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THE GEOLOGY OF THE AREA ALONG THE UGAB RIVER, WEST OF THE BRANDBERG

A THESIS

SUBMITTED FOR THE DEGREE

OF

DOCTOR OF PHILOSOPHY

IN THE

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AT THE

UNIVERSITY OF THE WITWATERSRAND

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OCTOBER, 1952

Theses

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CHAPTER I.

INTRODUCTION.

1) Scope of the Work:

The geology of an area of about 2,500 sq. km in the Omaruru District, S.W.A., is described. The description deals in detail with geomorphology, stratigraphy, tectonics, petrography, petrology and economic geology of the area. Conclusions are reached concerning the geological history, and the relationship of this area to adjoining areas.

The work consists of 165 typed pages, 26 tables, 18 diagrams, 43 photographs, 13 photomicrographs and 13 maps.

2) Situation:

The area to which the following description relates is situated in the north-western corner of Omaruru District, South West Africa. It comprises a strip of country from fifteen to twenty-five kilometres wide, along the south side of the Ugab River from its mouth to a point one hundred kilometres inland, where it skirts the northern side of the Brandberg. The Brandberg West Mine lies roughly in the centre of this area. (See Map, Fig. 1) Nearby but outside the area lie the Doros Crater and the Messum Alkali Complex, to the north and south respectively.

3) Communications:

The tin fields of Uis and the Omaruru River are to the south east, about one hundred and fifty kilometres away. In 1945 a passable road 130 km long was made from the area to Uis, the nearest permanent settlement, in order to open up the Brandberg West tin deposit. Uis is connected with Omaruru, the nearest railhead, by 130 km of poor road.

A fairly good road from Kubugabis on the Ugab River, north of the Brandberg, joins the Brandberg West-Uis road. Cape Cross can be reached from Brandberg West by a motor track. The distance is about 100 km.

All the large river beds, including most of the Ugab River bed, can be traversed by four-wheel drive trucks.

An airstrip has been cleared near Brandberg West Mine, and a radio transmitter will probably be installed at the mine soon.

/2 ....

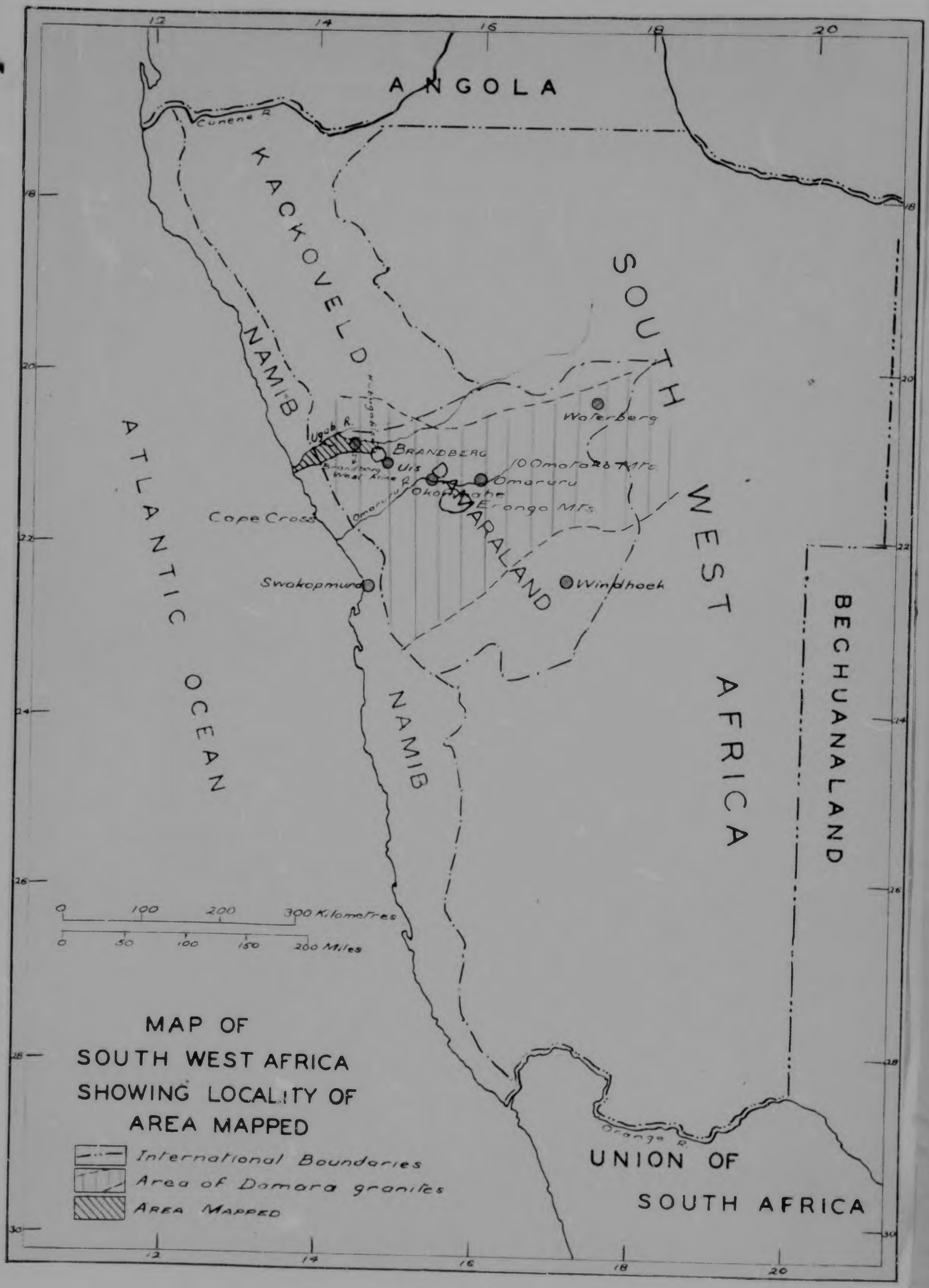

ANGOLA
Cunene R.
KAOKOVELD
NAMIB
ATLANTIC OCEAN
SOUTH WEST AFRICA
BECHUANALAND
Waterberg
Ugab R.
BRANDBERG
Uis
Brandberg West Mine
Omaruru R.
Omaruru
Okahandja
Erongo Mts
Cape Cross
Swakopmund
Windhoek
NAMIB
MARALAND
Orange R.
UNION OF SOUTH AFRICA
0 100 200 300 Kilometres
0 50 100 150 200 Miles
MAP OF SOUTH WEST AFRICA SHOWING LOCALITY OF AREA MAPPED
International Boundaries
Area of Damara granites
AREA MAPPED

Fig. 1.

4) Population:

Before the Brandberg West Mine was opened, there were no permanent human settlements in the area. A small group of nomadic Bergdamas existed by hunting, gathering wild fruits and plant tubers, and robbing ants' nests. These natives are only rarely met with in their primitive state today.

In many parts of the area, sites of old native villages are indicated by grouped rings of schist slabs. These, according to the local Bergdamas, were built after the heavy rains of 1934, when a large number of natives came to reap the benefits of grazing and game.

A possible earlier occupation can be deduced from the numerous rock artefacts and flakes which are found at almost all the sources of suitable material. Artefacts of imported material, together with broken ostrich egg shells, are found in some of the many caves and rock shelters, especially in those near water-holes or commanding a wide sweep of flat country.

5) Climate and Rainfall:

The area falls within the Namib Desert, and consequently has an arid climate.

The prevailing wind is from the south-west and blows the sea mist sometimes more than 80 km inland, from the cold waters of the Benguella Current. The east wind blows for only a few days per year, and is stronger than the south-west wind. It is also warmer, often causing a rapid rise in temperature from 60° F. to over 90° F. on the coast.

Scattered showers fall yearly within the area, but generally any given part of the area receives rain only once every six or seven years. At longer intervals, widespread and sometimes torrential rains cause a temporary flow in the river beds.

The large area of the Brandberg Mountain, part of which falls into this area, receives a higher rainfall than the surrounding desert, and a common occurrence is that of the Brandberg being under dense cloud formation while the low lying country about the mountain is free of cloud.

6) Water Resources:

The Ugab River is the main source of potable water in the are It floods if local rains are torrential, or if heavy rains have fallen further inland.

fig. 2.

At other times there is a sub-surface flow, and good water may be found by digging shallow wells less than five feet deep, at many points in the river, as far down-stream as one half mile from the sea.

Numerous weak springs exist, which are invariably salty during dry periods. They are commonly situated at positions where synclinally folded sediments are cut by deep transverse streams.

After rains, standing water is found throughout the area in pans and in solution cavities in granite and marble.

7) Vegetation:

The low rainfall supports only a sparse vegetation, which becomes spectacularly augmented after the rare good rains, when grass grows quickly on any flat area carrying sandy soil, and many varieties of flowering plants spring up in the river beds.

Trees and fairly thick bush grow in the larger river beds, notably in the Amis River and its tributaries. Thick patches of tamarisk are common in the Ugab gorge, and dense growths of reeds flourish where water is near the surface. Trees and thornbush are rare, probably because of the floods which occur almost yearly in the narrow gorge.

The curious plant, Welwitschia Mirabilis, is common in the area except on the coastal plain. The rugged heights of the Brandberg are overgrown by dense low scrub, which differs considerably from the vegetation of the desert below. This is probably because of the factors of, first, higher rainfall and lower temperatures, second, isolation from the larger species of grazing game, and third, the nature of the soil derived from the Brandberg granite.

The larger wild life is essentially migratory, varying in amount with the available grazing. This applies to the numerous springbok, gemsbok and zebra, and also to small groups of kudu, klipspringers, and rhinoceri. Lion follow the herds of game. In the Brandberg live many rock-rabbits, preyed on by leopards. The bird life there, and in the Ugab gorge, is plentiful.

8) Previous Geolcgical Work and Prospecting:

Up to the 1939 - 1945 war, little attention had been paid to this area owing to its inaccessibility.

No accurate topographical map existed and the geological maps showed the area to be underlain by Archeam schists. (Ref. Du Toit, 1939). Some work was done on the Karroo rocks to the north of the area by Reuning (Ref. 1925) and the geology of the Brandberg has been described by H. Cloos. (Ref., 1931).

During 1928, The Solar Development Company spent some time prospecting for zinc in the area, but nc maps or descriptions were published. The S.A. Mines Department, in Memoir No.39, mentions the occurrence of lead in the area. This account is presumably based on the work of The Solar Development Company.

During 1927 and 1928 the country to the southeast of the area from Okombahe eastwards, (see map Fig 1) was mapped by Gevers and Frommurze (1929) and together with later work by Haughton, Schwellnus and Rossouw, the results were compiled into the Omaruru Sheet published by the Department of Mines in 1939. (Ref. Sheet No.71, 1939). In 1938 the area was visited by Martin and Kron, who then discovered the Messum Alkali Complex lying immediately to the south.

During the last war parts of the area were visited in order to sample various tin and tungsten occurrences. The roads mentioned above were made when some of the prospects reached the mining stage, and thus the area became more easily accessible.

The area was geologically mapped from February to December 1946, as part of prospecting operations being carried out by the S.W.A. Co. Ltd. During the last five months of this period the writer was assisted by Mr. B. Worst. The period from December, 1949 to March, 1950 was spent checking the map, remapping some parts in detail, and collecting rock specimens.

Most of the mapping was done by pacing and compass survey, and a plane table was used for the more detailed work. The absence of trigonometrical beacons precluded any accurate control of the survey.

The period from March, 1950 to December, 1950 was spent at the University of the Witwatersrand, as follows:- The field maps were redrawn, and reduced from the scale of 1:15,000 to a scale 1:100,000.

From the 500 specimens that had been gathered, 350 were selected, and thin sections were made by the Geological Department Staff.

These thin sections were examined microscopically, and where necessary a crush was made and examined.

Under the "University Scheme", four complete silicate analyses, three limestone analyses and one wolframite analysis, were made at the Geological Survey, Pretoria, in 1951.

The petrological investigation was continued part-time during 1951 and 1952, during which period the writer was able to use the facilities of the Union Corporation, Geological Department and Research Laboratory.

The whole investigation was carried out under the direction of Professor T.W. Gevers.

9) Summary of the Geology:

TABLE I

MAIN GEOLOGICAL DIVISIONS

INTRUSIVES	FORMATIONS	SYSTEMS
	Recent Gravels - Kalahari age and younger.	3 Ages - Recent
Brandberg Granite Karroo Dolerites		
	Basic lavas. Sandstones - Stormberg Series. Sediments - Dwyka Series.	Karroo System
Acid Dykes Old Granite Intrusion (3 ages)		
	Upper Schist Series Upper Marble Series Middle Schist Series Lower Marble Series Lower Schist Series	Damara System.

Fig. 2.

The oldest known beds in this area are the sediments of the Damara system. After being deposited they were tightly folded along lines running northeast-south-west. After the folding had occurred, granite was intruded, in the form of a composite phacolith. There were at least three ages of granite intrusion, the second being more extensive than the first, and the third being less extensive.

Intrusion of pegmatites and quartz veins probably followed the emplacement of the granite.

After considerable erosion and peneplanation, sediments of the Karroo system were laid down, and these were covered by large thicknesses of basic lavas. At the end stage of eruption of Karroo lavas, all the rocks were intruded by basic sills and dykes. This was followed by the intrusion of the Brandberg granites. The small amount of faulting seen in the area is probably all of late Karroo or post-Karroo age.

During Kalahari and later times, gravels were deposited in and near the Ugab River Valley at successive periods, and were then left as high-level gravels after rejuvenation of the Ugab gorge had occurred, due to continental uplift.

Present Exposures:

The Ugab River has cut a deep valley through near-horizontal sediments and lavas of the Karroo System, and with its tributaries has exposed an area of highly folded schists and marbles intruded by granite. To the east, erosion has ravined the Brandberg with radial gorges cutting through a fringe of hills composed of flat-lying Karroo rocks. To the south lie the Goboboseb Mountains, a range composed of Karroo rocks, separated from those surrounding the Brandberg by schist exposed in the Amis River valley. A few outliers of Karroo rocks overlie the older rocks at high points in the dissected schist country.

The rocks in this desert area are well exposed, except in the western part, where a thin crust of sand, cemented with gypsum covers much of the surface. After the rare good rains, the consequent thick grass cover hides a large proportion of the outcrops, especially in country of low dissection.

Fig. 2.

CHAPTER II.

GEOMORPHOLOGY.

The part of the Namib Desert described in this report, consisting as it does of several different geological formations, presents examples of many features typical of desert landscapes. Deep and youthful dissection and the general lack of vegetation have combined to provide a rare display for the geologist and the geomorphologist.

The physiography will be described, and some of the details discussed, under the heading "Physiography and Drainage". This section, which will be mainly descriptive, will be followed by a discussion of the possible erosional history and the general processes of erosion in the area.

A) Physiography and Drainage.

The area can be divided into six well-defined physiographical units:- (See sketch map, Fig. 2).

1. The Ugab River Gorge.
2. The Dissected Schist Country adjoining the Ugab River valley.
3. The Brandberg granite massif.
4. The Gobobosed Mountains.
5. The Western Granite area.
6. The Coastal Plain.

1) The Ugab River Gorge.

Except in the coastal plain, the Ugab River flows through a deep and narrow gorge in the area mapped. Deepest near the Goantagab River junction, at a point where steep cliffs rise to 100 metres above river level, (See Photo, Fig. 3) the gorge becomes gradually shallower upstream towards the Brandberg and downstream towards the Sesob River confluence. In the last thirteen kilometres down to the sea, the river runs in a shallow channel which cuts about 8 metres into the gravels of the coastal plain and is up to 500 metres wide. Whereas the river runs nearly straight in its lower reaches, upstream it follows a winding course in sympathy with the changing strike directions of the geological features encountered, such as dykes, faults, and contacts between resistant and soft strata. The resultant path of the river has many sharp turns and indentations.

Fig. 2.

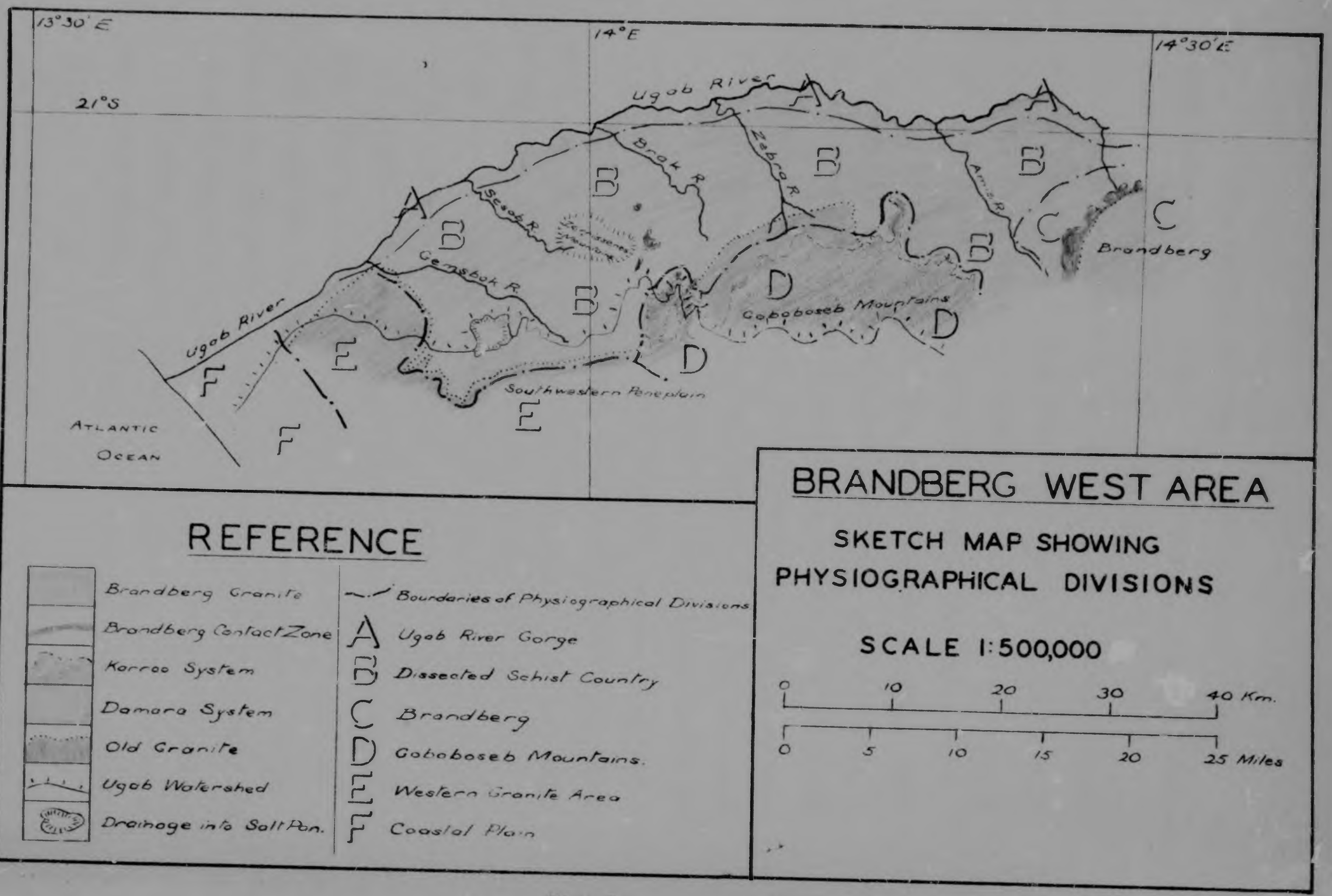

13°30' E
14°E
14°30' E
21°S
Ugab River
Brak R.
Zebra R.
Amis R.
Sesob R.
Gemsbok R.
Brandberg
Gobaboseb Mountains
Southwestern Peneplain
Atlantic Ocean
A
B
C
D
E
F
REFERENCE
Brandberg Granite
Brandberg Contact Zone
Karroo System
Damara System
Old Granite
Ugab Watershed
Drainage into Salt Pan.
Boundaries of Physiographical Divisions
A Ugab River Gorge
B Dissected Schist Country
C Brandberg
D Gobaboseb Mountains.
E Western Granite Area
F Coastal Plain
BRANDBERG WEST AREA
SKETCH MAP SHOWING
PHYSIOGRAPHICAL DIVISIONS
SCALE 1:500,000
0 10 20 30 40 Km.
0 5 10 15 20 25 Miles

Fig. 2.

