, however, only preserved in the form of small remnants at four isolated localities between the Schaf and Usib Rivers in the area around Kudis.

Its most conspicuous member is a massive conglomerate of fluviatile origin, in which the densely packed, well rounded pebbles of whitish quartzite by far predominate over the sandy matrix. The quartzite of the pebbles is very similar to that of the Damara System (Quartzite Series) building up the high mountains immediately to the north of these occurrences.

At the eastern end of the Kudis ridge these conglomerates together with coarse felspathic sandstones of reddish-brown colour and white fine-grained felspathic quartzites overlie steeply dipping

phyllites and biotite-schists in an almost horizontal position. Towards the west the dip of the former gradually becomes steeper, and at the Kudis spring the characteristic conglomerate is wedged in between highly inclined rocks of the Damara System. At this locality the pebbles consist predominantly of white quartz, which is found in the form of numerous large masses in the rocks of the Damara System of the immediate neighbourhood.

North-east of Aub, to the south of the Schwarzkopf Mountains, the characteristic conglomerate is overlain by alternating reddish-brown quartzites and graphitic phyllites containing numerous pseudomorphs of limonite after pyrite.

These latter rocks greatly resemble similar rock-types overlying the basal conglomeratic arkose of the Bastard Series near Stinkwater. The conglomerates, however, are totally different, those of the Kudis Series being typically fluviatile. Since, however, the coarse block-arkose at the base of the Bastard Series passes upwards into less coarse conglomerates with well rounded smaller pebbles, it is possible that the densely packed Kudis conglomerate may mark the site of steeply graded torrential streams and that the rocks of the two series may belong to the same period of sedimentation.

F.—Dordabis Series (Nama System).

In the south-eastern corner of the mapped area (Map 9), younger rocks assigned by Rimann to the Nama System have a wide distribution. They are faulted down against the older rocks of the Damara System and Bastard Series to the north. Unlike the Nama beds further south, they are highly, but regularly folded and vertical dips are common.

Making their appearance already west of the Schaf River, it is east of this river that these beds undergo a great development, and in the form of long ridges, separated by sand-covered plains, dominate the landscape. With a regular NE-SW strike they continue eastwards past Witvley into the Gobabis region.

Dr. Rogers has recently expressed the opinion that at least portion of these generally reddish quartzites and sandstones in the latter area belong to the Matsap Series (*Proc. Geol. Soc. S.A.* Vol. 33, 1930, p. lvi). De Kock, on the other hand, who has mapped the northern margin of the typical Nama beds south of Rehoboth in the Naukluft region (13), states that the rocks in question occurring in the Dordabis region are identical with the lower members of the Nama System further south. Possibly the two series occur interfolded in the Gobabis area.

Until more light has been thrown on this matter by mapping the intervening tracts, the writer proposes the provisional designation of "*Dordabis Series*" for these beds.

In the Dordabis region these rocks may be conveniently divided into an upper and a lower group.

(*a*) *Upper Group.*—These are found already west of the Schaf River, where they are faulted down against the older rocks to the north. They consist mainly of dense and compact, well-bedded quartzites, felspathic sandstones and massive conglomeratic arkoses, which build up the Gumdaub-Hamib ridge, the Kamtsas Mountain and, east of the Schaf River, the Grimmrücken near Dordabis, and still further east the northern Kleepforte ridge. The pebbles of the conglomerates comprise: Vein-quartz, grey and reddish quartzites, reddish porphyritic granite and red aplites and pegmatites.

The quartzites and sandstones are partly sericitic and of pale-reddish, greyish-white or whitish-yellow colour. In some varieties clay-pellets are not infrequent. Very characteristic are fine-grained reddish-grey quartzites, exhibiting numerous narrow bluish-grey bands and occasionally pyrite-grains. These rocks are strongly reminiscent of the typical Kuibis quartzites of the Nama System as developed in the Naukluft region. They form the northern edge of these beds along the great Hamib fault.

Intercalated with these quartzitic rocks is to be found a horizon of calcareous shales, limestone and dolomite, which separates the quartzites of the Kamtsas Mountain from those of the Grimmrücken. Along this softer horizon the Schaf River has cut its picturesque gorge through the quartzite mountains. The constituent rocks comprise soft light-greyish shales, mostly calcareous, variegated shales, soft argillaceous sandstones and lenses of greyish, yellowish and occasionally reddish limestone and dolomite. South of the Williams Mountain on Hatsamas there is a band of dolomitic limestone, over 30 metres wide, and identical in appearance with the typical greyish-black and yellowish-grey " Schwarzkalk " of the Nama System.

