TRANSACTIONS

OF

THE GEOLOGICAL SOCIETY

OF SOUTH AFRICA.

VOL. XXVII., 1924.

On a Great Trough-Valley in the Namib.

(Read 31st March, 1924.)

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(Translated and Communicated by P. A. Wagner.)

[Plates I.-V.]

CONTENTS.

I.—Introduction.

Up to the present geological investigation in South-West Africa has revealed few specially remarkable features in the structure of that country. The cañon-like valleys of the Fish and Konkip Rivers were at one time assumed to be " Graben " with a north and south trend

lying between horsts. The incorrectness of this view was established by Range (1)*. That author regards the structure of South-West Africa as very simple, comparing it with that of an up-turned saucer in which the steep outer rim is formed by the crystalline basement rocks, and the more gentle inner slopes by the Nama and Karroo Systems. The beginning of the precipitous outward slope in the eastern part of Great Namaqualand marks the position of the Great Escarpment, everywhere bordering the plateau tract of South Africa (2). According to Range, the only anomalous features in the structure of Great Namaqualand are the horsts of the Great and Little Kharas Mountains.

The folds, into which the sedimentary rocks exposed on the southern diamond fields of South-West Africa have been thrown, have a prevalent north and south trend. They have been correlated by Lotz (3) with those of the so-called "folded table mountains" in the neighbourhood of Wittpuetz, 120 kilometres south-east of Aus, first made known by the route-surveys of Range and Klinghardt. Lotz distinguishes in Great Namaqualand as in the Cape Province between a folded belt following the coast and the unfolded upland plains of the interior. The investigations of Rimann (4) and other geologists have shown that in Bastardland, and along the coast in the neighbourhood of Sandwich Harbour, the strike of the rocks of the Nama System and that of the gneisses and schists of the Basement Complex becomes west-south-west, east-north-east. The outliers of Waterberg sandstone[1] and of the igneous rocks connected with it which extend from the Erongo Mountains to the Waterberg have the same strike. Cloos calls the presumed tectonic line which they follow the Waterberg Line. Another tectonic zone, assumed by him to extend in a north and south direction along the foot of the table mountains of the Kaokoland with their covering of Karroo rocks and to meet the Waterberg Line in the Erongo Mountains, appears to be purely hypothetical. Rimann has also recorded the existence of faults and graben in the territory of the Khauas Hottentots, but these fall without the scope of the present discussion. To the faults which Lotz and Range observed at Kuibis and Bethany, and to the great flexure at Wittpuetz, mentioned by Wagner (11), reference will be made in a subsequent section, where their bearing on the subject under discussion will be dealt with.

Investigations carried out by the writer at the beginning of 1922 revealed the surprising fact that the Southern Namib is traversed by a great trough-valley trending east-south-east, west north-west. It begins at Huns, 85 kilometres south of Kuibis on the Luederitzbucht-Keetmanshoop railway, runs past Wittpuetz and can be traced as far as the coast. In the coastal belt it comes within the influence of more recent folds with a north and south trend. The name Wittpuetz

* The numbers in brackets refer to the bibliographical list at the end of the paper.

[1] The Waterberg Sandstone of South-West Africa is here referred to.

Trough-Valley is proposed for this great tectonic groove, Wittpuetz being the only permanently inhabited watering place between Aus and the Orange River.

Within the area occupied by the Nama System the Wittpuetz trough, which is bordered by great monoclinal flexures, is bounded on the north and south by tablelands cut up by powerful dislocations into great fault-blocks. These, by their attitude toward the trough, prove that they are genetically related to it. The northern block-faulted zone is succeeded toward the north by a broad belt of high ground. This is built of Archaean gneisses and the oldest recognisable pre-Nama sediments, intersected by a number of large granite bosses. The great ridge which, as we shall learn, is of the nature of a horst, runs from Heigoms, 35 kilometres south of Kuibis, through Aus and the Tschaukaib Mountains to Luederitzbucht. It is also bordered on the north by a tableland of Nama rocks broken up into fault-blocks, the block-faulting pointing to the presence of another great tectonic trough to the north of it. For this northerly trough-valley, the existence of which is still largely hypothetical, the name Koichab Trough-Valley is proposed; the name being derived from the Koichab river which traverses it between Aus and the Tiras Mountains.