Along most of the river's length can be seen remmants of low-level raised gravels, a high-level raised valley, and a much older erosional surface into which the latter was cut.

An intermittent bed of cemented gravel, occuring at heights of from 2 metres to 15 metres above the present river bed, forms the low-level gravel and is found usually along the insides of curves in the present gorge, and rarely lying on slightly elevated benches.

The high-level valley, generally containing gravel, occurs intermittently at elevations of from 15 metres to 65 metres above present river level, and thus forms more noticeable features than the low-level gravels. The raised valley (see photos, Figs 4,5,6,7) in places takes the form of dissected platforms covered with low hillocks of gravel, but generally it exists as a terrace along the side of the Ugab River, or as an elevated valley some distance from the present gorge.

Examples of this raised valley can be seen one mile west of Salzputz on the north side of the Ugab River, and near the confluence of the Zebra and Ugab Rivers, where the elevated valley runs for a short distance alongside the Zebra River, about 2 kilometres south of the Ugab River. (See photo, Fig. 8).

The older surface was not seen as a separate valley, but as valley sides up to 65 metres above the high-level valley, which cuts fairly sharply into the older surface. The older surface is not confined to the Ugab gorge, but extends intermittently over the whole area. Much of the surface is deeply dissected, and it is doubtful whether any of its original detritus survives. Good examples of this older surface occur west of the Brakputz and east of the Goantagab River. (see photo, Fig. 9).

2) <u>The Dissected Schist Country</u>.

The area from the Brandberg to the western schist-granite contact (see map, Fig. 2) is occupied by a deeply dissected area of schists and marbles, which form a ridge and valley topography trending north-east south-west near the Brandberg, and swinging to a north-south direction at the western granite-schist contact.

The monotony of the succession of ridges and valleys is broken by two elevated areas, the Zerissenes Mountains and a group of hills on the southwest side of the Gemsbok River. Both of these areas project beyond the fairly even summit level of schist and marble ridges. (See photo, Fig. 10). Most of the streams here flow into the local base-level of the Ugab River.

For the sake of clarity in describing the details of the physiography in this area, the following sub-divisions have been made:-

(a) Upper Marble Units.

(b) Schist and Lower Marble Units.

(c) The Western Schist and marble area.

(d) The Zerissenes Mountains.

(e) Pans and features due to Wind erosion.

a) Upper Marble Units.

The Upper Marble beds, situated stratigraphically between the Upper and Middle Schist series, form conspicuous ridges where exposed as synclinal troughs, and valleys usually lie along the anticlines. Rarely, when only the topmost band of the Upper Marble beds is exposed, a valley lies along a syncline. This top band of marble is of a compact nature, as opposed to the rather platy and schistose underlying marbles The normal shape of a ridge built by an Upper Marble syncline is a sharp hogback, slightly asymetrical when viewed along strike. (See photos, Fig 11, 12, 13). Ridges formed by the Upper Marble Series, where steeply dipping, show a more rounded summit with cliffs along the sides.

Each of the various components of the Upper Marble series respond to weathering in its own characteristic way. The Blue Marble band contains solution cavities, some large enough to have served as human habitations. (Photo Fig. 14). Yellow marble bands immediately underlying the Blue Marble display the solution runnels, about 1 cm. in width, which are found on the surface of marble and limestone outcrops. Small, about 0.5 m. diameter, shallow depressions are present where a marble band is lying flat, such as on occasional horizontal scree slabs.

Owing to differential weathering in the marble bands, flat shelves run along the sides of many of the ridges, due to erosion of soft members of the Upper Marble Series.

Pseudo mudcrack-weathering occurs in the Yellow Marble bands usually in slabs which have become half-decomposed. Arching of thin marble bands or exfoliation layers, is found where these are still partially attached to bedrock. W[illegible]erosion produces a fine-grained wrinkled surface on some dark hard varieties of marble. (See photo, Fig. 15).

Mural joining is widespread especially in bands of the yellow marble beds. (See photo, Fig. 16).

b) Schist and Lower Marble Units.

Schist, with a few narrow interbedded marble and quartzite beds, composes the greater portion of the dissected schist country.

The rule, in the Upper Marble series, of ridges being formed along synclines and valleys along anticlines, also applies in the schist country, but it is not so invariable. The even summit level of many schist ridges suggests a dissected peneplain, with high areas of marble.

Differential weathering in schist shows the banded structure well. (See Photo, Fig. 17). Dykes and faults usually form depressions. The quartz veins which are connected with the lead and tin occurrences of the area, stand out from the schist together with adjacent walls of indurated schists. This prominence of mineralised quartz veins is a factor which should be taken into account if aerial prospecting is carried out.

Near-horizontal sheets of dolerite occur in the schists, and are sometimes left as caps to mesa-like hills, with either marble or schist as a base.

The quartzites and Lower Marble series rarely give rise to prominent features.

Drainage of (a) and (b)

Except in its extreme western part, the schist area is drained by five main rivers, all of which flow into the Ugab River. The rivers cut across the strike of the sediments over most of their courses, following the direction of dykes or faults. Thus they interrupt the pattern of strike ridges and valleys, described below, that is produced by the action of their tributaries.

Raised gravels and raised valley floors exist along all the five main rivers. The degree of elevation of the gravels gradually increases towards the Ugab River, and is, for each stream, roughly proportionaly to the depth of the Ugab gorge at the point where the respective tributary joins the Ugab River.

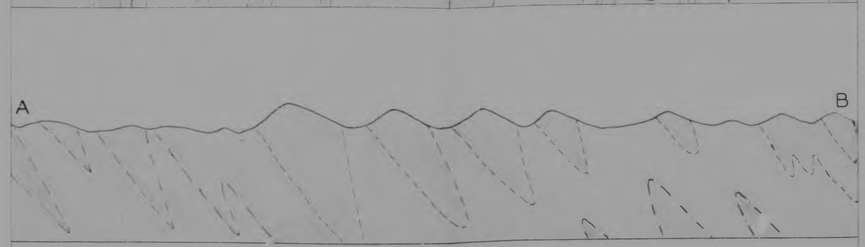
There is a lower level of raised gravels throughout the area, which corresponds with the low-level gravels of the Ugab River.

West of the Gemsbok River, only one major stream flows into the Ugab River. The remainder flow towards the Atlantic Ocean, their catchment area being separated from that of the Ugab River by low divides. At one point, near the source of the Gemsbok River, this divide is actually in the Gemsbok river bed, and is composed of gravel.

Erosion has formed numerous streams, commonly in a trellis-work pattern. The best example of this pattern is in the marble belt to the east of the Brandberg west Mine. (See Map, Fig., 18). The main controlling factors here are the strike and folding of the marble beds, so that the streams for the greater part of their courses are coincident with anticlinal axes. Rarely, valleys cut across the strike, along the paths of dykes or faults. Headward divides of strike streams are formed where dykes cut across a marble anticline.

The topography in areas of folded schist does not respond to the control of the fold structures as readily as it does in areas of folded marble. Consequently trellis-work drainage is less well-defined in schist country than in areas composed of marble. The strike of the bedding exercises less control, and the effects of dykes and faults become comparatively stronger.





SECTION A-B

REFERENCE

- Upper Schist Series
- Upper Marble Series
- Middle Schist Series
- Lower Marble Series
- Lower Schist Series
- Raised gravel bed
- Dolerite dikes
- Faults
- Anticlines
- Synclines
- Roads

GEOLOGY OF THE AREA TO THE EAST OF BRANDBERG WEST MINE, SHOWING THE SYSTEM OF DRAINAGE

SCALE

0 ¼ ½ ¾ 1 Kilometres

0 ¼ ½ ¾ 1 Miles

Fig. 18.

In the schist area east of Brakputz, zones of weakness running northwest-southeast, and faults striking about north-south, determine the direction of stream beds.

The drainage in areas where the Lower Marble is exposed follows a fairly regular pattern, which is shown in Figure 19.

Where folding in a Lower Marble anticline is comparatively open, the stream usually lies between the limbs of the anticline. But when the folding is nearly isoclinal, the stream lies along the southeast side of both limbs, assuming that the bedding has its usual southeasterly dip. (See Fig 19). The reason for this is possibly that the streams are superposed from positions in the Upper Marble series which is now completely eroded. On a broad fold, the stream would cut through the middle schist to a position within the Lower Marble anticline, but in tight isoclinal fold with inclined axial planes, the superposed stream would be deflected towards the southeastern side of the Lower Marble anticline by the resistant compact grey marble forming the apex of the fold.

c) The Western Schist and Marble Area.

In the part of the area lying to the southwest of the Ugab watershed (see sketch map, Fig. 2) the landscape is one of shallow dissection. The low broad ridges are mostly composed of schist belonging to the Upper Schist Series, and many of the valleys have been cut through the schist into anticlines of the Upper Marble Series. Sand-filled valleys are a feature of this area, and rocks are not as well exposed as elsewhere, owing to the widespread occurence of a surface crust composed of sand and rubble cemented with gypsum.

Drainage.

All the larger streams in this area drain towards the southwest, and their minor tributaries run in a trellis-work pattern identical with that of the dissected schist country, described above. Notable is one of the main streams which runs along a narrow tongue of schist projecting to the west into the granite.

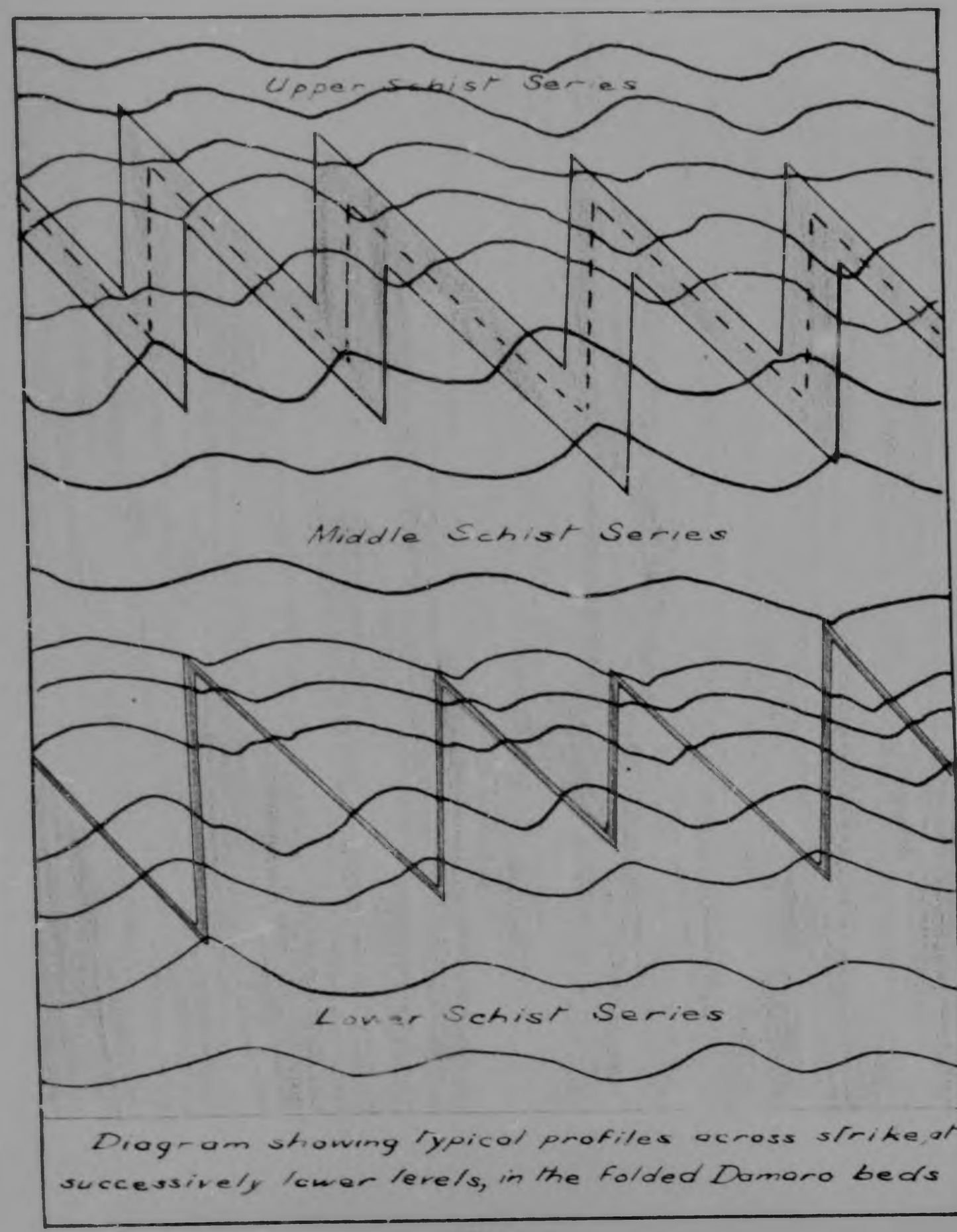
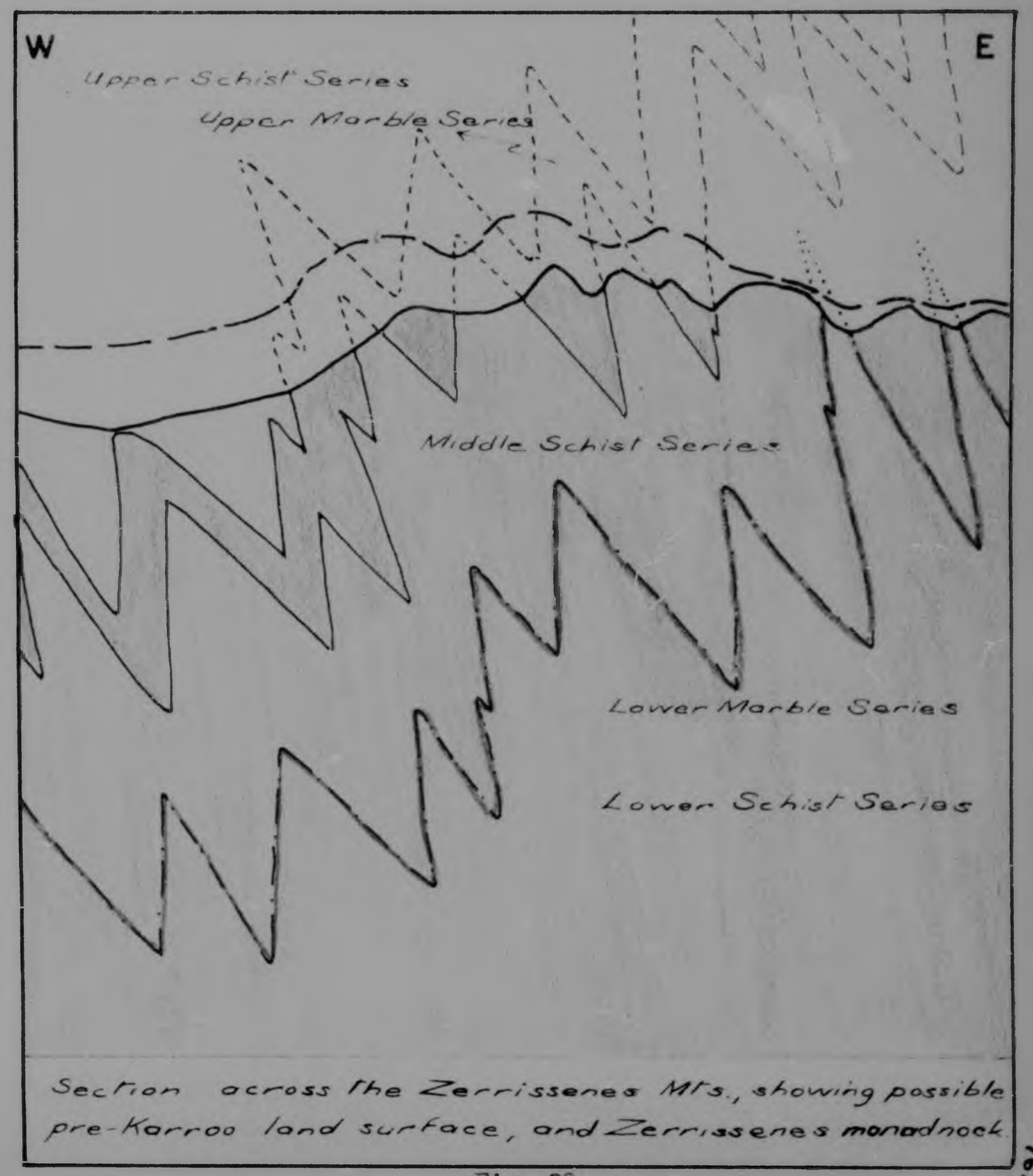


Diagram showing typical profiles across strike, at successively lower levels, in the folded Damara beds

Fig. 19.



Section across the Zerrissenes Mts., showing possible pre-Karroo land surface, and Zerrissenes monadnock.

Fig. 20.

d) The Zerissenes Mountains.

On old maps the name Zerissenes is applied to some high hills in the middle of the area, about 8 km south of Brakputz. On the map in the paper written by Reuning and v. Huene (Ref. 1925), these hills are called the Messumberg, but this name is now accepted as belonging to the well-known mountains north-east of Cape Cross. For the purpose of this description, the older name will apply. The Zerissenes Mountains cover some twenty square kilometres, and represent the highest exposure of schist and marble in the area, their summit being about 65 metres higher than the base of the nearest Karroo Rocks. When viewed from the south-west, the mountains are seen to include a number of peaks, each of which contains a syncline, and the valleys between the peaks are on anticlinal structures. (See sketch, Fig. 20). To the south of the mountains lies a pediment, composed of an area of Middle Schist, four kilometres wide across the strike, by five kilometres long. To the west, an area of about 25 square kilometres of Upper Schist lies between the steep flank of the mountains and a long synclinal ridge composed of Upper Marble and Upper Schist. This area of Upper Schist is lower than the above-mentioned Middle Schist pediment, the two areas being separated by a ridge of Upper Marble which is continuous with the structure of the western side of the Zerissenes Mountains.

Drainage.

The southern pediment of the Zerissenes Mountains drains to the local base-level formed by the broad stream flowing towards the west into the Sesob River. The pediment, sloping gently to the south, is shallowly incised by numerous rubble-filled strike streams, the surfaces of which lie about 15 metres below the top of the intervening ridges. (See photo, Fig. 21). Some of the strike ridges between the streams appear to be nearly buried beneath the gravel. Braiding and splitting occur in the minor streams which run on the surface of the large stretches of rubble.

e) Pans and Features due to Wind Erosion.

Three types of pans are found in this area:-

(a) Wind-scoured pans.

(b) Barrier basins.

(c) Animal formed pans.

Coastal pans are described under section (F), "The Coastal Plain".

i) Wind-scoured Pans.