There is little doubt that these rocks represent the " Schwarzkalk " horizon of the Nama System further south. It is a noteworthy point that also along the northern margin of the Nama beds to the south-west of Rehoboth there is found not a single massive limestone horizon, but several quartzite layers of Kuibis type occur intercalated with the " Schwarzkalk," and *vice versa*.

Silicified oolites were found in dark limestones of this horizon on Hatsamas. Near Dordabis limestones and dolomites of this horizon are invaded by masses of pegmatitic quartz and epidotic diabase. As a result they have been completely recrystallised in places.

Narrow zones of calcareous shales with intercalated narrow lenses of dolomitic limestones also occur in other horizons of the massive quartzites, *e.g.*, in the elevated valley on the Grimmrücken.

(*b*) *Lower Group.*—These light-coloured quartzites are followed to the south by an endless succession of ridges and hills, composed of deep-red and even chocolate-coloured quartzites and sandstones with sedimentary breccias and conglomerates. Boreholes and wells put down in the sand-covered plains between these red hills and ridges

have yielded either epidotic diabase or deep-red shales. On Dordabis and Ibenstein, *i.e.*, closer to the former group of quartzites, there are also found greyish, platy and flaggy, phyllitic sandstones separated by greyish-green shales.

On Dordabis and the adjoining farms to the east and west these rocks are traversed and cut up into narrow strips by numerous faults, parallel to the great Hamib fault and frequently marked by zones of brecciation. The folding is regular (NE-SW) and mainly isoclinal, with steep dips. In this way an endless succession of parallel red quartzite ridges has been produced.

The deep-red sandstones and quartzites usually possess a fine grain, but coarser varieties and conglomeratic layers also occur. Reddish clay-pellets are universally distributed in great abundance, as well as narrow intercalated layers of red shales. At several localities mud-cracks and ripple-marks were found. Felspar is not always present.

Of special interest are deep chocolate-brown sedimentary breccias on Dordabis, Ibenstein, Autabib and Skumok. In a felspathic and arkosic matrix they contain mostly angular fragments of the basement rocks, such as quartz, quartzite, granite, black diabase, etc., as well as occasional contemporaneous fragments of clay-pellet type.

Without a doubt these rocks represent rock débris accumulated under arid conditions of climate near the base of this series. The actual base of a similar nature is clearly exposed somewhat further south between Rehoboth and Düdoabib on the Schaf River. The basal breccia here is particularly rich in epidote and rests on granite.

Lithologically these beds strongly recall similar reddish rocks at the base of the Nama System to the south-west of Rehoboth, which Beetz more recently is inclined to correlate with the Auborus Series of the upper Konkip System. The unconformity between the latter and the Kuibis quartzites, according to Beetz, is frequently only slight. (Verbal communication.) At the same time part of the deep-red sandstones is highly reminiscent also of the Matsap Series, and it remains to be shown by further investigation of the area adjoining to the east, how far the latter is actually present and interfolded with the Nama System. In the Dordabis region the bulk of the evidence suggests correlation with the basal Nama beds.

(*c*) *Omitara Quartzites.*—Just west of Omitara on the White Nossob River there is a group of " Inselberge " rising out of the covering of wind-blown sand and built up by light coloured, very hard and compact quartzites. They are well bedded; cross-current bedding is frequent and occasionally ripple-marks are to be seen. Pale-reddish flagstones are found on Otjivero Nord.

Further south, on Rustig and Otjuhundu, a number of similar hills in addition to quartzites of the above description also show yellowish-brown and reddish-grey types. Intercalated with them occur layers of bluish-grey and yellowish limestone, partly cherty.

These quartzitic rocks, separated from those previously described from the Dordabis-Kleepforte region by a covering of wind-blown sand, no doubt belong to the same group of sediments and exhibit most affinity with the upper group, *i.e.*, the quartzites of Kuibis Type with intercalated beds of " Schwarzkalk."

G.—Post-Nama, Pre-Karroo Eruptive Rocks.

(*a*) *Epidotic Diabase.*—On Ibenstein, Dordabis, Autabib and the adjoining farms to the east, the red sandstones, quartzites and shales of the lower group of the Dordabis Series are intruded by innumerable, mostly parallel sills and lenses of greenish epidotic diabase. Occasionally, *e.g.*, on Dordabis, Protea and Mountain View, this rock builds up high hills, and its lenticular bodies possess a considerable thickness.