In the following pages it is proposed in the first place to give a brief account of the geology of this part of South-West Africa, and then to treat separately of the several tectonic regions, above referred to, under the following headings:—

(A) The Wittpuetz Trough.
(B) The Folded Belt along the Coast.
(C) The Block-faulted Zones.
(D) The Aus-Luederitzbucht Gneiss Horst.
(E) The Koichab and other Tectonic Troughs.

II.—Outline of the Geology of the Area.

The part of Great Namaqualand under review is occupied mainly by pre-Cambrian gneiss, sedimentary rocks of pre-Nama age, the Nama system, and igneous rocks of widely differing age.

Archean gneisses containing no recognisable sediments have a wide distribution in the neighbourhood of the coast. They are in the main basic gneisses much injected with a plagioclase-rich granite. Lying between the gneisses and the Nama beds is a very thick succession of sedimentary rocks embracing a number of different formations, the importance of which has up to the present not been sufficiently appreciated by students of the geology of the Namib. The Konkip System, more fully dealt with in a previous communication to this Society, includes the younger members of this succession. But in addition to the Konkip Beds there are present older sedimentary rocks, about which at present very little is known.

The oldest undoubted sediments that the writer came across are distinctly bedded rocks occurring in the neighbourhood of Aus. They

comprise mica schist, beds of marble and conglomerates, amphibolites and the like. They are intruded by a peculiar type of granite which has metamorphosed and in part assimilated them. The granite itself, as a rule, is metamorphosed and rich in garnet. It may provisionally be correlated with the grey biotite granite that forms numerous large and small stocks along the coast at Luederitzbucht and in the Kovies Mountains, and everywhere exhibits a discordant relation toward the older gneiss. Both types may for the present be designated as Grey Granite to distinguish them from the more ancient plagioclase-rich granite. The youngest of the granites is a fresh-looking, red, leucocratic rock with a tendency to aplitic or pegmatitic development. It will be referred to as the Red Granite. Its precise age has not as yet been fixed. It cuts through all the other granites and is older than the Nama Beds. The several granites will be again referred to when dealing with the Aus-Luederitzbucht gneiss horst.

The Nama System has been sub-divided by Range (1) as follows:—

Upper Nama System	Fish River Beds Schwarzrand Beds.
Lower Nama System	Schwarzkalk Kuibis Quartzite Basal Beds.

According to the map of the same author the Konkip River roughly defines the western limit of the Nama Beds. The writer's investigations of the Wittpuetz trough prove, however, that both the Schwarzrand beds and Fish River beds were involved in the subsidence and that the Fish River beds extend outward into the Namib as far as the eastern and north-eastern declivities of the Klinghardt Mountains, that is, about 150 kilometres farther west than is indicated by Range.

III.—The Wittpuetz Trough *(Graben)*.

The Wittpuetz trough strictly considered, that is, including only what lies within the great bounding monoclines, extends from the neighbourhood of the water hole and deserted police post Huns, 85 kilometres south of Kuibis, to the coast, a distance of 185 kilometres. The average width is 42 kilometres, so that it has an area of roughly 7,770 square kilometres. To appreciate its magnitude and importance it may be pointed out that the greatest European rift-valley, the Rhine Valley Graben, has a length of 300 kilometres and a width of 33 kilometres, its area being thus 9,900 square kilometres. If the Wittpuetz Graben be made to include only the better known block-faulted zone lying to the north, which is clearly connected with it, and the corresponding gneiss strip running down to the coast, its breadth being thereby increased to 77 kilometres, its total area would exceed 14,245 square kilometres. The Wittpuetz trough is thus of the order of magnitude of the Rhine Valley Graben.

In the following discussion the writer adopts the prevalent view that, in dealing with faults and folds affecting originally horizontal strata, it is necessary to distinguish between those due to horizontal or tangential (orogenic) crustal movements and those that are the result of vertical or radial (epeirogenic) movements.

A Graben is a foundered strip of the earth's crust lying between more or less parallel faults or monoclinal flexures, along which it has been let down as a result of epeirogenic movements. In the Wittpuetz trough we have to do with an extensive crustal segment that has thus subsided, but which in its western portion has also been subjected to independent tangential or orogenic movements. Its great magnitude, the clearness of the evidence of the superimposition of one set of movements on the other and the important bearing of these phenomena on many widely discussed problems in structural geology and in the structural geology of South-West Africa in particular, invest the trough with quite exceptional interest. To the important role that folding, though on a comparatively small scale, has played in the trough, reference will be made subsequently. The folding is responsible for the table topped mountains at Wittpuetz, being in part referred to as " folded table mountains " on the map of the Sperrgebiet (13).