Several examples of this type exist, mostly in the marble in the western part of the area, in country of shallow dissection. They were probably formed by the alternating action of wind and mist. The salts probably originate in the sea, and are brought into the catchment area of the pan by sea mist, and then are washed into the pans by the rare rains.

The largest of these pans lies to the southwest of the Gemsbok River, and is 1.5 km long by 0.8 km wide. The bedrock here is folded marble. The pan has a small catchment area, and is only partly fed by the large stream flowing north-west across the strike, about one km north-east of the pan. In this stream-bed is a gravel divide, splitting the drainage. The pan bottom contains a mixture of salt and sand of unknown thickness. Transparent crystals of gypsum up to 15 cm in length lie on top of the salt. Along the perimeter of the pan, the salt forms a smooth surface having a network of lines formed by ridges of salt, about 2.5 cm high. (See photo, Fig. 22). Most of the surface of the pan is covered with a layer of mixed salt and mud, which has been formed into a rough surface consisting of numerous concave surfaces edged by ridges with differences of elevation up to 45 cm. The flatter type of surface is found in patches within the rough-surface area. This pan is about 300 metres above sea level. The lowest point of the catchment area is about 12 metres above the surface, and lies on the west side of the pan. The pan bears some resemblance to Ehrhorn's Pan (Gevers, 1931 (b)). No samples were taken, as prospecting for salt in this area is prohibited.

Small shallow pans are found on the flats near the western end of the Goboboseb Mountain pediment, (described in (4) below), close to the Brak River divide. They are also probably due to wind action.

ii) Barrier Basins.

At two localities, one south west of the Zerissenes Mountains, and one near the Brandberg, pans have been formed at the confluence of small and large streams by the damming of the smaller, due to aggradation in the larger stream.

iii) Animal formed Pans.

Saucer shaped depressions, about 2 metres in diameter and as much as 0.7 metres in depth, are found throughout the area. These occupy flat soft ground, such as river beds and headward divides, and rarely, several are found grouped together.

After heavy rain the water does not drain away, but remains until it is evaporated. These depressions are probably made by zebra, stamping and turning on muddy ground.

The numerous game paths have provided a noticeable pattern of horizontally lengthened mullions along the sides of most hills and ridges. (See photos, Figs. 23 etc.).

Wind Erosion.

Owing to the lack of plant cover, wind erosion, deflation and aggradation have played an important role in this area. Although the prevailing wind is from the south-west, it is the violent and hot east wind blowing for only a few days in the year, that causes the most noticeable wind effects. Sand collects on the western sides of north-south ridges, and exposed boulders are deeply wind-worn on their east-facing sides.

Many of the river beds, especially in the more exposed western part of the area, are filled with a mixture of water-borne sediment and windblown sand.

Dunes are rare, except at certain localities in or near the Ugab Gorge, where the sand is probably derived from the abundant material in the Ugab River bed, brought down in times of flood.

(See photo, Fig. 24). No dune belt exists on the coastal plain in this area.

Typical "desert pavement" due to deflation is seen throughout the area. Dust storms arise only immediately after the rainy season, when the fine material deposited on stream beds has dried.

3) The Brandberg Granite Massif.

The north-western corner of the Brandberg lies within the present area. The description of the physiography of this mountain by Cloos (Ref 1931) leaves little to be added. For the sake of completeness the major points will be summarised in the description below. Physiographically the Brandberg in this area can be divided into 4 units.

(a) The Brandberg granite Mountain.

(b) The Contact of the Granite and Karroo Beds.

(c) The Karroo Table Mountains.

(d) The Old Pediment of the Brandberg and the elevated gravels.

a) The Brandberg Granite Mountain.

The Brandberg granite forms typical smooth surfaces, with occasional rounded prominences. (See Photo, Fig. 25). The drainage from this large mountain mass is, in general, radial, several deep gorges having been cut into granite. The longest of these drains towards the north into the Ugab River, which runs close to the north side of the mountain, ("Ugab" is translated roughly as "the river which cuts deep into the mountain"), and lies about 650 metres lower than the ground to the south of the mountain. Of the Brandberg streams mapped, one has its source near the centre of the granite mass, about 10 km from the fringe of Karroo hills. The remainder are short, steep streams averaging about 2 km in length in the Brandberg granite. A local base level to the west is the Amis River, which flows in a northerly direction into the Ugab.

b) The Contact Zone.

The nearly vertical contact zone between the Brandberg granite and the Karroo rocks is a zone of weakness compared with the adjoining formations, and has determined the position of some of the tributaries of the larger streams draining the Brandberg.

c) The Karroo Table Mountains.

These form an almost complete girdle around the base of the Brandberg. They are mostly typical Karroo mesas, and some approach a conical form. Their width radially from the Brandberg granite is fairly constantly about 0.8 km. It is possible that this chain of hills owes its preservation to the hardening of the Karroo strata through the contact-metamorphic effect of the Brandberg granite. The Karroo strata produce the effect of a hard capping overlying softer beds.

In the north-western Karroo hills, a basal conglomerate forms low cliffs above waning slopes of Upper Schist. (See photo. Fig. 26). Higher in the Karroo strata, cliffs are formed by arenaceous beds.

d) The Old Pediment of the Brandberg and the Elevated Gravels.

On the north-western and western sides of the Brandberg, a well-developed pediment existed before the lowering of the Ugab River caused deep dissection into the pediment's northern side. The rejuvenation of the landscape is not so pronounced on the western side of the pediment where the Amis River forms a local base-level, and the equilibrium of the pediment has not yet been disturbed. There are however evidences of an even older land surface here, in the form of small plateaux of schist covered with gravel. These hills, which lie to the south of the Naib River, rise about 30 metres to 50 metres above the level of the present land surface, and represent the remnants of a landscape which here went through the cycle of rejuvenation to near-maturity. On this nearly mature landscape rejuvenation is again making its mark near the Ugab River.

A good example of a remnant of the older landscape is the narrow plateau of schist, topped by gravel, which runs along the north-east side of the Naib River. (See general plan, Fig. 27 and plan 28 (a).

The younger landscape, which is being deeply dissected near the Ugab River, includes two large alluvial fans at the mouths of gorges draining the Brandberg. In the area south of the Naib River, these alluvial fans and wide gravel beds show little dissection, and present-day drainage takes place along their surfaces. North of the Naib River, only remnants of these fans exist. For example, 6.5 km south

of Kubugabis a wide expanse of gravel caps an escarpment which faces northeast and drains towards Kubugabis. This gravel is part of a dissected alluvial fan. Patches of gravel can be traced from this escarpment northwards to a point about one mile southeast of Natibeb on the Ugab River. The gravels occupy high ground, and often form the headward divides of present day streams. The river of which these gravels are the remnants, was probably captured by a strike stream flowing towards Kubugabis. (See plan, Fig. 28 (d). This elevated river bed makes a fortunate link-up between the high-level raised bed of the Ugab River, and the younger raised gravels of the Brandberg pediment. The Naib River raised gravels are therefore possibly the same age as the older land surface above the high-level gravels of the Ugab River.

North of the Brandberg, broad rivers run northwards to the Ugab in channels cut about 60 metres into the Brandberg pediment. (See photos, Figs. 25,26,29). The processes of formation of alluvial fans are in action there today.

4) The Goboboseb Mountains.

The Goboboseb Mountains are composed of Karroo rocks rising to about 500 metres above the surrounding country. They separate the area mapped from the area of the Messum Complex which lies to the south, and they represent the southernmost outlier of the range of Karroo Mountains which stretches northwards of the Ugab River for 400 km.

These mountains show forms similar to those of the Karroo hills, described above, which surround the Brandberg.

To the north-west of the Goboboseb Mountains, several minor outliers consist mostly of thick sills of coarse-grained Karroo dolerite overlying thin layers of basal Karroo sediments. As a result, the typical shape of bedded Karroo hills is seldom seen. The dolerite sills make gently rounded hills, or rounded cappings to steep dissected slopes of Damara System rocks.

Wherever erosion has cut through the base of the Karroo system the effect of the resurrected pre-Karroo landscape on the drainage pattern is marked.

The pre-Karroo rocks also affect the drainage pattern within the Karroo rocks, i.e., streams advance headwards into weak points, such as anticlines or soft bands, in the slopes composed of Damara System rocks. Thus, valleys parallel with the strike of the older rocks are cut into the Karroo rocks.

Post-Karroo structures which control present drainage are rare. A north-so valley to the west of the outliers runs along a fault which is pr..able post-Karroo in age.

The Karroo rocks of the north-western portion of the Goboboseb Mountains, overlie a mass of granite, the exposed portion of which is 16 km long, northeast-southwest, by 4 km wide, northwest-southeast. (See map, Fig. 27). This area of granite slopes gently down towards the north and northwest, and is partly covered by a thin layer of Karroo rubble, which usually obscures the Karroo-granite contact. The even topography of the granite is relieved by a few granite "castle kop-pies", lying near the granite-schist or granite Karroo contacts, and improminent ridges are made by schist xenoliths.

The area forms a typical pediment, similar to that which adjoins the southern side of the Brandberg. Where the Karroo rocks of the Goboboseb Mountains overlie schist and marble, this pediment is not well formed. The reason is probably that the erosional forces, which would normally form a pediment to the flat-bedded mountain mass, have been diverted by the effects of the strongly folded schists and marble beds.

Drainage.

Within the area of granite the pediment is drained by the Brak and Zebra Rivers, two large tributaries of the Ugab River. To the northeast, near the schist contact, a low north-south divide is the head of a number of streams flowing towards the northeast and adjoining the Ugab. To the southwest, a similar low divide composes part of the watershed between the Ugab River catchment area and streams which flow towards the Atlantic Ocean.

5) The Western Granite Area.

The large expanse of granite which lies to the west of the Goboboseb pediment described above, can be divided into:-

(a) a granite peneplain, (the South-Western Peneplain).

(b) a stretch of dissected granite country.

a) The South-Western Peneplain.

This peneplain extends towards the west and south from the Karroo outliers mentioned above, its northern boundary being the granite-schist contact. The granite has been worn down to a flat plain, featureless except for low hills composed of schist or metamorphosed limestone xenoliths, and rare dyke ridges of slight elevation. (See Photo. Fig. 44). A thin layer of rubble covers the granite, which is exposed intermittently in broad shallow streambeds.

b) The Dissected Granite Country.

This area consists of typical rolling granite country standing at a lower elevation than the granite peneplain which lies to the south-east. At or near the granite-schist contact, there is generally a low dissected scarp, the schist occupying the higher ground.

Features typical of granite country, such as exfoliated boulders and solution cavities (Banke) are found throughout this area, and the grey granite has in places weathered to a smooth rounded surface with numerous projecting pillars.

Basic dykes crop out along the crests of prominent ridges, and the drainage pattern is partly determined by the pattern of intrusion of the network of dykes which cut the granite.

The larger streams flow westward and generally cut through dyke ridges in places where two dykes intersect.

The country gradually falls away westward to the coastal plain where the drainage becomes ill-defined as a result of the joining and braiding of several streams.

6) The Coastal Plain.

Fifteen kilometres from its mouth, the Ugab River enters the coastal plain, an almost flat area covered with gravel and sand into which the river cuts a broad channel about 7 metres to 10 metres in depth.

At the river's mouth is a sand bar which is transgressed during floods. High tides sweep over this bar to maintain a small lagoon behind it.

Rare schist outcrops indicate that the gravel cover of the coastal plain is shallow. Small features, such as a dolerite-capped mesa about 12 metres high, 4 km from the Ugab mouth, show up prominently.

Unlike most of the coastal desert of South West Africa, large sand dunes or barchanes are not found here. The occasional small dunes have as nucleii logs which are brought down from inland when the larger rivers, such as the Ugab, Omaruru and Swakop, are in flood. Wind-blown sand soon collects round the obstacles and also round whalebones, driftwood from wrecks, and small bushes.

A series of salt pans extends along the coast south of the Ugab mouth. They are separated from the sea by a strip of beach and low dunes about 100 metres wide, and are only rarely fed by inland streams. They receive their supply of water from the sea during spring tides, and possibly from condensing sea mist.

The gravels of the coastal plain are probably similar in age to the high-level gravels of the Ugab River. Large areas of gravel lying to the north of the Ugab River on the coastal plain lie at approximately the same altitude above the river as the high-level gravels further up stream. (See photo, Fig. 30)

B) Erosional History of the Area.

The available evidence regarding the geomorphology of the area has been given above, and the conclusions regarding the erosional history are as follows.

1) The Pre-Karroo Land Surface.

After the folding of and the intrusion of the Damara sediments, peneplanation took place on a large scale, resulting in a surface which was rather uneven especially in areas of schist and marble. At least one pre-Karroo monadnock still exists, as the Zerissenes Mountains. The reason for these mountains withstanding erosion so well was probably because the top of the monadnock consisted of a folded mass of the resistant Upper-Marble Series.

Remnants of this body of marble survive in the form of synclinal troughs. (See Fig. 20).

Deposition of the fluvio-glacial basal Karroo beds place on this peneplain, and partly filled most of the depressions. Continued deposition of alternating coarse and fine sediments resulted in a nearly level surface, on to which where extruded the thick flows of Karroo basaltic lavas. These cooled and were eroded to a featureless lava peneplain, the End Jurassic Peneplain described by Dixey. (Ref. Dixey. 1939).

In and near the area, there followed the intrusions of Brandberg, Doros, Messum and Cape Cross. A small amount of gravity faulting tock place.

Thus at the end of the last known magmatic activity, a practically flat land surface of lava was developed, broken by four major prominences. Following a slight westward tilt of the continent, the Brandberg, Messum and Cape Cross complexes probably constituted a range forming the southern watershed, and possibly the Doros volcano formed part of the northern watershed, of a river which cut through at least 600 metres of Karroo rocks, and was superposed on the rocks of the Damara system. This was the origin of the Ugab River valley and probably of the Amis River valley. (See map, Fig. 31).

2) The Post-Karroo Land Surface.

Possible remnants of the oldest land-surface in the area exists as the upper surfaces of the Goboboseb Mountains and of some of the Karroo hills surrounding the Brandberg.

3) The Kalahari Land Surface.

The wide flat valley that was cut into this old land-surface to a position below the pre-Karroo peneplain, separated the Goboboseb and Brandberg Mountains from the southern portion of the extensive Etendeka range lying to the north.

An indication as to the age of this valley exists in the area of red sand dunes which lie on the north side of the Ugab River, opposite the Brandberg. The aspect of these dunes is that of typical Kalahari sand. Thus it could be inferred that the Ugab River Valley originated in pre-Pleistocene times.

Therefore, before the Kalahari Period, this broad valley had

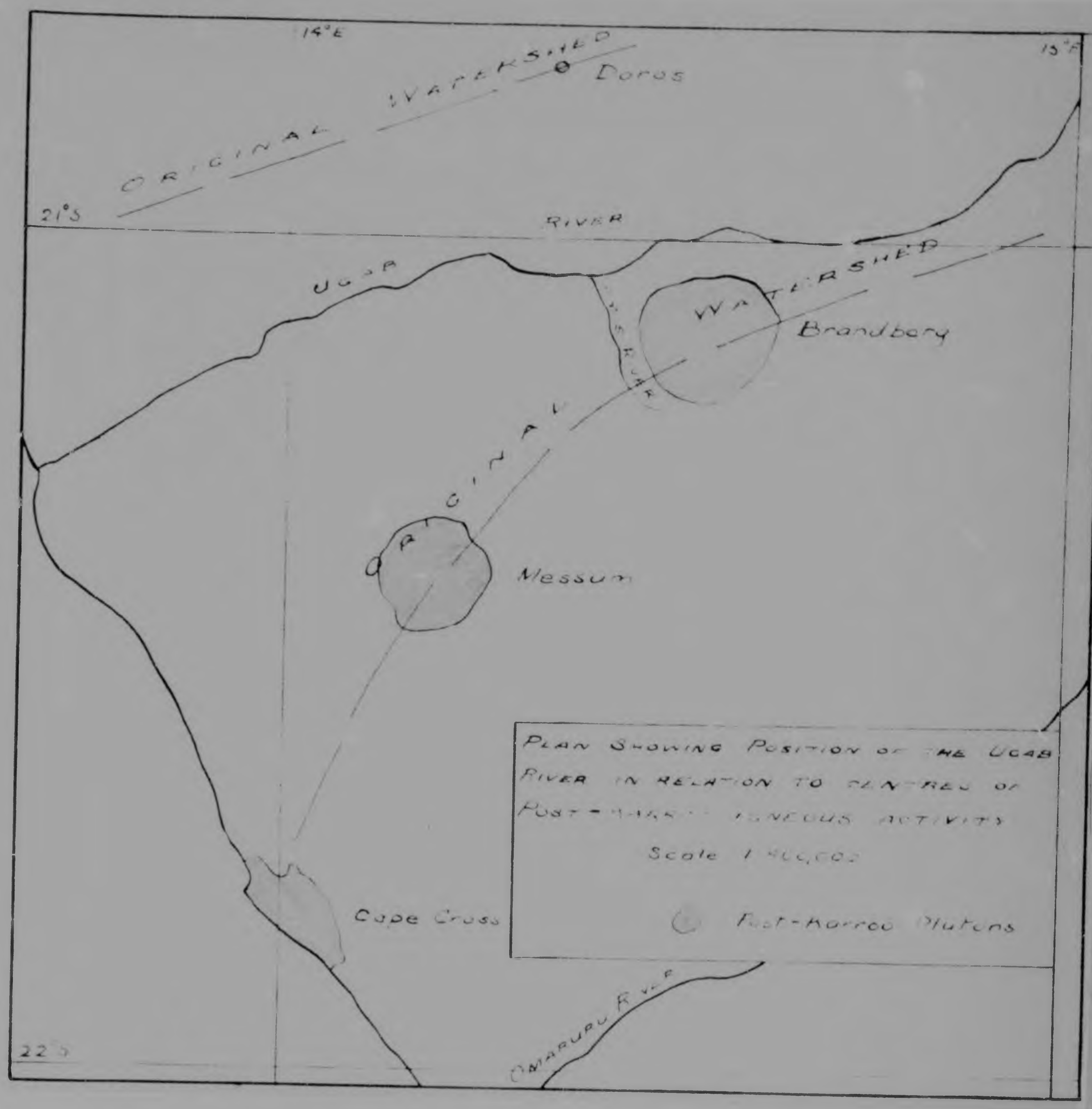

14°E
15°E
ORIGINAL WATERSHED
Doros
21°S
RIVER
UGAB
WATERSHED
Brandberg
Messum
Cape Cross
OMARURU R. MOUTH
22°S
PLAN SHOWING POSITION OF THE UGAB RIVER IN RELATION TO CENTRES OF POST-KAROO IGNEOUS ACTIVITY
Scale 1:4,000,000
Post-Karroo Plutons

Fig. 31.

been eroded to a level some 80 metres below the pre-Karroo land-surface and about 500 metres below the summits of the nearby Karroo Mountains. The valley sides formed part of the pediments of the surrounding mountains, mentioned above, and the valley bottom probably occupied a position about 150 metres above that of the present Ugab River. The area of granite, schist and marble exposed was similar to that seen today, but the degree of dissection was probably less, as is evinced by the widespread remnants, in the form of even summit-levels to many ridges, of a fairly mature topography.

During the Kalahari period, a large part of the present area was probably covered by dunes, none of which have survived. No fossils have been found in any of the recent deposits to give an indication of age, nor were any buried artefacts discovered.

4) Recent Rejuvenations.