Contact phenomena are common, mainly evidenced by baking and epidotisation of the quartzite and sandstones. At numerous localities the latter have been brecciated by the diabase, the fragments being frequently recemented by epidote. Fragments of quartzite in the diabase are common.

The diabase is partly amygdaloidal and in this case particularly highly epidotic, partly finely holocrystalline and doleritic. The former type is invariably very greenish in colour, the latter mostly greyish-green and frequently, *e.g.*, on Mountain View, greyish-blue to greyish-violet.

The structure of the latter type is ophitic, but the felspar-laths have to a large extent been altered into an aggregate-polarising decomposition-product. Augite is only present in remnants, its bulk having been transformed partly into epidote, partly into magnetite and ilmenite with leucoxene. Epidote is very abundant and occurs partly in the form of crystals projecting into amygdaloidal cavities filled with chlorite. In the highly amygdaloidal types the original structure can hardly be recognised, the rock consisting of an irregular mixture of epidote, chlorite, calcite, quartz, abundant magnetite and ilmenite, together with isolated relicts of augite. The amygdales consist mainly of epidote, frequently together with chlorite, quartz and calcite.

At a number of localities Cu-sulphides occur in this type of diabase. On Renown a rock of this type, showing specks of chalcopyrite and irregular lumps of chalcocite, contains numerous amygdales filled by chrysocolla, drusy cavities containing dioptase and malachite, as well as isolated amygdales showing native copper.

This post-Nama epidotic diabase is very different from the older black diabase so common in the granite of the Rehoboth area and found as fragments in the basal breccia of the lower Dordabis beds.

(*b*) *Pegmatitic Quartz.*—At the foot of the Grimmrücken on Dordabis quartzites, calcareous shales and limestones of the Upper Dordabis Series have been invaded by several large masses of apparently pegmatitic quartz. The invaded limestone has been recrystallised and is veined by numerous stringers of quartz.

The quartz was nowhere seen to cut the epidotic diabase occurring in close proximity, and hence appears to be older.

H.—Post-Karroo Alkali-Rocks and Hot Springs.

The interesting occurrences of youthful alkali-rocks in the region of the Auas Mountains, between Windhoek and Reboboth, have been described by Rimann (1), Rennie (14) and the author in the following papers: (1) "The Hot Springs of Windhoek, S.W.A., *Trans. Geol. Soc., S.A.*, Vol. 35, 1932; (2) "Alkali-rocks in the Auas Mountains South of Windhoek, S.W.A.," *ibid.*, Vol. 36, 1933; (3) Jüngere-Vulkanschlote in den Auasbergen Südlich von Windhoek in S.W.A.," *Geological Review*, 1934. The reader is referred to these papers for reference.

I.—Tectonics.

The most important tectonic features have already been briefly alluded to in the foregoing text of this paper. It is proposed in the following to draw attention to a number of additional features, which mainly concern the elevated ridge of the Khomas Highlands as the most outstanding structural and morphological element of South-West Africa.

Along the whole length of South-West Africa, the basin shape of the sub-continent, due to a pronounced marginal upwarping, is well displayed. In broad outline the Great Escarpment marks the area of maximum elevation, from which the land surface gradually slopes to the east into the great intracontinental basin of the Kalahari, and more rapidly to the coast in the west. This feature suggests that originally the crest of the flexure lay still further west towards or possibly even outside the present coast-line.

If a series of altitudes be taken along the whole length of the Great Escarpment, it soon becomes evident that the marginal flexure did not possess a uniform elevation, but that, to the contrary, it has been affected by secondary transverse warping movements resulting in an undulatory rise and fall of the crest of the Great Escarpment and a concomitant buckling of the whole land surface of the territory.

Stahl has attributed these features to a very regular system of block-faulting with alternating "horsts" and "graben" (4). In the writer's opinion, however, the available evidence goes to show that the movements responsible for these alternating elevations and depressions of morphological phenomena were mainly of the warping kind, supplemented in a number of instances by well-marked faults of considerable throw, *e.g.*, the *Great Waterberg fault* in the north, the *Hamib Fault-Line* in the centre (referred to in the foregoing pages) and the *Karras Horsts* in the south.