The eastern boundary of the Wittpuetz trough is formed by a great monoclinal flexure which first appears about 10 kilometres south of Huns (Plate I. and Plate II., Figs. 1 and 2). The strike of the flexure in its northern portion is N.30°E. Its southward continuation appears to have the same strike. About 6 kilometres from its northern end it breaks off abruptly to begin again some distance to the west. The writer was able to follow this eastern flexure for a distance of some 40 kilometres. It is clearly exposed, being demarcated by a steep escarpment. It should be stated that the Rhine Valley Graben is also bordered in part by a similar monocline (34).

The big monoclinal flexure along the northern side of the trough extends from 10 kilometres south of Huns across Pockenbank to the Numitsoab Berg (Fig. 1).

The southern bounding flexure was first met with in the neighbourhood of Breckbout. It was later examined more closely near Wittpuetz, from where it can be followed through the southern range of table-topped hills across Godaus Poort to the Gabusib area.

The western boundary of the trough is formed by the most easterly of the folds of the folded belt along the coast. It is situated immediately east of the Klinghardt Mountains.

The bounding monoclines are only in part rectilinear. While the retrogression of the eastern monocline, previously referred to, could be explained by an abrupt deepening of the trough in the area in question, it is none the less necessary to assume the existence in the latter of transverse faults. The writer noticed several such at Wittpuetz. Transverse faults of greater magnitude appear to be

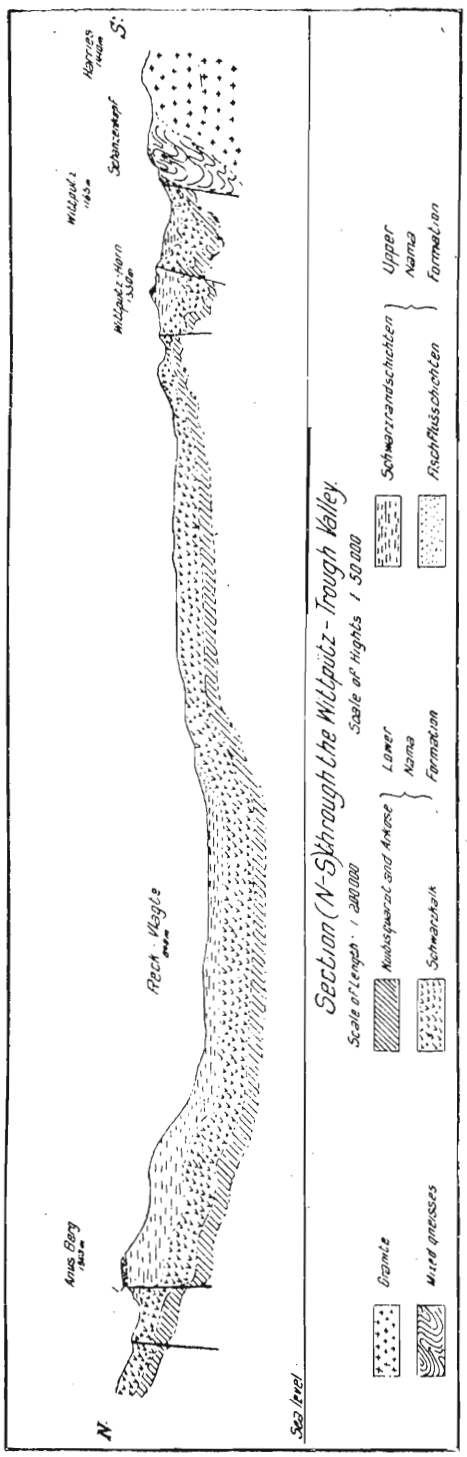
Section (N-S) through the Wildpitz-Trough Valley.
Scale of Heights 1 : 50.000
Scale of Length 1 : 200.000
Granite
Mica gneisses
Nubibquarzit and Amose
Schwarzkalk
Lower Nama Formation
Schwarzrandschichten
Rothflasschichten
Upper Nama formation
Sea level
N.
S.
Rock Eagle
Wildpitz-Horn
Schwarzkamp
Kaus Berg

FIG. 1.

present in the Namib east of the Klinghardt Mountains, where to the north-west of the Heioab Berg, an abrupt jutting out of the edge of the table-topped mountains toward the south can be made out. Actual investigations on the spot will, however, have to be made to settle this point.