Since Kalahari times the most important changes in the position of the Ugab River and its tributaries have followed the successive rejuvenations of the Ugab River. The basic cause of these rejuvenations was probably continental uplift, the effects of which are seen in the raised beach terraces of the Atlantic coastline of the northern Kaokoveld as well as on the coast southwards towards the Orange River. As a cause of these rejuvenations, continental uplift rather than lowering of sea-level, is postulated, owing to the fact, observed on the northern Kaokoveld Coast, that the oldest of three raised beaches varies in height above sea level as much as 15 metres. Similar observations have been made on the coast towards the Orange Mouth. (Ref. Haughton, 1931). Although this does not preclude lowering of sea-level it indicates that a somewhat uneven continental uplift has taken place.

About 110 km to the south-east of the Ugab mouth, cemented gravels can be seen on the shore at low tide, indicating that there has been depression of the land surface, as well as elevation.

A contributary cause of rejuvenation must have been a sudden increase in rainfall.

a) The First Rejuvenation.

The first rejuvenation of which records remain, left at least one example of a raised valley which exists today, running along the north side of the Naib River. The raised valley, and the several small gravel-topped plateaux which project above the Brandbergs's western pediment, represent the oldest known raised gravels of the area. These are probably similar in age to the red dunes and the older land surface of which remnants occur throughout the area. Thus the gravels, dunes and old land surface are possibly of Kalahari age. (See Fig. 32).

b) The Second Rejuvenation.

A younger set of raised gravels, which is correlated with the elevated valley of the Ugab River, would be post-Kalahari in age. This set of gravels and the accompanying raised valleys represent a drainage system which was partly abandoned during a second period of rejuvenation.

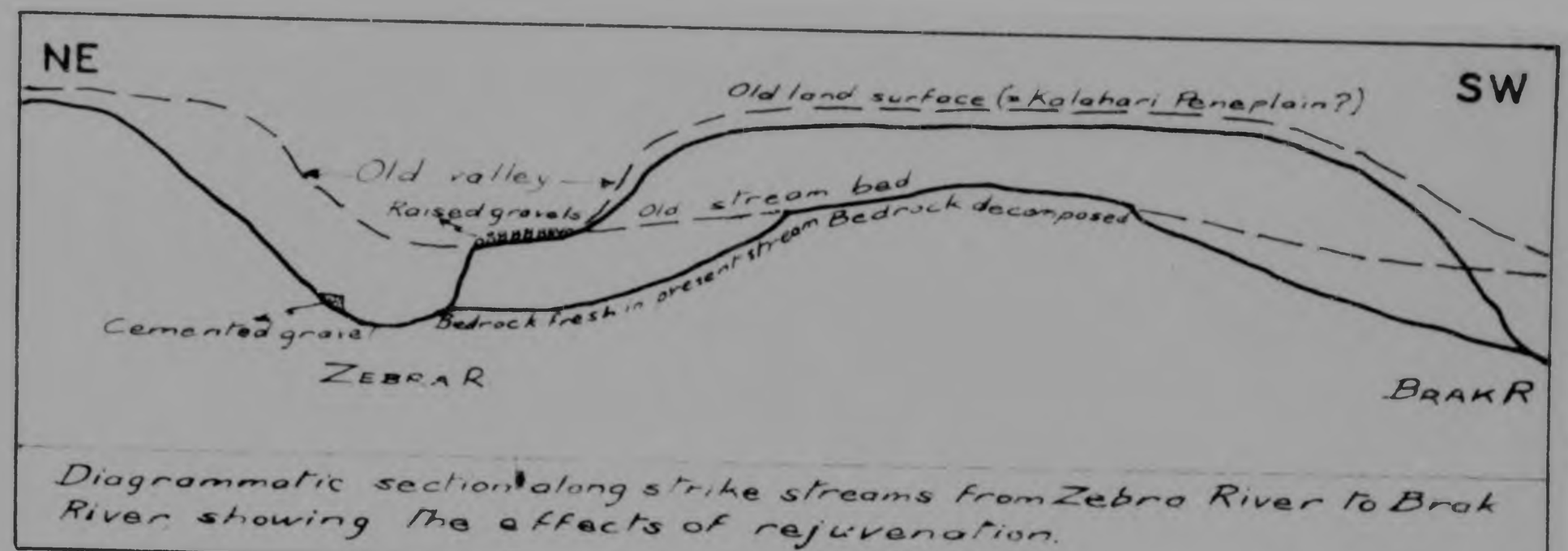
The widespread changes in position of the Ugab River were mostly due to local capture by tributaries. (See below under "River Capture"). However, deviations in the old course due to strong features such as high ridges, were commonly adhered to after rejuvenation. For example, five kilometres west of Salzputz the present river is deflected to the south along strike by the same ridge that deflected the old river. East and west of the barrier, the old valley lies to the north of the present valley.

During this period the coastal plain was brought to an advanced stage of maturity, probably by sheet-flood action.

No major lowering of the Ugab River has taken place since the second rejuvenation, but minor changes tending towards degradation are shown by the occurrence of low level cemented gravels within the present Ugab River gorge.

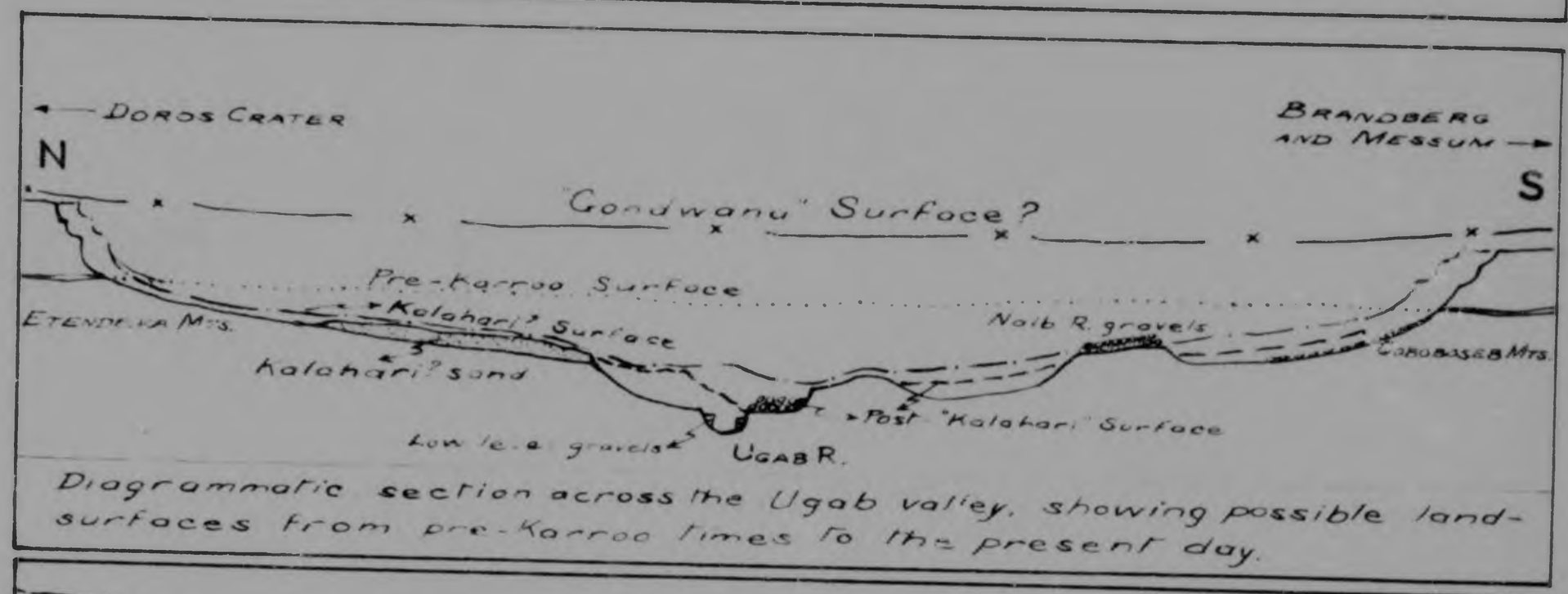
The counterparts of these cemented gravels in tributaries of the Ugab River have been found covered with travertine deposited by springs. The original springs are now dry, but salt water is found nearby.

Fig. 35.



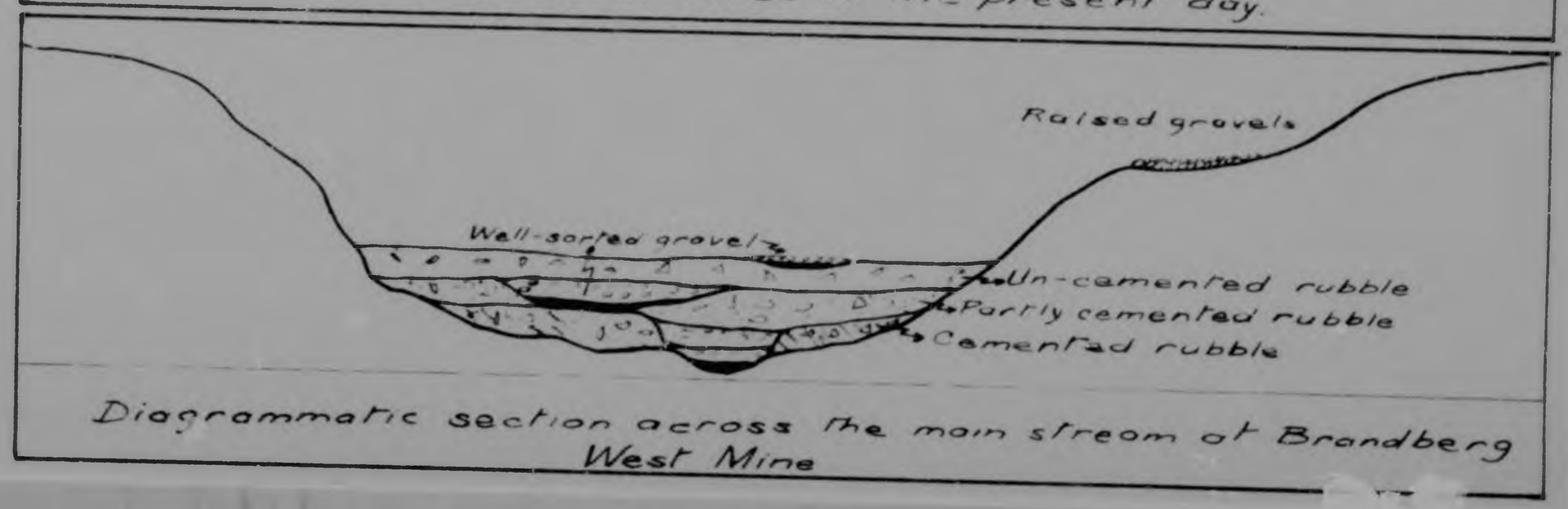
Diagrammatic section along strike streams from Zebra River to Brak River showing the affects of rejuvenation.

Fig. 32.



Diagrammatic section across the Ugab valley, showing possible land-surfaces from pre-Karroo times to the present day.

Fig. 33.



Diagrammatic section across the main stream at Brandberg West Mine

c) Later Gravels.

At Brandberg West Mine the poorly sorted cemented gravels are cut by well-sorted gravels lying on bedrock, and are covered by fairly well sorted partly cemented gravels. (See plan of streams at Brandberg West Mine, Fig. 77, and section, Fig. 33). These facts indicate that much of the gravel and alluvium that fills the numerous valleys in the area originated after a period of pluvial activity during which the landscape had been cleansed of loose material and channels had been scoured into the cemented rubble that filled the valleys. At the close of the pluvial period, the lowermost tin-bearing gravels were deposited. Arid conditions followed, and periodic torrential rains filled the valley floors with weathered material, some of which became cemented later. Then increased rainfall formed the second age of tin-bearing gravels. Arid conditions and periodic torrential rains followed. again depositing the unsorted gravels. Today the tendency seems to be towards increased rainfall, as is evinced by the shallow tin-bearing streams on the surface of the unsorted gravels. Thus, in this area, aggradation followed by partial degradation occurred twice after the scouring of the streambeds. Today, degradation is in progress. Cloos, (Ref. 1931) has described the post-Kalahari valley near the Brandberg, but did not mention the existence of gravels within the valley.

d) Present Erosion.

The recent rains appear to have been the heaviest in the area for many years. Although there are no past records of rainfall here, the large number of landslides that occured after the rains of 1949 and 1950 indicate that these rains were usually heavy. A good example of these landslides can be seen on the left side of the Brak River, 12 km from this river's confluence with the Ugab River. At this point a small natural amphitheatre exists in the rocks of the Upper Marble Series. In 1946, only one large block had fallen from the top, but in 1950 the slopes were littered with blocks of marble. Earthquake activity is not admitted as a cause of these recent landslides, as there has been no recent increase in seismicity in S.W.A. (Verbal communication from Dr. H. Martin).

It will take many years for these boulders to disintergrate and be removed by wind action, as the only catchment area for water is the amphitheatre itself. From this it may be inferred that the recent rains are the heaviest that this locality has had for possibly hundreds of years.

5) Correlation with other Areas.

Comparing this area with other areas in Africa, and using the nomenclature of King, (Ref, 1951) the following tentative correlation is put forward.

TABLE II.

CORRELATION OF LAND SURFACES.

Summits of Goboboseb Mountains.	Gondwana Surface.
Uplift and Rejuvenation.	
Red dunes, Naib River gravels, and older land surface, (Kalahari)	African Surface.
Uplift	
High-level gravels of Ugab River and coastal plain	Lowveld Surface?
Uplift	
Low-level cemented gravels and present Ugab Gorge	Limpopo Surface?

Only the "Kalahari" surface and the coastal plain surfaces are well-developed. The possible old surface on the few surviving table tops of the Goboboseb Mountains can only be inferred to exist from the mode of weathering of the lavas, which tends to preserve the upper surface of the mountains. No detritus is known to be preserved on top of these mountains.

The high-level gravels of the Ugab River, which are probably the same age as those of the coastal plain, represent only a narrow strip of country inland, and not a true peneplain surface.

The present Ugab Gorge is still in a stage of extreme youth. Figures 32 & 33 show the relationship of the erosion surfaces in the area, and of the gravels at Brandberg West Mine.

C) Discussion of Main Geomorphic Features.

Most of the nomenclature used here is that of Lahee. (Ref 1941).

Hills and Mountains.

Three main features come under this heading, viz., the Zerissenes Mountains, the Goboboseb Mountains, and the Brandberg Mountains.

a) The Zerissenes Mountains.

This represents the oldest topographical feature of the area, being a resurrected pre-Karroo monadnock. No definite reason can be given for the survival of this mountain mass up to Karroo times. The fact that steeply dipping Karroo dykes are comparatively rare in these mountains indicates that the area was one of compression rather than tension, hence possibly its survival. The geological factors controlling the form of these mountains have been discussed.

b) The Goboboseb Mountains.

These are a group of residual hills separated from the large area of Karroo rocks lying to the north by the Ugab and Amis Rivers, and dissected on their south side by the Messum River. (Hungorab River).

These mountains exhibit features, such as mesas and buttes, typical of flat-bedded Karroo rocks.

c) The Brandberg Mountains.

This great granite massif, the highest mountain in South West Africa, presents a combination of topographic features which is probably unique. The normal shape of a mountain formed from a granite plug is complicated here by the encircling Karroo hills which are integrated with the main mass and by the circular zone of metamorphic rocks at the Karroo-Brandberg granite contact.

The circle of hardened Karroo strata has acted as a barrier to normal processes of pedimentation, and the rate of lateral advance of the pediment is now probably subordinate to the rate of lowering of the pediment.

The fact that the Brandberg granite has cut through both schist and old granite has materially affected the form of the pediment which would normally exist to such a mountain in this arid region. Further, the dissection caused by the Ugab River, with its successive rejuvenations, has been a major factor in determining the form of the pediment on the north and west sides of the mountain. To the south and southeast, outside the area mapped, a well-formed pediment exists, old granite forming the floor.

2) Destructional Plains.

Several types of destructional plains are represented here.

a) Pediments.

In this desert area, the term "pediment" is more readily applied to the features skirting the Brandberg, the Goboboseb Mountains and the Zerissenes Mountains, than the term "piedmont alluvial plain".

In all three examples, only a part of the mountain mass is composed of a formation different from that constituting the floor of the pediment. The Zerissenes Mountains are partially capped by rocks of the Upper Marble Series, and the pediment where best developed is made of Middle Schist Series. The Brandberg pediment is composed of rocks of the Damara System, or old granite. The Goboboseb Pediment is the best example of the three, although it is by no means perfect. A fairly well developed bajada lies along the base of the mountains. The rejuvenations caused by the successive lowerings of the Ugab River have not yet cut into this pediment, whereas the pediments of the Zerissenes and Brandberg Mountains have been deeply dissected due to the lowering of the Ugab River, the local base-level.

b) Peneplains.

Mature peneplains do not exist in the area, but the term "peneplain" is being applied to roughly level land surfaces that belong to one period of erosion.

Little remains of the two oldest post-Karroo peneplains in the area.

As mentioned above, the table tops of the Goboboseb Mountains and the even summit level of many of the ridges possibly correspond with the original elevation of these two surfaces. (See photos, Fig. 10 and 34).

The surface of the lower of these two peneplains was broken by prominences such as the Zerissenes Mountains, and by marble ridges which at that time had a comparatively low elevation and may have been remnants of ridges that existed before the Karroo period. The summit levels of most of the ridges have not been lowered to any great extent by the first or second periods of rejuvenation, except near major rivers. Indeed, in some parts of the area such as that lying to the south west of the Gemsbok River, even the beds of the rivers and streams have not been appreciably lowered. Near the Ugab River, however, elevated gravels and valleys, abandoned after the second rejuvenation, exist at heights of up to 65 metres above present river level. Tributaries of rivers such as the Zebra and Brak run in steep narrow courses near their junctions with the larger rivers, and their headward divides are at the heads of broad shallow valleys which are remnants of the Kalahari peneplain. (See diagram, Fig 35). These old headward divides show their comparatively great age by the decomposed condition of the bedrock.

c) The South-Western Peneplain.

This nearly mature feature, shown on the map, was formed during a period of post-Karroo peneplanation, and lies not far below the position of the pre-Karroo peneplain. It is probably of Kalahari age. It consists of a nearly flat plain, sloping at a low angle towards the west and covered with a thin layer of rubble deposited by sheet-flood action. Wind deflation has removed all finer material from the surface, leaving typical desert pavement.

This peneplain has escaped rejuvenation, and in the streams lying in the hilly country to the north aggradation has occurred. This is demonstrated by the numerous examples of splitting of drainage, filling of valleys, and stream braiding. The cause of the aggradation is that the rare rains are insufficient to remove the abundant material which is available through bedrock decomposition, caused by the prevalent sea-mist.

Aeolian sand composes part of the material filling the valleys. These valleys were probably formed during the second rejuvenation period, and aggradation occurred during a later arid period.

d) The Coastal Plain.

There is no definite evidence as to the origin of this plain. Sheet-flood action was probably a major cause. Raised marine terraces, such as those found along the coast to the north and the south, are absent here.

The gravels along the sides of the Ugab River appear to be fluvial in origin. They are best developed on the north side of the Ugab River, (See photos, 5,6,10,30) and possibly represent remnants of an old flood-plain of the Ugab River.

This plain is therefore more probably a peneplain than a true coastal plain, and is probably not of marine origin. The coastal landscape has reached a fairly mature stage, as is shown by the lack of outstanding features and the braiding of streams.

3) Raised Valleys and Gravels.