The tract most highly elevated by these two interfering warping movements is represented by the *Khomas Highlands*, the term here being used to include the entire elevated ridge extending in a NE-SW direction across the centre of S.W.A. from the Great

Escarpment into the Kalahari Basin. Its Southern margin appears to be faulted (Hamib Fault-line) as far west as Wortel on the Windhoek-Rehoboth Railway. This zone of faulting could not be shown to extend further west as far as the Great Escarpment or the coast. How far it continues in an easterly direction is not definite. Whether it continues under the sand-covering of the Kalahari right across the latter to join the Deka-Fault of the Wankie-Zambesi region of Southern Rhodesia is a matter purely for speculation.

The Hamib-fault is not marked by an escarpment, the formation of the Khomas Peneplain, probably in early Tertiary times, having levelled all differences in altitude consequent upon faulting. The latter is in part at least of post-Nama age, although the faulting movements affecting the *Dordabis Beds* (Nama) may to a large extent have been rejuvenations of earlier movements. The Great Waterberg Fault in the north shows these NE-SW faulting movements, similar to Southern Rhodesia, to have taken place or been continued in post-Karroo times.

The Northern edge of the Khomas Highlands, on the other hand, is marked by a prominent escarpment as far east as Lievenberg, beyond Otjimbingwe. The more or less constant level of the numerous mountains beyond this escarpment and the Swakop River, and its agreement with that of the Khomas peneplain, would tend to suggest that this sudden inward bend of the Great Escarpment is not due to faulting, but mainly an erosional feature. Here, opposite the region of highest rainfall in the interior, the Great Escarpment has not only been deeply indented and cut back, but, except for the very suggestive " gipfelflur " of the isolated mountains of this area, it has been almost completely destroyed by the large intermittent rivers conveying the comparatively high rainfall of the interior into the sea, namely: the Swakop, Khan, Omaruru and Ugab Rivers. The levels of the " Gipfelflur " suggest a gradual down-warping of the Khomas Peneplain to the north again.

This inward bend of the Great Escarpment is further marked by the long and regular intrusive contact between the large granite area of Hereroland and the wide tract of schists forming the Khomas Highlands. The contact is, moreover, steeply inclined, generally more or less vertical. It is marked by a profusion of pegmatities in the schists on the one hand and of schists xenoliths in the granite on the other. Several hot springs (Gross Barmen 69° C., Klein Barmen 61°C.) occur along this contact. While faulting movements have not been proved and apparently were not a very pronounced feature, it is obvious that such a line of marked inhomogeneity, running parallel to the " grain " of the rock-floor for hundreds of kilometres, must always have represented a zone of instability to a greater or lesser degree.

While the Khomas Ridge thus represents a rigid block, elevated mainly by two interfering warping movements (that jointly produced

a maximum) and to a lesser extent by faulting movements, its structure otherwise is that of a great syncline of beds of the Damara System. The lower members of the latter, the Marble and Quartzite Series, crop out on either side and form a marginal strip to the enormously thick schistose rocks of the interior. The southern margin of the syncline dips less steeply than the northern, which is often slightly over-folded towards the south.

Very striking features of the Khomas syncline are: (1) The exceedingly regular NE-SW strike of its schistose rocks; (2) the very low dips common in its southern half; (3) the practically complete absence of granitic and igneous intrusions in general.

All these features offer a sharp contrast to the normal development of the Fundamental Complex of Central South-West Africa. In all other regions the latter exhibits the marked influence of multilateral stresses, that have resulted in a most irregular pattern of folding and very frequent deviations from the general NE-SW strike. Dips, moreover, are predominantly high and overfolding, generally directed towards the NW and N, is common. Contemporaneous with these irregular folding movements went an invasion of the sediments by granitic material on a vast scale. The sediments have largely been reduced to a skeletal frame-work, the interstices between which are filled by granitic magma.

These very marked differences clearly show, that already in those ancient times, there was a rigid factor in the crustal floor of what now are the Khomas Highlands, which prevented the intense crumpling up of the ancient sediments and their invasion by magmatic material. This latter feature is no doubt dependent on the former, it having been found in other parts of the Fundamental Complex of Central South-West Africa, that low dips and a minimum of folding in certain localised areas are marked by the comparative paucity or absence of granitic, aplitic and pegmatitic intrusions. The same holds for great regularity in strike, there generally being a profusion of the above intrusions at sudden bends and twists in the general strike. It is very suggestive to note, that where the schistose rocks of the Khomas Highlands in the Namib Desert beyond the great Escarpment take a turn to the south, and where in the east between the Seeis and White Nossob Rivers the strike locally deviates from the rigid NE-SW direction, granite intrusions at once make their appearance in the otherwise barren Khomas schists.