(See Diagrams, Figure 32)

Corresponding with the two main periods of peneplanation are two main sets of raised valleys, in places containing gravels. The older and higher valley is found near the Naib River together with preserved gravels, and also west of Brakputz as described above. It is possible that the area west of the Brakputz will yield gravels of the same age. The younger set is found throughout the area in the form of terraces along the main rivers, and as raised plateaux and valleys, sometimes gravel-covered and up to 2 km away from the rivers. A much lower set of gravels is found within the valleys of the larger rivers, and at Brandberg West Mine, these gravels are overlain by still younger gravels.

4) Basins.

Barrier basins, windscoured pans, and typical desert playas are found in the area, as well as small basins formed by chemical action in marble. Their origin has already been discussed.

5) Drainage Patterns.

The almost complete absence of vegetation in this part of the Namib Desert has been an important factor in the control of the drainage. There is nothing to bind what little soil exists, and the result is that stream beds of various sizes have formed along every outcropping line of weakness except where such lines are protected by talus. Thus, the factor of vegetation cover being absent, only mechanical and chemical agencies are left to control erosion, and for any given set of geological conditions, the resultant topography is usually the same.

The predominant drainage pattern in the area of Damara rocks is a rectangular one, modified by changes of strike and by oblique fault line valleys. The strike of the bedding is the main control of the smaller, consequent streams, and a set of dykes, and some faults, at right angles to the strike, completes the rectangular pattern. (See Plans, Figs. 18 & 85).

The Ugab and possibly the Amis Rivers appear to be superposed, as has been noted above, but the remaining large streams are probably all consequent streams which have swung in an anticlockwise direction to their present positions, across the strike. In all the large rivers however, local control of structure is pronounced. Contact valleys exist along several stretches of the schist-granite contact, as well as along the contact of the Karroo beds and the Brandberg Granite.

6) Stream Capture.

The strong control of geological features on drainage, combined with the rejuvenation of the landscape, have produced many examples of stream capture. These may be classified according to age.

(a) Stream Capture caused by the first rejuvenation.

(b) Stream capture caused by the second rejuvenation.

(c) Later stream capture not directly connected with the second rejuvenation.

a) Stream Capture caused by the first rejuvenation.

The Naib River, flowing northwest from the Brandberg, is an example of this (See Fig. 28 (a)). The old course of the river can be clearly seen, parallel with the present river.

28

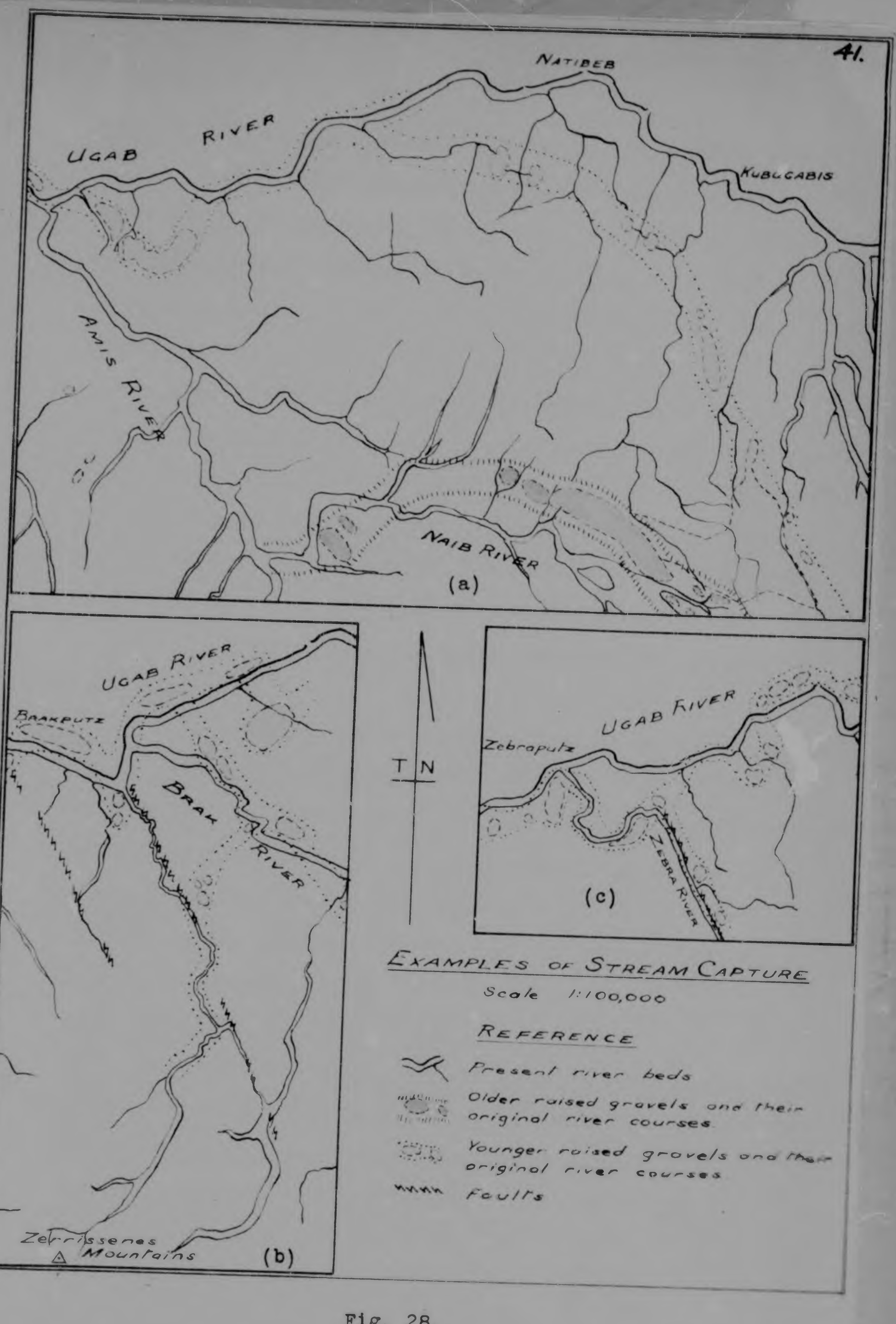


Fig. 28.

The stream that joins the Ugab River about 0.75 km south of the Brak Ri mouth has captured a stream which once ran into the Brak River. (See Figure 28 (b)). The captor stream, which runs along a line of faults, cut headwards through a monocline of the Upper Marble

28

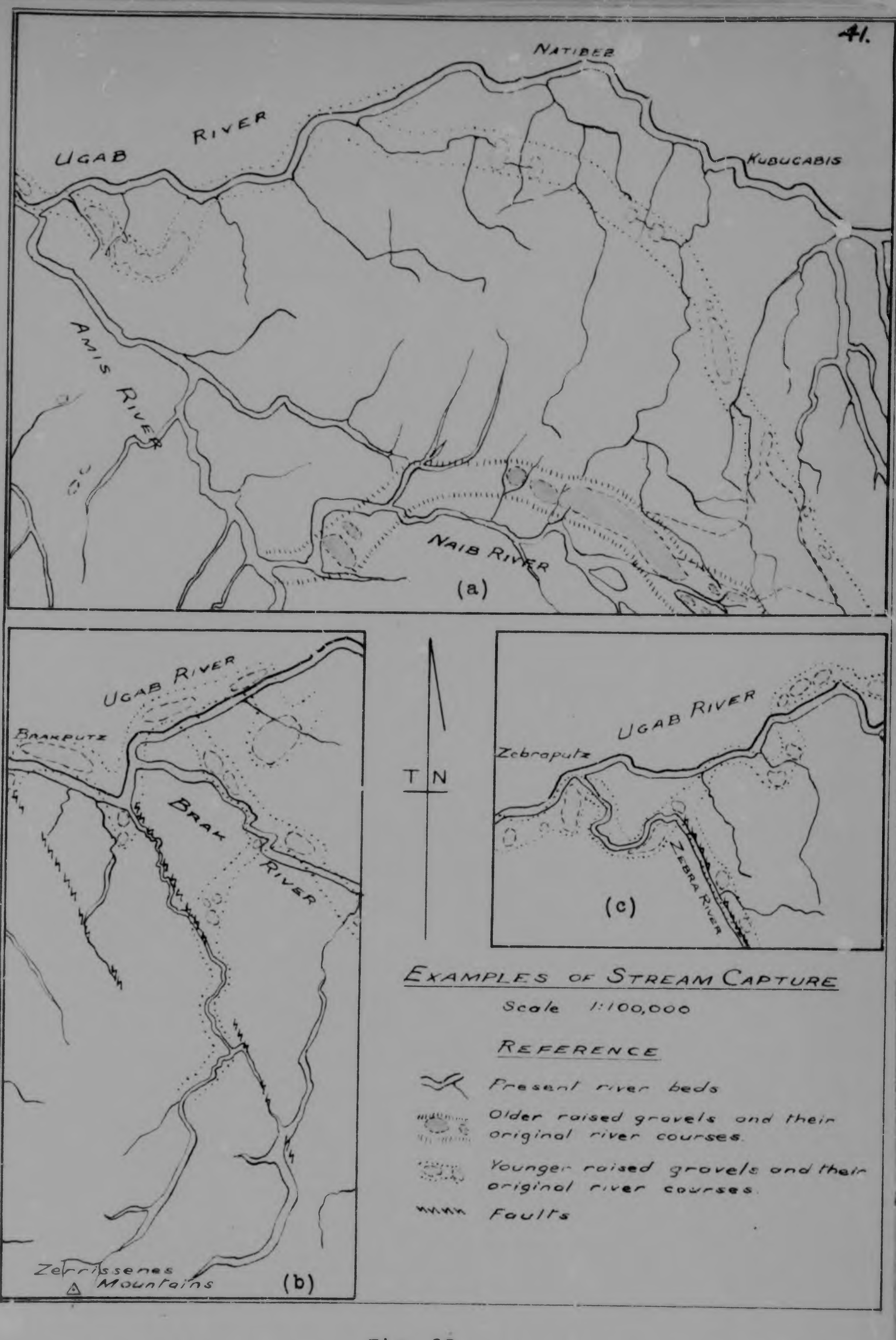

NATIBEB
KUBUCABIS
UGAB RIVER
AMIS RIVER
NAIB RIVER
(a)
UGAB RIVER
BRAKPUTZ
BRAK RIVER
Zebraputz
ZEBRA RIVER
(c)
T N
Zebrissenes Mountains
(b)
EXAMPLES OF STREAM CAPTURE
Scale 1:100,000
REFERENCE
Present river beds
Older raised gravels and their original river courses.
Younger raised gravels and their original river courses.
Faults

Fig. 28.

The history of the Naib River is a series of captures by minor tributaries during the headward advance of streams excavating downwards to the rejuvenated base level. The result is more a shifting of the river's course than a capture by a different stream. The old Naib River probably joined the Amis near the point of confluence of the present Naib River.

b) Stream Capture caused by the second rejuvenation.

Examples of stream capture caused by the second rejuvenation can be seen along most of the length of the Ugab River (See map Fig. 27). Major changes in the course of the river have occurred east of the Amis River confluence, at the Goantagab River confluence, and at Zebraputz. At Brakputz and Saltputz, the present Ugab River still runs within the confines of the ancient Ugab valley, although it is displaced laterally in several places.

The raised gravels of the Zebra River indicate that its course has been considerably changed near the Ugab River. (See Fig. 28 (c). The Ugab River has shifted to the north, and the Zebra River has occupied about 2½ km of the old course of the Ugab River, at an altitude about 40 metres below the original river bed.

Further examples of river capture are seen near Kubugabis and south of Brakputz.

i) Kubugabis.

At Kubugabis, raised gravels extend for eight kilometres from a point near the Brandberg to a point near Natibeb. Much of the catchment of this ancient river has been captured successively by three streams running northwards to Kubugabis. (See Fig. 28 (a)).

This example illustrates the strong effect of lateral ravining from a rejuvenated river, (Ref. Rich, 1938), especially where geological control, in this case the strike of the bedding, permits stream formation.

111) South of Brakputz.

The stream that joins the Ugab River about 0.75 km south of the Brak River mouth has captured a stream which once ran into the Brak River. (See Figure 28 (b)). The captor stream, which runs along a line of faults, cut headwards through a monocline of the Upper Marble

Series probably after rejuvenation commenced. (See photo, Fig 36).

The flow in the captured streams was diverted through the fault gap, from a strike joining it to the Brak River, probably because the effects of rejuvenation were stronger in the fault-line stream than in the strike stream.

c) Later stream capture not directly connected with the Second Rejuvenation.

An example of this exists near the source of the Gemsbok River, (See Map, Fig. 27). Aggradation of gravel in the Gemsbok River bed at this point has diverted towards the west much of the flow that originates in the alluvium-covered south-western peneplain.

CHAPTER III

GEOLOGY OF THE AREA.

The description of the geology will be treated chronologically starting with the oldest rocks. Detailed descriptions of the rock specimens listed are given under "Petrography".

The geological formations present are shown in Table III.

(A) Rocks Of The Damara System:

1. The Lower Schist Series:

The oldest rocks seen in this area are the Lower Schist Series, These consist of a stretch of intensely folded schists in the form of three anticlinoria exposed in the Ugab River valley from the Goantagab River confluence to a point 16 km to the west.

Owing to the absence of marker horizons within this series, its exposed thickness can not be measured, but can only be judged from the measured thickness of the overlying Middle Schist to be at least 500 metres. The lower schist weathers dark chocolate brown and is commonly compact, rather schistose, breaking with a subconchoidal fracture.

The dominant rock is a quartz biotite schist, (Nos. 391, 417, 422, 424 and 429).

Where the metamorphism is of medium grade, mottled and spotted granulites and hornfelses are developed giving rise to amphibole granulites, amphibole-biotite granulites, and amphibole-pyroxene hornfelses. (Nos. 277, 278, 279, 280, 281, 282, 283 and 284). Tourmaline-muscovite hornfels is developed in the Lower Schist at quartz vein contacts at Brandberg West Mine. (Nos. 404, 409, 413, 414 and 420).

2. The Lower Marble Beds:

This is a consistent marker which can be traced over a large area, and which separates the Lower Schist from the Middle schist, (see photos, Figs. 7, 78, 80). The marble band consists of two main components above which lie about 5 metres of schist topped by a narrow marble band. The Upper component is bluish grey marble, two to four metres thick and medium to coarse grained. Microscopic examination shows that it contains more than 95% calcite and the remainder is mostly quartz. (Nos. 263 and 390).

TABLE III

STRATIGRAPHY OF THE AREA WEST OF THE BRANDBERG.

System or Relative age.	Series	Stage	Character	Thickness	Igneous Intrusions.
Recent			Alluvium, sand Cemented gravels	From less than 1 metre to more than 15 metres.	
Post-Kalahari		Younger high-level gravel.	Partly cemented gravels.	From less than 1 m. to more than 5 metres.	
Kalahari ?		Older high-level gravel.	Partly cemented gravels.	From less than 1 m. to more than 3 m.	
Post-Karroo			Fault breccia	From less than 1 m. to about 7 m.	
Late-Karroo				At least 2000 m. vertical thickness. From less than 1 m. to more than 50 m.	Brandberg Granite, Dolerite dykes sills and plugs.
Karroo	Stormberg	Stormberg lavas	Amygdaloidal and porphyritic basalts.	Approximately 450 m.	
		Cave Sandstone	Sandstones and pebble bands.	Approximately 40 metres.	
	Dwyka		Mudstones, shales, sandstones, limestones & fluvioglacial basal conglomerates.	From 150 m. to 260 m.	
Pre-Karroo, post-Damara					Aplitic granite, acid pegmatites & quartz veins. Biotite Granite Granodiorite & quartz diorite.
Damara	Upper Schist		Schists & thin quartzite bands	650 m.	
	Upper Marble		Marble & thin schist bands.	125 m.	
	Middle Schist		Schists	350 m. to 500 m.	
	Lower Marble		Marble & thin schist bands.	10 m.	
	Lower Schist		Schists	500 m.	

The lower component of the main band is about as thick as the upper, and consists of alternating yellowish and dark brown to black bands averaging about 5 cm. to 10 cm. in thickness. The yellow rock is an impure marble, with up to 30% quartz grains as the impurity. The dark bands consist of schistose brown marble (No.264) and quartz phlogopite schist, (No.265). Actinolite appears in the schist at localities of medium grade metamorphism (No. 285). The total thickness of the two components is usually less than 7 metres.

The topmost marble band is about 0.5 m. to 0.7 m. thick and weathers to a yellowish brown colour. It is a marble similar to the yellow marble of the main band.

At Brandberg West Tin Mine, a calcareous band underlies the lower marble band about 75 metres below it. This band is a poor marker, as it is dark brown and rather schistose and weathers similarly to the Lower Schist. (No.408). This rock becomes an actinolite-diopside-orthoclase hornfels in areas of medium grade metamorphism. (No.389).

3. <u>The Middle Schist Series</u>:

Above the Lower Marble Series and below the Upper Marble Series lies a considerable thickness of schists. This series has been called the Middle Schist. Owing to the nature of the folding, its thickness could be measured at only two places, on the Zerissenes Mountains and on the Brak River (See map Fig. 27). The first measured thickness (350 metres) is thought to be more accurate than the second (500 metres) because in the first case only one minor fold occurs between the exposures of Lower and Upper Marble. In the second case at least two such folds occur.

The Middle Schist includes several bands of blocky granulite which resist weathering better than the more schistose rocks. These bands consist of biotite granulite and weather a reddish-brown colour, and form scree slopes of large angular blocks (Nos. 59, 274). The more schistose components of the Middle Schist consist dominantly of quartz-biotite schist, and weather to a darker colour, forming smooth slopes (Nos. 60, 63, 261 and 286).

Medium grade metamorphism in the Middle Schist has produced hornfelsic rocks similar to those in the Lower Schist (Nos. 72, 73, 75, 273, 288, 298), and more rarely pseudo-diorites, (Nos. 287, 288, 289, see under "Petrology").

(a) Conglomerate:

Near the top of the Middle Schist series, an impersistent narrow conglomerate occurs at two localities on the Sesob River. A third possible locality is on the Brak River, where conglomerate float was found. The occurrence at one of the Sesob River localities consists of a line of scattered pebbles up to 30 cm. in diameter, of granite, gneiss and amphibole quartzite. The pebbles are sheared and are set in a sheared dark matrix, (No. 71). They were found in the comparatively fresh rock in the side of the small canyon used as a road from the south into the Sesob River. Another occurrence, further upstream on the Sesob River shows a better sorted conglomerate about 15 cm thick, consisting of lenses of sheared, well-rounded pebbles of quartz, biotite quartzite (No. 61) and granite averaging about 1 cm diameter, in a quartzitic matrix. Laterally, this conglomerate grades within a few yards into a bed of scattered sub-angular pebbles of similar composition to that given above, in a schistose matrix.

A third possible locality is at the headward divide of a small stream leading into the Brak River from the north. The only occurrence observed here was in the form of a loose block 0.6 metres by 0.3 metres by 0.25 metres in size. This consisted of sheared, well sorted conglomerate, containing mostly quartz pebbles, average size 1 cm., in contact with a band of biotite schist. The source of this float could not be found. The area is one of Middle Schist, with synclinal ridges of the Upper Marble Series.

It is difficult to judge the significance of this conglomerate. If it represents evidence of an unconformity, then it is the only such evidence. An angular unconformity would be imperceptible in the extreme folding, and the apparent parallelism of the Upper and Lower Marble Series seems to allow of a disconformity only. The scattered distribution of the pebbles and the occasional well-sorted conglomerate lenses suggest fluvio-glacial origin, but it must be stated that the conglomerate by no means resembles any of the typical glacial beds found in South West Africa; indeed the occurrence of a tillite over so small an area would be unusual.

Above the horizons of the conglomerate and immediately below the Upper Limestone series, a soft band is found in the schist. This weathers to a powdery talcose material, which is too decomposed to permit microscopic identification, but which appears to be mostly sericite, with iron oxides.

In the Sesob River area, ellipsoidal bodies occur which contain considerably less biotite than the surrounding biotite schist. These bodies vary from a few centimetres in length to as much as two metres, and from 1 cm. in thickness to 25 cm. They are oriented parallel with the strongest cleavage direction present (No. 261).

Ellipsoidal bodies similar in shape and size to the above, but differing in composition, were found in the schist in the Gemsbok River area. The ellipsoids consist of zoned aggregates of unsheared coarse-grained calc-silicate minerals, (Nos. 287, 288, 289), and are similar to certain pseudo-diorites described from the Southern Appalachian region and from the Gold Coast, and the Karroo system. These are described more fully under "Petrology".

4. <u>The Upper Marble Series</u>:

The Upper Marble Series bears a remarkable lithological resemblance to the Lower Marble Series. The series is made up of three main components, the Yellow Marble at the bottom, the Brown Marble in the middle and the Blue Marble at the top. (see photos. Figs. 37, 38). The total thickness, however, is about 25 times that of the Lower Marble Series.

The average thicknesses of fifteen sections measures in the area are shown on the following table:-

TABLE IV

THICKNESS OF UPPER MARBLE SERIES FROM BASE OF YELLOW MARBLE ZONE TO TOP OF BLUE MARBLE.

Area	Dip over-turned.	True thickness of southeast side of syn-cline (in feet).	True thickness of northwest side of syn-cline (in feet)	Dip
Sesob River	53°	468	144	31°
"	55°	228		
"	63°	480	216	30°
"	77°	564	252	45°
2 miles north-east of Sesob R.	58°	456	172	30°
Ugab R. west of Sesob River.	58°	290?		
Brak River	60°	444		
Tributary on east side of Zebra R.	73°	540	216	47°
"	60°	420		
"	49°	290		
Averages		418	200	
		= 125 metres	= 60 metres.	

Thicknesses of adjoining limbs in the same fold are joined by dotted lines.

The above figures illustrate the consistent thickening of the overturned limbs of folds, relative to the limbs that are right side up. (See under Tectonics, "Fracturing and Deformation connected with the Folding").

The distance from the Blue Marble to the topmost marble band is as much as 300 metres in the Sesob River area.

(a) The Yellow Marble Zone. (See Section 11, Fig.39).

The Yellow Marble consists of about 40 layers composed of yellow quartzitic marble, (Nos. 235, 240, 241, 395), black or brown schistose marble (Nos. 231, 232, 234, 237), and some light brown biotite marble bands (Nos. 230) at the base. Rare bands of light grey marble (No. 238) occur in the Yellow Marble zone.

In some areas, the biotite bearing marbles have been metamorphosed to actinolite-biotite schist, (No. 293), actinolite-diopside-orthoclase rock (Nos. 291, 295), actinolite-orthoclase rock (No. 294) and amphibole-garnet rock (No. 292).

Some of the yellow quartzitic marble bands attain a thickness of 3 metres in the western part of the area, but most are between 0.25 m and 0.45 m. in thickness.

The darker bands are somewhat thinner. Narrow dark lines are seen traversing the marble bands, or interbedded with them, and microscopic examination shows these lines to be made up of minute mosslike graphite particles.

The Yellow Marble Zone comprises about half of the total thickness of the Upper Marble Series. Individual yellow marble bands vary considerable in thickness laterally. Towards the top of the Yellow Marble Zone brown marble bands appear in increasing numbers.

(b) The Brown Marble Zone:

The Brown Marble is a comparatively narrow group, averaging 10 to 12 metres in thickness. It consists mostly of a light chocolate brown biotite marble (Nos. 242, 243), similar to that described above. There are a few intercalated schistose bands (No. 13).

Yellow marble bands which are rare within this group in the central and eastern part of the area, become more plentiful to the west (No. 245) where the brown marble group loses its individuality and appears to become an extension of the Yellow Marble.

(c) The Blue Marble Zone:

This is the most distinctive of the three marble zones and typically it consists of even-grained bluish-grey marble, (Nos. 47, 117, 118, 252) over 60 metres thick. It is quite different from the underlying marble bands, and shows no bedding through most of its thickness. In the eastern part of the area, it immediately overlies the Brown Marble, and to the west a group of yellow and brown marble bands totalling up to 20 metres in thickness and similar to those composing the yellow Marble Zone, separates the Blue Marble from the Brown Marble. This group has been called the Intermediate Marble. (No. 247). A well marked black band, 10 cm to 15 cm. thick, occupies a position in the centre of the Blue Marble band, and is being referred to as the Middle Black Line. (See photo, Fig. 37). The rock is a biotite schist, (Nos. 48, 249 and 299) and is usually accompanied by two thin white marble bands. It is generally better exposed in the western part of the area than in the east.

The Blue Marble is commonly overlain by a narrow (15 cm.) but distinctive yellowish-white quartzitic band, and continuing upwards, from 6 metres to 20 metres of biotite schist (No.50) and calcareous

granulite (No. 57), on which lies a layer of fine-grained dark blue or black graphitic marble, 3 metres thick. (Nos. 251, 258, 259). The latter is not a prominent band, and usually lies along the bed of a strike stream.

In the Brakputz area, two narrow (45 cm. to 90 cm.) marble bands, weathering an olive-brown colour, lie respectively 45 metres (No. 253) and 65 metres (No. 254) above the black marble. In the Amis River area, these bands are represented by two bands of almost pure marble (Nos. 134, 135). Biotite schist, or biotite granulite separates the bands (Nos. 52, 53, 54, 55, 83, 103, 108, 109, 111, 208, 255, 256, 257). In the Sesob River area, the topmost marble band is as much as 300 metres above the Blue Marble.

Metamorphism has produced the following rock types in the Blue Marble Zone:

Intermediate Marble - Actinolite marble (Nos. 46, 46A)

Blue Marble - Orthoclase marble (No.49) actinolite-anorthite rock (No.77), actinolite-diopside rock (No.113).

Schist above Blue Marble - Actinolite granulite (No.114).

Dark Blue Marble - Quartzitic Marble (Nos. 51, 56), and schistose muscovite marble (No. 300).

Upper Marble Beds. Diopside-vesuvianite rock (No. 69), Diopside-wollastonite-garnet-versuvianite rock, (No. 102), and Quartz-garnet-diopside-wollastonite rock (No. 101).

Upper Schist Bands - Actinolite granulite (Nos. 76 and 105), and Actinolite-diopside granulite, (No. 104 and 112).

A garnet-fluorite rock (No. 85) apparently the product of metasomatic action, occurs in the top of the Blue Marble band near the fault which lies to the north-east of the Gemsbok River. (See under "Petrology").

Xenoliths of rocks probably belonging to the Upper Marble Series have been found in the granite, and include the following rock-types: diopside-plagioclase-vesuvianite rock (No. 79) sericite marble (No.121), actinolite biotite granulite (No. 80), actinolite-diopside granulite (No.81), and tourmaline-hornblende-diopside rock (No.217).

5. The Upper Schist Series:

The Upper Schist series is composed of biotite schists (Nos. 136, 197, 199, 200, 202) some of which are spotted or knotted, biotite-cordierite hornfels (Nos. 83, 377) and knotted calcareous quartz schist (No. 204). Some of these schists are locally altered to actinolite hornfels (No. 319) quartz-muscovite-biotite schist (No.219) and chlorite schist (No.311).

Biotite-poor ellipsoidal structures, similar to those found in the Middle Schist Series, are common in the Upper Schist Series, in the western part of the area.

The thickness of the schists above the top of the Blue Marble band could not be determined with any accuracy owing to the intense folding and the lack of marker horizons. The next distinctive formation above the Upper Marble horizon is a sheared quartzite band about 6 metres thick (No. 191) with a poorly developed gritty pebble-bed at its base. The quartzite is locally altered to actinolite quartzite (No.137) and actinolite-diopside quartzite (No. 1). This quartzite and about 60 metres of overlying biotite schist are the youngest members of the Damara system that exist in this area.

The thickness of the intervening schists is certainly more than 300 metres, if the prevailing pattern of tight folding is repeated to the east, and it is probably of the order of 600 metres.

The rocks of the Damara System were tightly folded and later intruded by several ages of granite, which caused minor warping and folding. (See under Tectonics). No field evidence has been found for the presence of basic dykes that are pre-Karroo or pre-granite in age.

(B) Post-Damara Acid Intrusions:

1. Granitic Rocks:

The oldest granitic rock in the area is a fine- to medium-grained grey granodiorite (Nos. 125, 366, 374, 375). This rock covers a large area, to the west of the Gemsbok River but is present only in small bodies in the eastern part of the granite area. The field relations of the granite and the later intrusions are difficult to determine, owing to the resemblance between varieties of granite belonging to two different periods of intrusion.

The rare well-defined contact exposure give an indication of the age relationships, but over wide areas the impracticability of exact determination of rock types in the field makes accurate mapping of granite contacts difficult.

The grey granodiorite appears to merge with a fine to medium grained grey quartz diorite (Nos. 100, 130, 216). A minor amount of fine to medium-grained pinkish grey granodiorites (Nos. 126, 301), and medium-grained pinkish grey quartz diorite was intruded later. Dykes and sills of pink quartz diorite (Nos. 106, 107) cut the Upper Marble Series in the west.

The major intrusion of the area followed, consisting of a pinkish grey or grey biotite granite (Nos. 99, 306, 308, 309, 312, 313, 373), generally coarse-grained and porphyritic but with fine-grained varieties. The phenocrysts where well developed usually have a linear orientation, parallel with the schist contact. Individual phenocrysts are up to 7 cm. in length. This granite is similar to the Salem Granite (Ref. Wagner, 1915, p. 40) and is generally intruded between the schists and the granodiorite. It is best developed in the eastern part of the area.

The final phases of granite intrusion in the area consist of a pinkish aplitic biotite granite (No. 326), which cuts porphyritic biotite granite, and a coarse salmon-pink granite rich in orthoclase (No.388). These granites occur in small quantities near the schist-granite contact. Their age relative to each other is not known.

The form of granite body is described below in the discussions of the history of the Damara period and under "Tectonics".

A small plug of vesicular acid lava (No.24), containing large phenocrysts and inclusions of quartz, occurs in the Lower Schist Series, ½ km northwest of Brandberg West Mine. Its age is unknown, but it possibly belongs to the same period of intrusion as the Brandberg.

2. Acid Dykes:

Most of the acid dykes in the area lie in schist within four kilometres of the granite. They are rare in the granite, except near the schist contact.

Only two small groups of acid dykes lie as far as 4 km from the granite, one at a position east of the head of the Gemsbok River, (No.270), and one to the east of the large salt pan,(No. 88). They are rarely as much as 3 metres thick and average about 0.6 metres in thickness. Lengths vary from 3 metres to about 1.8 km. The dykes almost invariably contain quartz, microcline albite and muscovite.

Tourmaline was found in only two specimens (Nos. 302 and 378). A pegmatite 2½ km from the old granite near Kubugabis differs from all the others examined, in that it contains about 2% pyroxene and also about 2% apatite (No. 141).

Aplite No. 226 cuts the biotite granite near No.216, and pegmatite No. 307 is in granite No. 306. Pegmatities Nos. 315 and 324 have been intruded into pink biotite granite.

Most of these dykes are intruded along bedding planes in the schist or marble (see map, Fig. 40). Oblique or cross-dykes are rare, and are always smaller than the strike dykes.

Generally, pegmatites are rare compared with the Uis and Erongo areas. About half of the number of acid dykes are fine-grained aplites, (e.g. Nos. 88, 132, 226, 303), the remainder being medium to coarse-grained pegmatites.

3. Quartz Veins:

The three types of quartz veins that occur in the area are described under "Economic Geology". A large amount of quartz veining has occurred in the schist country, but quartz veins are rare in the granite. Eluvial concentrations of vein quartz in parts of the schist country have formed "desert pavement" consisting almost entirely of quartz.

An unusually large concentration of quartz-tourmaline veins occurs in the Upper Schist Series about two miles east of the eastern end of the granite lying to the south of Brandberg West Mine. No economic mineral has been found in this area, which is situated along an anticline in the schist.

The area around the Sesob River lead occurrences contains a large number of quartz veins and vein patterns similar to those described in the lead occurrences are found in most of the anticlines there.

BRANDBERG WEST AREA

PORTION OF THE SCHIST-GRANITE CONTACT SOUTHWEST OF THE GEMSBOK RIVER

SCALE:

0 ¼ ½ ¾ 1 Kilometres

0 ¼ ½ ¾ 1 Miles

REFERENCE

- Surface Crust
- Alluvium
- Raised Gravels
- Upper Schist Series
- Upper Marble Series
- Middle Schist Series
- Vesuvianite-diopside rock
- Pink Granite (Biotite Granite)
- Grey Granite (Granodiorite)
- Acid dykes
- Dolerite dykes
- Flat-lying dolerite sheets
- Faults
- Anticlines
- (123) Specimen numbers

FIG. 40.

Small areas with profuse quartz veins lie in anticlines to the west of the bend in the Zebra River near its confluence with the Ugab River. These veins have the typical criss-cross fracture pattern, and the wallrock is tourmalinized, but no economic mineral is present.

No reason can be given for the presence of quartz veins in anticlines adjoining unveined anticlines. The age of the veins with respect to the Karroo Rocks is unknown, but they are probably pre-Karroo. No quartz veins were found in the Karroo rocks in the area.

(C) Geological History of the Damara Period.

1. Deposition of the Sediments:

The Damara system as exposed in this area consists essentially of fine-grained rocks that were, before metamorphism, arenaceous shales, arenaceous and argillaceous limestones, and pure limestones. Sandstones and pebble bands are rare and in comparatively thin beds. Deposition probably took place in deep water, near the centre of a deep geosyncline. The land bordering this sea was the source of sedimentary materials. During each of two stages, the supply of fine material diminished, and finally ceased, while limestones were being formed. The limestone deposition seems to have been seasonal to some extent. Thin layers of calcareous mud were laid down alternating with layers of purer calcareous material, and finally nearly pure carbonate was deposited over a comparatively long stretch of time. Then, carbonate deposition stopped suddenly and clay and fine sand accumulated again. Two or three thin layers of carbonate material were deposited at fairly long intervals after this, but were finally overlain by large thicknesses of arenaceous muds. The second formation of limestone, (now the Upper Marble Series) was much greater than the first, but followed an almost identical pattern of formation, and rhythmical development of layers, alternately rich and poor in carbonate matter occurred. In between the two limestones the presence of conglomerate pebbles in a shaly matrix, and of quartz pebbles in a sandy matrix, indicates that there was possibly a short period of glacial deposition; part of this glacial material was rewashed, probably under shallow water conditions and the sandy pebble beds were formed. The presence of calcareous nodules, now highly altered, near this horizon is possibly indicative of glacial action, since similar nodules are common in the Dwyka series.

After the upper layers of limestone had been laid down, argillaceous sediments were deposited over a long period. Then the sea-level dropped once more, possibly exposing dry land, and an advancing shore line led to the formation of a thin covering of sandstone with a basal gritty pebble-bed. The material of this arenaceous facies was formed by concentration of the material in the argillaceous beds. On the evidence of the fold structures, as explained under "Tectonics", this facies possibly marks an unconformity. The water level rose once more, and the deposition of argillaceous sediments was resumed. There the record ends in this area. The formation of about 1,700 metres of sediments has been described. above. A large thickness of sediments probably lay above the known upper limit of the Upper Schist Series before erosion of the Damara land surface began. Towards the northeast, across the Ugab River lie folded sediments that are probably higher in the system. Rocks older than the Lower Schist Series, as seen west of the Goantagab River confluence, are probably not exposed in this region, as the known exposures are in dome-like anticlinoria which are closed, both north and south of the Ugab River. North of the Ugab River the strike of the beds swings towards the north, and most of the Damara rocks below the Upper Schist Series become hidden under Karroo beds.

2. Folding of the Sediments:

After deposition, the sediments were folded. There is no evidence, such as thickening of beds in synclinoria, to suggest that folding began during deposition.

The present attitude of the folds could have resulted from pressure from the southeast and east. The cause of the movement was probably connected with the filling in of the geosyncline and the isostatic adjustment which followed. Minor folding effects were caused by attenuation and squeezing, especially in the limestones. The larger effects could have been caused by similar processes, due to the great thickness of sediments deposited. Most of the movement took place along bedding planes, but the near-horizontal cleavage in places suggests movement independent of bedding.

In the present area, the regularity of folding of the sediments, which now occupy less than half their original area, suggests that they were moved on a slightly uneven floor, which possibly consisted of the rocks underlying the basal Damara beds. A small degree of relief in this floor could have caused the over-riding folds to rise and be stretched, along strike, and to be dragged behind the axial line of the folds on either side. Bends in the plan positions of the folds, convex towards the south, indicate localities of such probable "humps" in the floor of the folds. The stretching of the folds occured mostly along strike, as stretching in a northwesterly direction would merely cause a local opening of the folds. The bends in the folds (see plan, Fig. 27) are generally the loci of dykes and of faults, as at Brakputz, along the Sesob River and between the Gemsbok and Sesob Rivers. These lines of weakness were residual up to the time of the post-Karroo disturbances. The bends that lie within the main body of the Damara rocks, are not of the same origin as the bends near the granite contact, which are due to the intrusion of the granite.

Another cause of folding could have been the movement of the floor of the sediments towards the southeast, due to convection currents in the underlying magma. Whatever the cause, the effect would have been similar, namely, the production of a series of overturned folds with axial planes dipping towards the southeast.

3. <u>The Granite Intrusions</u>:

The granitic rocks were intruded after the main folding had occurred. Quartz diorite and granodiorite were the first rocks to be intruded, but the intrusion of biotite granite was of greater extent than the earlier intrusion, and now separates most of the earlier intrusions from the sediments. The granite was intruded in the form of a composite phacolith, which forced its way in between bedding planes in the Upper Schist Series a short distance above the top of the Upper Marble Series. Thus the shape of the phacolith was largely determined by the positions of the anticlinoria and synclinoria of the Upper Marble Series. The edge of the phacolith followed, not necessarily along a horizontal plane, the top of the Upper Marble Series. The wedge-shaped edge of the phacolith bent the southeast-dipping folds towards the west, the direction of least resistance.

The sedimentary roof of the phacolith was possibly highly altered by the earliest intrusions, especially directly above the areas where the intrusives broke through from below. The roof material was possibly reconstituted into granodiorite and quartz diorite.

The granite-schist contact exposed today represents partly the lower and partly the upper contact of the phacolith. The subject of the structure of the granite is dealt with in greater detail under "Tectonics".

Some of the pegmatites and quartz veins in the area were directly derived from this granite, in places where the Upper Schist is underlain by granite. Other acid dykes, such as those east of the salt pan, are indirectly the result of the granite intrusion which bent the sediments lying to the south downwards on an east-west hinge-line. Lines of weaknes along this hinge line were intruded by acid dykes which probably originated in a deeper granite. Structural controls affecting the emplacement of quartz veins in the Damara beds are described under "Economic Geology" Apart from some mineralised quartz veins and a form of vertical zoning, described under "Petrology", there is little evidence to indicate the presence of a deep body of granite. The postulated "humps" underlying the folds may have been caused by such a granite, which could have been intruded at the same time as the known granite intrusion.

The biotite granite, the aplitic granite and the pegmatites belong to successively later stages in the differentiation of a parent magma. (See under "Petrology").