In later geological history the rigid block of the Khomas Highlands continues to play an important part as a dividing element in conditions of sedimentation.

If, as is generally done, the Otavi beds of the north are taken to be the equivalent of the Nama System in the south, very marked differences in facies at once present themselves: north of the Khomas ridge long continued shallow-water conditions and the accumulation of a great thickness of limestone and dolomite; south of it mainly

terrestrial sedimentation under predominantly arid conditions of climate resulting mainly in the accumulation of red psammitic and pelitic sediments. The intense folding of beds of the Nama System along the south-eastern margin of the Khomas ridge in the Dordabis area, in contrast to their horizontal disposition further south, is probably due to the former acting as a resistance block.

During the sedimentation of the Karroo beds the difference in the development of the latter to the north and south of the Khomas ridge is very marked, and apparently the latter already formed a tract elevated above its surroundings. Very probably a part of the "Nama"-ice had its origin in this region. In any case the Dwyka Tillite is well developed south of the Khomas ridge, but has nowhere yet been found to the north of it. While to the south the lower Karroo beds are well developed (the Ecca Series in Cape Facies), and the upper Karroo beds, particularly the Stormberg Series, are but poorly represented, in the north there appears to have been but a sparing sedimentation in lower Karroo times, but quite an extensive one during the Stormberg period, the Red Beds and Cave Sandstone (Etjo Beds and upper portion of Kaoko Beds) being well developed and spread over a large area.

The close of the Karroo period in the south saw the extrusion of normal basaltic rocks showing practically no differentiation, in keeping with conditions typical of the interior parts of the Karroo basin. North of the Khomas ridge basic lavas (Great Omatako) were also extensively extruded, but, on the whole, these are subordinate to intermediate and acid lavas, which at the Erongo and in the Kaokoveld attain a great thickness, the intense differentiation ending up with highly acid granites and their effusive derivatives.

These considerations show that the consolidation of the Khomas ridge into a rigid block had already been established in very ancient times. Further, it is evident that it not only divides South-West Africa geographically, but also geologically into two different halves. Down to the present day it has remained one of the most outstanding morphological features of the territory.

INDEX TO LITERATURE.

(1) Rimann, E.: "Trachyt, Phonolith, Basalt in D.S.W.A." *Central-bl. f. Min.*, etc., 1914, No. 2, pp. 33-37.

(2) Rimann, E.: "Geologische Untersuchungen des Bastardlandes in D.S.W.A." Berlin, 1915.

(3) Reuning, E.: "Geological Map of Central South-West Africa." *Geol. Rundschau*, Vol. 14, No. 3, 1923.

(4) Stahl, A.: "Die Grundzüge der Schollentektonik Südwest Afrikas." *Zeitschr. d. Deutsch Geol. Ges.*, No. 3/4, Vol. 79, 1927.

(5) Beetz, W.: "Versuch einer stratigraphischen Gliederung der praekambrischen Formationen Südwest Afrikas." *Neues Jahrbuch f. Min.*, etc., Blgbd. LXII, Abt. B., 1929.

(6) Krenkel, E.: *Geologie Afrikas*, Vol. II, Berlin, 1928.

(7) Frommurze, H. F., and Gevers, T. W.: "The Geology of North-western Damaraland in S.W.A." *Trans. Geol. Soc. S.A.*, Vol. 32, 1929.

(8) Gevers, T. W.: "An Ancient Tillite in S.W.A.," *ibid.*, Vol. 34, 1931.

(9) De Kock, W. P., and Gevers, T. W.: "The Chuos Tillite in the Rehoboth and Windhoek Districts," *ibid.*, Vol. 35, 1932.

(10) Gevers, T. W.: "The Hot Springs of Windhoek, S.W.A.," *ibid.*, Vol. 35, 1932.

(11) Gevers, T. W.: "Alkali Rocks in the Auas Mountains, South of Windhoek, South-West Africa," *ibid.*, Vol. 36, 1933.

(12) Gevers, T. W.: "Jüngere Vulkanschlote in den Auasbergen Südlich von Windhoek in S.W.A." *Vulcanological Review*, 1934.

(13) De Kock, W. P.: "The Geology of the Western Rehoboth District, Windhoek," 1934

(14) Rennie, L. V.: "Notes on Some Trachyte Necks in the Moltkeblick Region of the Auas Mountains, South of Windhoek." *Trans. Geol. Soc. S.A.*, Vol. 29, 1926.