The older granodiorite is possibly a true igneous rock, and one of the first products of differentation of a parent magma. There is no field evidence to suggest that it originated through the alteration of the Damara rocks, but microscopic evidence indicates that some of it is a reconstituted sediment.

(D) Correlation:

1. The Folded Schists and Marbles:

In their lithological, stratigraphic and tectonic features, the pre-Karroo rocks of this area are closely similar to rocks of the Damara System as found elsewhere. A comparison of the stratigraphy of the present area with that of other areas is tabulated below:-

TABLE V

CORRELATION OF SCHISTS AND MARBLES.

Area West of Brandberg			Western Damaraland (Frommurze Gevers, 1929).	Windhoek and Rehoboth (Gevers, 1934 and De Kock 1934).
Series	Rock Types	Thickness.		
Upper Schist Series	Schist, Quartzite Unconformity Schist with narrow marble bands near base.	Total 600 meters	Khomas Series Schist & Quartzite.	Khomas Series Schist & Quartzite. Tillite Horizon.
Upper Marble Series	Top band of Blue Marble up to 600 metres thick. Many lower bands separated by schist.	Av. 125 m.	Marble Series Numerous marble bands incl. a top-most band, up to 30 m thick Intercalated schist bands.	Marble Series. Marble bands, schist and Itabarite.
Middle Schist Series.	Schist Altered limestone nodules Tillite? horizon Schist	350 metres to 500 metres.	Tillite Horizon.	
Lower Marble Series.	Marble band	10 metres.		
Lower Schist Series	Schist	At least 500 m.	Quartzite Series Quartzites and schist with some marble bands.	Quartzite Series Quartzites, arkose and conglomerates.
	Total	± 1,700 m.		

The Lower Schist Series appears to be a lateral variation of the Quartzite Series, similar to that found in the northern part of Damaraland.

The possible tillite horizon could have originated in floating ice, swept by currents towards the west from the Western Damaraland area, which was probably the focus of glacial activity.

2. The Granitic Rocks:

The granitic rocks of this area bear a strong resemblance to the post-Damara granites of adjoining areas, both lithologically and in mode of emplacement. The differentiation series is present in almost all the areas where Damara rocks are invaded by granites (Gevers, 1929, p.42) The granites in the other areas are almost invariably emplaced as concordant bodies in the schists and marbles (Gevers, 1929, p. 39).

Mineralogically the biotite granite of the Brandberg West Area is similar to the Salem Granite of the Omaruru District, as described in the Dept. of Mines publication, "The Geology and Mineral Deposits of the Omaruru Area", 1939, p. 19. The aplitic granite (No.326) could well be the equivalent of the Aplitic Granite described on page 21, op cit. The older granodiorites and quartz diorites are probably equivalent to the rocks that are described as being older than the Salem Granite, c ge 22, op cit.

There is no evidence of any deposition of rocks from the last acid intrusion up to Karroo times. Rather, erosion cut deep into the Damara rocks and granite, and there were probably no large earth movements. The Karroo rocks were deposited on the uneven surface of an imperfect peneplain. The correlation of these rocks with the Karroo System has long been recognised. (Ref. Du Toit, 1939).

(E) The Karroo System:

The following is a tabulation of the Karroo rocks found in the area.

TABLE VI

GENERALISED SECTION THROUGH THE KARROO ROCKS.

1) Section in the Amis River area.

Rock types.	Approx. thickness.	Series.
Dolerite dykes and sills		Post-Karroo
Amygdaloidal and porphyritic basic lavas with intercalated sandstone lenses at base.	450 m.	Stormberg
Sandstones, grits and pebble bands with intercalacted mudstone bands.	40 m.	Stormberg
UNCONFORMITY ?		
Red, brown and black mudstones with three main zones of sandstone, the lower one being fossiliferous.	70 m to 80 m.	Dwyka
Brown limestones and limestone nodules in brown shale with intercalated pink sandstone and dark purplish brown shale.	20 m.	Dwyka
Alternating pale sandstones, grits, purple sandstones, purble, greenish and reddish brittle shales and dark mudstones, with some brecciated layers.	60 m. (W. of Amis R. 110 m. (E. of Amis R.)	Dwyka
Basal conglomerate (fluvioglacial?)	Up to 2 m.	Dwyka
Red and yellow mudstones or mudstone breccia.	Up to 6 m. Up to 12 M.	Dwyka

TABLE VI (Contd)

GENERALISED SECTION THROUGH THE KARROO ROCKS.

2) Section in the Northwestern outlier of the Goboboseb Mts.

Rock Types	Approx. thickness.	Series.
Dolerite Sill	Up to 25 m.	Post-Karroo
Shale and mudstone, varved at the base.	Up to 12 m.	-Dwyka-
Basal conglomerate (Fluvio-glacial) or grit.	Up to 2 m.	-Dwyka-

1. Basal beds:

The basal beds of the Karroo system in the present area are subject to considerable lateral variation. The most common facies is a basal conglomerate (Nos. 17,90) which is of fluvio-glacial origin at least in part of the area.

A brecciated mudstone forms an alternative basal bed, and only rarely is this mudstone unbrecciated. Where both conglomerate and breccia are present, the breccia overlies the conglomerate.

The brecciated mudstone is well exposed in the foot hills of the Goboboseb Mountains where it attains a thickness of 12 metres (No.332). It makes prominent rounded cliffs of distinctive reddish orange hue. In the hand specimen this rock is seen to consist of small angular to sub-angular fragments, of various colours, orange and yellow being the most common. Many of the fragments have dark rims. The fragments and matrix are very fine-grained. Thin sections give little more information because of the fineness of the grain.

The brecciation seems to have taken place before the sediments were consolidated, and the material appears to be derived from a somewhat calcareous mudstone. The origin of this formation is not known but it is possibly connected with the Dwyka glaciation. A similar breccia is described by Du Toit,(1915, page xlv), who ascribes its origin to the mashing up of older beds by glacial action.

About 2 km west of the fault in the Karroo sediments near the Omaruru road, the basal beds consist of two layers of brightly coloured mudstone, each about 3 metres thick. The lower layer is orange-yellow (363) and the upper layer is brick red in colour.

None of the minerals composing the rock can be identified microscopically. The surface weathers like a fine-grained impure limestone, and fresh surfaces on both the red and yellow varieties are dark brown. On breaking the rock, curved starchlike fragments are produced, similar to those described by Wagner, (1915, p.65) in his account of the Dwyka boulder mudstone. This rock is possibly an undisturbed occurrence of the brecciated basal beds described above.

The conglomerate is typically developed in the Karroo foothills of the Brandberg (see photo, Fig. 26) and in an outlier of the Goboboseb Mountains situated between the Brak and Gemsbok Rivers, where its fluvioglacial nature was inferred from the presence of a glaciated pebble, (see photo, Fig. 41) found in a basal conglomerate 1.5 metres thick overlain by 3 to 10 metres of mudstone and varved shale (No.4). The shale is seldom more than 1 metre thick.

The conglomerate generally consists of well rounded, ill-sorted pebbles, average size 2.5 cm. in diameter and rarely reaching 15 cm. in diameter, in a light greenish grey matrix consisting dominantly of fine to coarse quartz grains. The pebbles consist of quartz, granite, pegmatite, quartzite, amphibole granulite and rarely feldspar.

The upper contact of the conglomerate is sharp against the shale. Rarely, the basal band is a reddish conglomerate grit (No.327).

The shales overlying the conglomerate show considerable variation in thickness, partly due to the extensive intrusions of dolerite sheets within them, and partly because of the uneven pre-Karroo land surface. This unevenness was not completely compensated by the deposition of the basal conglomerate. The shales appear in part at least to be varved shale. The thin section shown (No.4, photo, Fig.64) was made from a specimen found near the glaciated pebble.

Markings similar to worm trails are found in these shales (see photo, Fig.42). This is not an uncommon feature of Dwyka shales. It was seen at two places, the one mentioned above and another on the Omaruru Road on the west side of the post-Karroo fault shown on the map 12 km. south of Schilfputz. Near the fault, a thin skin of shale covers a resurrected pre-Karroo outcrop of schist, and the "worm trails" follow the uneven surface. At the first locality mentioned, the markings occur on flat bedded varved shale.

Alternating sandstones, shales and mudstones overlie the basal beds, the sandstones being grouped near the bottom. The sandstones and grits are pale and purplish brown (Nos. 154, 174, 175, 330, 333) and the shales and mudstones are reddish brown, purplish and greenish brown (Nos. 153, 155, 156, 169, 170, 171, 172, 173, 328, 329). The shales are somewhat fissile. Sedimentation appears to have been erratic, probably due to the unevenness of the pre-Karroo land surface.

2. The Calcareous Zone:

The first well-defined marker horizon to be deposited above these sediments was a calcareous band about 20 metres thick. This band is found at points on both sides of the Amis River, 16 km. separating the two extreme outcrops. The wide distribution of this bed indicates that it was probably laid down on a flat surface. The thickness of the underlying Karroo beds varies from 60 metres, west of the Amis River to 110 metres on the northwest side of the Brandberg. The calcareous band consists of nodules of brown limestone and crystalline calcite, (Nos. 1[illegible], 334, 382) with some chert, in compact beds a few feet thick (No. 336) or in platy layers. Fine-grained pink sandstone (No.342) and dark purplish brown shale and dark mudstone (Nos. 168, 225) occur as intercalations in the main bed, and scattered brown limestone nodules from 1 cm. to 10 cm. diameter appear in some of the shale bands.

3. Sediments above the calcareous zone.

Above the calcareous zone lie shales and mudstones (Nos. 167, 337, 338, 343, 345) with intercalated sandstone (Nos. 340, 344, 380, 381) and gritty bands (Nos. 339, 341) totalling from 65 m. to 80 metres in thickness. The total thickness of these bands is fairly constant, and varies between 70 and 80 metres. The sandstones are reddish brown, and the shales and mudstones are red, brown, purple and black. Individual sandstone bands are rarely more than 1½ metres thick.

One reddish brown sandstone band near the post-Karroo fault contains lenses (No. 380) up to one metre long by 10 cm. thick, of quartz grit and chalky grains up to 1 cm. diameter. These grains occur in sub-rounded and elongated and curved shapes, (see photo, Fig. 43). A positive phosphate reaction indicates that the grains are probably particles of bone matter.

Above these sediments, on a sharp contact, lie 40 metres of pale sandstones and pebble bands, (Nos. 165, 346). The pebbles are quartz and average about 1 cm. diameter. Two bands of mudstone (No.166) totalling 6 metres in thickness are intercalated in the quartzites. These rocks make prominent light coloured cliffs, on the Karroo hills skirting the Brandberg.

4. The Basic Lavas:

Overlying the sediments described above, occur about 450 metres of dark coloured dense amygdaloidal and porphyritic lavas (Nos. 163, 164 347, 348, 349, 350, 351, 352, 353, 354, 355, 356, 357, 358, 360) with lenticular intercalations of purplish sandstone (Nos. 361, 362) near the bottom of the lavas. The individual lava layers are more easily recognisable through their colour on weathered surfaces, than by microscopic examination. Green, brown, black and grey weathering lavas are present (see section No.4, Fig. 39). The rock types are altered amygdaloidal, porphyritic, and amygdaloidal porphyritic basalts.

5. Metamorphosed Sediments:

The Karroo sediments in the Brandberg foothills have been metamorphosed into hard, dense rocks. The mudstones and shales form dark fine-grained hornstones breaking with a conchoidal fracture, a quality which has led to their widespread use as stone implements. A fine-grained purple rock with pinkish patches is a common and peculiar variety of indurated mudstone. The light coloured patches form along cracks, and as rounded shapeless masses, giving the rock the appearance of an amygdaloidal lava.

The sandstones have formed pale glassy quartzites, which on the southern side of the Brandberg, outside the present area, are lightly mineralised with tourmaline and pyrite.

These altered rocks dip at a low angle towards the Brandberg from which they are separated by a ring-like body of Karroo rocks that have been subjected to more intense metamorphism. The body is about 0.75 km. wide and at first sight resembles a ring-dyke, as the bedding structure of the original rocks has been destroyed. Damara rocks were probably mixed with Karroo rocks during the formation of this body. The petrography of these metamorphic rocks has been described by Cloos and Chudoba. (Ref. 1931).

In the Western part of the area, as is shown on the sections, Fig, 39, only small amounts of Karroosediments exist. Thick dolerite sheets (No.78) cover the thin layers of shale or conglomerate, and rarely rest on what is apparently the uneven pre-Karroo land surface. The manner in which the dolerite fills valleys in the pre-Karroo land surface suggests that the rock was extruded, but the absence of vesicles indicates intrusion under cover. Sills commonly follow, and uneven surface at a major unconformity. The sills have produced indurated shale and chloritic quartzites in the Karroo rocks, but even where xenoliths of Karroo or other rocks were found enclosed in dolerite, (see below under "The Karroo Dolerites"), the grade of metamorphism is low.

6. <u>The Karroo Dolerites:</u>

Dolerite dykes have intruded all the formations in the area up to and including the Karroo Lavas (No.359). Two main types are found - dolerite and olivine dolerite. A third type, picrite dolerite, is rare. The thick sill in the western part of the area is a coarse-grained rock, with andesine-labradorite feldspar (No. 78). The sill is younger than any of the dolerite dykes found in contact with it.

Before the intrusion of this sill, at least three ages of basic rocks were intruded butthe dykes are so variable in mineral composition that no means was found for identifying the different ages, apart from field criteria. Olivine dolerites are present in about the same quantity as the dolerites. Only five picrite-dolerites were found out of 50 dolerites that were examined, and four of them lie in and near the Upper Marble band, from a point about 16 km. southwest of Brandberg West Mine to a point 6 km. south of the mine.

Many of the dykes are porphyritic or amygdaloidal. These types rarely contain olivine, and weather to a light reddish brown colour, similar to the upper lavas of the Goboboseb Mountains. Ophitic structure is not common in the amygdaloidal dykes, the augite if present being granulitic to sub-ophitic. An amygdaoidal diabase dyke in the old granite (No. 87) was found to be older than a dolerite dyke. The olivine dolerites weather dark brown or greenish black.

Erosion gaps are formed where dykes cut across schist ridges, but in areas of marble, headward divides of strike streams are usually formed where dykes cut across marble bands.

In granite country, dykes always form prominent ridges (See photos, Figs. 29 and 44). In the rare cases where dykes cut the Karroo lavas, either depressions are formed, e.g. at the top of the Goboboseb Mountains (No.359) or the dyke stands out in a wall-like structure. (see photo, Fig. 45). Dolerite sheets in the lavas form low cliffs.

Where dolerite sheets dipping at a low angle cover granite or Damara or Karroo rocks, they protect the older rocks from erosion and the exposed surface of older rocks falls rapidly away from the dolerite capping in areas of deep dissection.

The dykes normally have a maximum thickness of 3 metres, and some thin down to a point where they pinch out. They are found in flat sheets, and dipping at all angles up to vertical. The steeper dipping dykes run in two major strike directions - one parallel with the strike of the sediments and one roughly at right angles to this direction. Where they run oblique to the strike, they usually follow a twisted path, alternately running parallel with the bedding and cutting at right angles across the bedding. (See plans, Fig. 46 and 85).

A diagonal shift is commonly made by the dyke pinching out, and "making" again slightly to one side of the line of strike, en echelon. Lenths vary from a few metres to 8 kilometres.

No flat-lying sheets were found more than 250 metres below the base of the Karroo rocks.

Where the smaller dykes intersect thick marble bands, they usually pinch out, but larger dykes cut straight through.

Where dykes cut the Upper Marble or Lower Marble, they occasionally seem to replace part of the marble band. West of the Zebra River, two such examples occur, as follows; southwest of the small tin deposit that lies northwest of Brandberg West Mine, a dolerite dyke (No.22) runs into the Lower Marble Band, and replaces about 15 metres of the band along strike. The marble at the dyke contact is unchanged.

Farther to the south a vertical coarse-grained picrite dolerite dyke 15 m. thick (No. 394) cuts across a folded body of Upper Marble. The dyke pinches out rapidly in the confining Upper Schist that lies to the north and south of the Marble. Boulders of conglomerate (Nos. 392, 393) up to 3 metres in diameter are found in the dyke. The conglomerate pebbles are well-rounded but poorly sorted, and are set in a chloritised quartzitic matrix.

The pebbles vary in size from 1 cm. to 15 cm., and consist of quartz, granite, pegmatite, quartzite and hornfels. The conglomerate has a fresh and unsheared appearance, and some of the pebbles are not strongly cemented in the matrix. This rock is probably derived from the basal conglomerate of the Karroo system, and must have sunk approximately one hundred metres to its present position. Thin veins of light greenish decomposed material (No.400) cut the dyke in all directions. The material appears to be a mixture of magnesite and asbestos.

A large plug-like body of bronzite dolerite (No.13) cuts through marble without causing any appreciable displacment, at a point on the right bank of the Brak River where the river makes a large S-bend, 8 km. S.S.W. of Zebraputz. This is the only occurrence of bronzite dolerite that was found in the area.

Numerous dolerite dykes occur northwest of the Brandberg, but do not appear to be genetically related to the intrusion of the Branberg granite.

A swarm of dykes, trending north-west, occurs in the Sesob River - Gemsbok River area over a length of 16 km. and an average breadth of 7 km. Parts of the swarm appear to follow the rare anticlinal structures in the Damara sediments that run across the strike of the fold axes. (See plans, Figs. 46 and 85)1 These structures are parallel with the large anticlinal structure running northwest from Brakputz.

The sediments of the Karroo system contain numerous sills, especially the more fissile Dwyka sediments, but sills are only rarely found in the lavas, and none were found in the sandstones.

(F) Comparison with the Karroo System in Other Areas.

1. Area to the north:

The Karroo rocks of the Etendeka Mountains are similar to the Karroo rocks in the present area. Intermittent basal sediments covered by thick layers of basic lavas, occur over an area of about 16,000 square km.

Sections made by Reuning (Ref. 1925) at Doros, Khuab and Atsab closely resemble sections of the Karroo rocks in the Amis River area. (See section No.4, Fig. 39). The Khub section, about 50 km. northwest of the Brandberg, is almost identical with section No.5 made on a hill at the northwest side of the Brandberg. The positions of the Brown

limestone zone, the "Main Sandstone" and the bottom of the basic lavas, can be correlated, and the two sandstone bands lying in between the Brown Limestone zone and the Main Sandstone at Khuab have their counterparts at the Brandberg and possibly in the northeastern Goboboseb Mountains.

Beneath the Brown Limestone zone, deposition seem to have been erratic, but a basal conglomerate is common to both areas.

Layers of tuff were not positively identified in the Amis River and Brandberg area.

Above the Main Sandstone, the thickness of lava at Khuab is about 500 metres and at the northeast corner of the Goboboseb Mountains the lava is 430 metres thick.

2. The Erongo Mountains:

The sediments of the Karroo system in the Erongo Mountains (Ref. Gevers. 1929, p. 45) contain much coarser facies than those found in the Brandberg area 130 km. to the northwest, but the pattern of alternating coarse and finer beds is common to the two areas.

The lavas, in their similarity of appearance and composition provide a closer correlation between the two sets of rocks.

3. South-east of the Brandberg:

The sequence here is somewhat different from that on the north-west side of the mountain. According to Cloos (Ref. 1931) the old granite is overlain by a breccia on top of which is about 100 metres of melaphyre. This is followed by "hundreds of metres" of conglomerates and sandstones and finally by the main mass of extrusives. Further to the west, melaphyre lies directly on granite.

4. South-west of the Brandberg:

Here, according to Cloos (op cit.) three light bands of conglomerate and sandstone are separated by slates, and probably by extrusives. These layers correspond with those found northwest of the Brandberg in the present area. These sediments, southwest of the Brandberg, are covered by basic lavas, which in turn are covered by more acid lavas.

Cloos does not mention the existence of any tuffs. The only fine-grained rocks described by him are shales, shaly sandstones, and fine-grained sediments.

For the Erongo-Brandberg area, Cloos stated that the lateral extension of the earth's crust due to dolerite intrusion, was between 0.1% and 1.0%. These figures apply to the present area, certain parts showing greater concentration of dykes than others. (See map, Fig.27).

The overlying lavas in the northeast Goboboseb Mountains are somewhat different from those described form the Erongo, Brandberg and Kaokoveld areas, in that amygdaloidal and porphyritic layers are found alternating throughout the whole thickness of lavas. Porphyritic varieties containing phenocrysts are common. No quartz porphyries were found.

5. The Omatako Mountains:
(Ref. The Etjo Beds of Northern Hereroland, S.W.A.)
T.W. Gevers. T.G.S.S.A. Vol. XXXIX).

In South West Africa, thick dolerite sills are rarely found in rocks other than those of the Karroo System. In the Omatako mountains, thick coarse grained olivine dolerite sills are intrusive into the lower portion of the Karroo system.

The sills in the northwestern outliers of the Goboboseb Mountains are similar in type and relative position to the sills at the Omatakos.

6. Dolerite in the Union of South Africa:

According to Du Toit, as quoted by Walker and Poldevaart (p.602) dolerite is comparatively rare in areas of pre-Karroo strata from which the Karroo rocks have been stripped.

In the present area, dolerite sills and dykes are abundant both in the Damara and Karroo sediments. In the Karroo lavas, however, dolerite dykes are rare.

(G) History of the Karroo Period:

1. (a) The Dwyka Series:

Glaciation followed by the action of rivers and lakes, played some part in the spreading of the basal sediments throughout the area, and low forms of life probably existed in the lakes.

Inundation of the whole area followed, and fine-grained sediments were deposited. Later these sediments underwent local brecciation, probably before the sediments had consolidated . Alternate lowering and raising of the water level, and corresponding coarse and fine deposition, proceeded until most of the irregularities of the pre-Karroo land-surface

had been filled in. During this period, some of the basal beds may have been eroded in parts of the area. Rare monadnocks, such as the Zerissenes Mountains, projected above the sediments.

The Brown Limestone Zone was then laid down. The intercalated sandstone band indicates fairly shallow deposition. Fine-grained sediments, containing angular quartz fragments and calcite are also interbedded in this zone. The origin of these sediments is not known. The fine-grained material is possibly of volcanic origin, but there is no local evidence to support this theory. The presence of melaphyre, underneath the main sandstones and conglomerates on the southeast side of the Brandberg (Ref. Cloos, 1931) indicates a possible source of volcanic tuffs.

The brown limestone layers and nodules which contain crystalline calcite are difficult to account for. Chemical concentration from a calcareous shale is a possible explanation. The presence in the area to the north, of fossilised wood beneath, and reptilian fossil above, the Brown Limestone Zone, points towards a possible origin in living organisms.

Reuning's original theory which is generally not admitted (Du Toit, p. 301) that the nodules represented volcanic tuffs and bombs is further disproved now that the calcareous zone has been identified 50 km away from Doros Crater.

After the final deposition of calcareous matter, rhythmic lowering and raising of the water level produced at least three bands of sandstone and of shale or mudstone. Rarely the lowest sandstone layer contains lenses with broken bone matter. This occurrence is in a position similar to that of the bone-bed at Doros crater, and the material is similar to that found by Reuning beneath the fossilised wood horizon south-east of Atsab Mountains. (Ref. 1925).

2. <u>The Stormberg Series</u>:

A distinct change in sedimentation occurred after the deposition of the topmost shale. Coarse-grained sandstones and conglomerates were deposited in three successive layers, separated by two layers of dark fine-grained sediment, which is now somewhat sheared.

These beds are well-defined and have a sharp basal contact. Thus they possibly indicate a disconformity and the beginning of a new series of deposition, the Stormberg succession.

The way in which lenses of reddish sandstone are intercalated in lava flows, adds to the resemblance between these sediments and their equivalent, the Cave Sandstone.

The feeding channels of the lavas were probably the widespread basic amygdaloidal dykes, which have been found to be older than the dolerites.

The sequence of magmatic differentiation is not so well displayed here as in the Karroo lavas in the Kaokoveld (Ref. Reuning 1929) and in the Brandberg and Erongo Mountains. No acid porphyries or dykes were found with the exception of the acid lava plug, of unknown age, north-west of Brandberg West Mine.

3. The Karroo Dolerites:

The end of the Karroo period was marked by extensive dolerite intrusions. Few of the intrusions penetrated the Upper lavas, most of the dykes and sills within the Karroo rocks being in the lower sediments. Extensive intrusion probably took place along and near the basal contact of the Karroo rocks, and near-horizontal sheets were intruded into joint planes in the Damara rocks down to about 250 metres below the base of the Karroo. This shows that the sheets were intruded under a thickness of at least 600 metres of rock.

The flat sheets were injected before or together with the steeply dipping dykes.

The dykes followed two main directions, one parallel with the strike of the Damara rocks, and one roughly at right angles to this direction, along lines of weakness that probably originated in the post-Damara folding.

4. Post-Karroo Faulting:

After the intrusion of the dolerite dykes, faulting occurred, some of the larger faults being across the strike of the Damara beds. These were essentially gravity faults of small throw, and they usually pinch out at both ends. This faulting occurred possibly during the period of the Brandberg intrusion.

5. The Brandberg intrusion:

Cloos has fully described the Brandberg intrusion (Ref. 1931).

The position of the intrusion was probably determined by the intersection of the Cape Cross-Messum line of weakness with the schist-granite contact that cuts through the Brandberg area. The intrusion consists of a plug of granitic rocks in a sheath of metamorphosed sediments. Six zones are recognised in the contact ring, between the intrusive granite and the surrounding Karroo rocks. Cloos states that the granite plug becomes narrow downwards. This feature was observed in the northwest Brandberg, but the contact of the altered zone with the Karroo iments dips outwards at 50° to 70°.

The age of intrusion is post-Stormberg, and probably earlier than the Khuab-Atsab stream melaphyres described by Reuning (1925). Preserved lava flows that might have originated in the Brandberg are absent in an area where old river beds exist that are possibly counterparts of the river beds containing the Stream-melaphyres. The latter rocks could have been extruded in late Karroo times, as were the late basic phases of the Lebombo. (Ref. Du Toit, 1939, p. 504). But the great amount of erosion preceding their extrusion suggests that they were of much later age, and possibly belong to the Cretaceous volcanics that are scattered through South West Africa and Angola. (Ref. Du Toit 1939, p. 376 and Beetz, 1933).

(H) Post-Karroo Sediments:

1. The High Level Gravels:

The structural age and extent of these gravels have been discussed under Geomorphology. Pits have been sunk in only one section of these gravels, near the Ugab River of the west side of the Zebra. (See photo, Fig. 7). These gravels belong to the old bed of the Ugab River. All rock types in the area are represented in the gravels, which are cemented with layers of gypsum. The gravels are badly sorted and the component rocks vary in size from slabs of bedrock one metre long, through rounded boulders up to 0.5 metre diameter, down to fine sand. No artefacts were recognised in the material in the sides of the pits, although the surface is littered with rock implements.

Near the Brandberg, rounded boulders of Brandberg granite up to 0.6 metres diameter are found in the old gravels.

The gravels of the coastal plain contain smaller, well rouded and better sorted pebbles.

Both ages of high level gravels exhibit similar characteristics. The rock types present naturally differ in the old gravels of the Gemsbok Sesob, Brak and Zebra Rivers, from those of the Amis and Ugab Rivers, where rock types derived from the Brandberg and the surrounding Karroo hills are common.

The bajada running along the base of the Goboboseb Mountains is probably of the same age as the younger set of high-level gravels.

2. The Low-level Cemented Gravels:

These gravels are composed of rock types similar to those found in the older gravels, but are generally more angular, indicating torrential deposition in an arid climate. The occurrences of these gravels are mostly in present-day river beds, and are therefore subject to erosion. Thus, only the more resistant portions have escaped erosion, and the persistance is due to strong cementing by secondary limestone. Gravels of this age in the lower tributaries of the Ugab are distinguished from gravels of similar age in the Ugab River by their grey colour, which is due to small particles of schist in the matrix. In the Ugab gravels the matrix is composed of light coloured quartz aand cemented by calcareous material.

3. Younger Gravels:

The ages and origin of younger gravels at the Brandberg West Mine are described under "Economic Geology" and "Geomorphology". Both of these gravels are older than those produced by present day drainage.

Travertine deposits, which are probably similar in age to one of these sets of gravels, are found overlying the earlier cemented angular gravel near Brandberg West Mine, in the stream running from the southwest into the Zebra River, on the line of the Brandberg west anticline.

4. Salt Pans:

The inland salt pans contain a mixture of salt, aand and gypsum. The gypsum occurs as transparent blades on the surface of the pans. The depth of the salt is unknown.

The coastal pans contain a mixture of salt, gypsum, fine sand and mud. None of the coastal pans appear to be of economic interest.

The possible origins of these pans have been discussed under "Geomorphology".

5. Surface Crust:

In the area southwest of the Gemsbok River, a surface crust composed of sand and gypsum, about 20 cm. to 45 cm. thick covers large areas of schist and granite. The composition of the crust is independent of the nature of the underlying rock. This crust is universal in the Namib desert, and is probably due to the action of sea mist. Porous material, such as surface rubble and raised gravels, is impregnated and cemented with gypsum to a depth of at least 3 metres. The gravels were probably cemented soon after deposition.

6. Sand Dunes:

Sand dunes are found inland only in protected areas, usually near or in the Ugab gorge west of Brakputz. The favourable areas are those protected from the east wind, which probably builds the dunes. The sand is clean and yellowish white in colour, and is mostly derived from the bed of the Ugab River.

On the coast, sand accumulated around obstacles forming small dunes which all "tail off" towards the west. Much of this sand has been brought a short distance inland from the beach by the southwest wind, and has then been re-distributed by the east wind.

7. Soil:

In spite of the coarse grained, sandy appearance of surface rubble, fine sand and dust composes a large proportion of the underlying material (up to 30% - 1 mm in 1½" material at the Brandberg West Mine).

The strong growth which follows the sporadic rains is probably a result of enrichment of the soil during long periods of no growth, aided by moisture from dew precipitated by the sea mist.

CHAPTER IV

T E C T O N I C S.

This area consists of folded Damara beds intruded by granite, and from the point of view of structure can be divided into two main zones:-

A. The Zone of Folded Schist and Marble.

B. The Zone of Schist and Marble intruded by Granite.

(A) The Zone of Folded Schist and Marble:

1. Folding:

In the area which was mapped, strongly folded sediments occupy a portion about 80 km long by 16 km broad. Intense folding has taken place along axes which run north-south in the western part of the area, and which gradually turn to a northeast-southwest direction, towards the east. (See map, Fig. 46). The fold axes do not run perfectly straight but show an appreciable undulation along their lengths in a horizontal plane, and to a lesser extent in a vertical plane.

Generally the axes of the folds are horizontal, and the beds are overturned, dipping towards the east or the southeast. The overturning is ascribed to rotational stress produced by drag on the decollement of the folds. The folds are essentially closed similar folds. Near the Brandberg the dip is towards the northwest, a feature unusual in this part of South West Africa. As shown on the map, 70 Upper Marble anticlines and 34 Lower Marble anticlines are exposed. The wavelength of the folds is fairly constant, being of the order of 400 metres in both Lower and Upper Marble: minor folds, drag folds and crenulations exist, especially in the marbles, and grade down to microscopic size. Single folds rarely branch into, multiple folds along their axial lengths. This feature is possibly more common in the narrow band of Lower Marble than in the Upper Marble, and is well displayed in the Lower Marble anticlinorium which contains the Brandberg West Mine. Towards the southwest, from the mine, bands of Upper Marble converge and probably meet under the Karroo cover. (See map, Fig.27). Near the Brandberg West Mine, there are at least nine anticlines of Lower Marble which lie in between the converging Upper Marble bands.

Lower Marble is not exposed at the point of convergence but lies below surface, probably at a depth of between 650 and 800 metres. Whether the nine folds persist at this depth, or converge into a single fold is unknown. The latter structure is more probable because elsewhere the Upper and Lower Marble bands follow similar structure patterns. In either case, the beds are probably tightly folded. This convergence of the axes of folding is probably due to crustal shortening. Analogous conditions exist in the Appalachians of Southeastern Pennsylvania and Maryland. (Ref. Cloos, E).

Although unusual in its structure, the forgoing is but one example of crustal shortening in the area. As mentioned under Geology, fold axes that are convex towards the south or southeast are probably the result of dragging of the mass of folds over prominences in the possible decollement of the folds. The bending of the fold axes is due to friction and to the raising of the dipping folds; erosion to an even plane after raising accentuates the bent shape.

2) Fracturing and Deformation connected with the folding.

The stretching of the crust formed lines of weakness which persisted up to late Karroo times, when they were intruded by dolerite dykes. Later, gravity faulting occurred along these lines. The Sesob River Lead occurrences are possibly connected with two of these postulated stretched and weakened zones, which run northwest-southeast. The lines of weakness lie mostly perpendicular to the fold axes. Any tendency to stretching in a northwest-southeast direction would be relieved by an opening of the tightly closed folds, and lines of weakness parallel with fold axes would not appear.

In places, the thickness of a marble series has been increased due to numerous even drag-folds and crenulations, with the effect that the individual marble beds have become compressed laterally causing an actual thickening of the beds. (See photo, Fig. 38). Certain bands in the marble have shown structures possible only in a more or less plastic substance.

The intense folding has resulted in marked attenuation at the apices of some of the folds.

The Blue Marble band tends to resist bending, as it is partially free from bedding planes, whereas the lower, well-bedded marble bands make sharp bends with ease. (See photo, Fig. 47)

Areas of compression formed inside folds found relief by crumpling of the beds. (See photo., Fig. 48). Most of the drag folds within the marble bands are congruous but, as is to be expected in such plastic rocks, incongruous drag folds do occur.

During the mapping drag folding was generally used only as confirmatory evidence for the determination of the nature of folds.

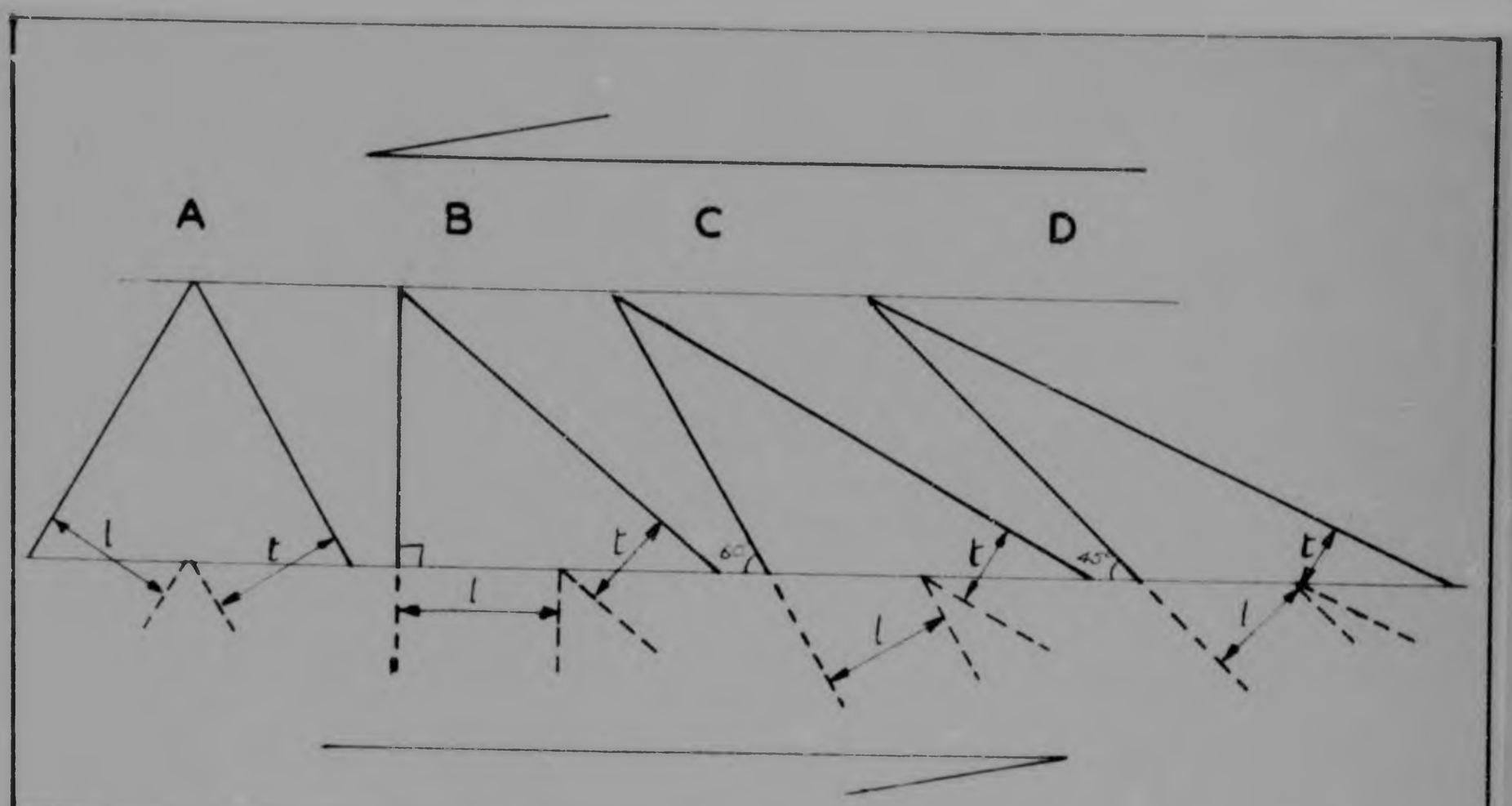
An example of boudinage was seen on the east side of the Gemsbok River, in the Middle Black Line, interbedded between two thick beds of "blocky" light grey marble. The boudins average about 0.6 metres long along strike by 10 cm thick.

The northwest limbs of synclines invariably show compression and attenuation, being about one half the thickness of the corresponding southeast limbs. (See Figs. 20 & 49, photo, Fig. 49(a) and table IV under "Geology").

This feature is probably directly connected with the overturning of the folds. The change from normal folds to overturned folds would not involve a change in volume. Therefore, as shown in Figure 49, the crests of the folds would move forward in a horizontal plane. The leading limb of anticlines would be shortened, and the trailing limb would be stretched.

Maximum shortening of the leading limb would occur when it became vertical, (Fig. 49, (b) and as it became overturned, it would begin to be stretched. (Fig. 49, (c) and (d).

The stretching of the beds would cause them to become thinner and the shortening of the beds would cause them to thicken. The ratio of thickness of leading limb to thickness of trailing limb (l to t in the diagram) would be greatest where the leading limb was overturned and dipping at an angle between 45° and 60°, and would be about 1.8:1. (Fig. 49, C and D). Other factors, such as rucking of the leading limb (see plate) and drag caused by hard cores of anticlines against plastic overlying beds could increase this ratio to the existing figure of about 2.8:1.



Diagrammatic sections through folds, showing effects of overturning on thicknesses of limbs.

Fig. 49.

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