On the south side the Wittpuetz trough descends in two great steps formed by two distinct monoclines to the centre of the sunk area, whereas along the northern side there is a continuous bounding monocline with a sharp bend at the middle. The position of these bounding flexures is marked at the surface by two ranges of table-topped mountains, of which the southern trends W.38°N. and the northern W.18°N. Whether or not there is a change in strike toward the interior of the Namib, the writer was unable to ascertain, but it appears as though the monoclines converge somewhat. If this be so, then transverse faults must again restore the trough to its normal width, as the table-topped ranges maintain their relative positions as far as the Heioab Berg.

The rocks lying between the two bordering flexures on the south side of the trough are in part disposed horizontally and in part cut up by faults into great wedges. These fault-wedges are, as a rule, considerably folded. The hills capped with Fish River Sandstone, lying between Wittpuetz and Godaus Poort (Fig. 2), afford good exposures to such fault-wedges.

The southern bounding flexure is intersected at Wittpuetz by a number of faults. One of them, having a length of several kilometres, trends E.17°N. from Wittpuetz. It is occupied by a quartz-cemented breccia. Several faults, noted by the writer near the watering-place Breckbout, have the same strike. Strong folding was observed at Wittpuetz and also to the south of the Nasep Mountains, within the belts of country occupied by the bordering monoclines, particularly in the neighbourhood of faults.

The northern bounding flexure, as already stated, is of the nature of a continuous monocline with a sharp bend at the middle. Its upper part takes in the highest peaks of the area, those of the Anusberge, with their capping of Fish River sandstone. The central part of the great trough is occupied by a plain some 15 kilometres in width and trending east and west. It is known as the Reckvlagte, which is evidently a corruption of Reck Vlaakte. Only a small part of this plain is included in the map of the Sperrgebiet (13). Its surface is formed by a layer of desert waste, below which, along the route followed by the writer, thin-bedded red, grey and greyish-green shales of the Schwarzrand series are everywhere in evidence. As in other parts of the country the Schwarzrand beds, like the rocks belonging to the lower part of the Karroo system, tend to give rise to great plains. The run-off from these is very small, erosion being mainly the result of sheet-flood action. The Grootfontein plain to the south of Maltahöhe and the flats between Gibeon and Mariental are illustrations of such plains.

The depth of the Wittpuetz Trough, meaning thereby the vertical measure of the subsidence can be estimated at Wittpuetz with a fair degree of accuracy. To the south of the bounding flexure the country rises fairly rapidly at Wittpuetz, attaining in a granite dome at Harries an elevation of 1,410 metres above sea-level. As this dome was without doubt originally covered by Nama beds, the height stated is a minimum figure for the original level of the base of the Nama system.

The floor of the trough itself, which is clearly demarcated at the surface, has a mean elevation of 840 metres[2]. At this level of 840 metres a considerable thickness of Schwarzrand beds appears still to be preserved as the underlying Schwarzkalk was nowhere found to outcrop in the Reckvlagte, where it was crossed diagonally by the writer. Wagner places the combined thickness of the Kuibis quartzite and the Basal beds of the Nama system at between 120 and 385 metres (11). At Wittpuetz it is nearer the lower figure. A measured section which had, however, been cut off by a fault, showed 80 metres of quartzite and arkose. The Schwarzkalk, on the other hand, appears to be very thick in the neighbourhood of the trough. The writer saw sections to the east of Wittpuetz where the thickness is estimated at 250 metres. The thickness of the Schwarzrand beds below the Reckvlagte may be placed at about 700 metres. The total measure of the vertical displacement is thus as follows:—

Difference in elevation, Reckvlagte-Harries ...	570 metres.
Basal Beds and Kuibis Quartzites	120 metres.
Schwarzkalk	250 metres.
Schwarzrand Beds	100 metres.
Total	1,040 metres.

In the neighbourhood of Wittpuetz the minimum value may thus be taken at 1,000 metres. If the crest of the gneiss horst of Aus be taken as a datum plane, this figure would be increased by about 300 metres.

At Wittpuetz the Great Escarpment cuts across the trough without producing any noticeable disturbances, proving that it is of more recent origin than the latter. The escarpment is well defined within the trough itself, from the middle of which there stands out in relief the great table-shaped mass of the Nasep Berge with their capping of Fish River sandstone, and the mountains to the north of them. The writer unfortunately was not able to make a detailed examination of this part of the escarpment.

The Uguchab River has cut back deeply into the trough from the west and upper tributaries of the Huns River from the east. The erosion is so advanced that the broad valleys containing the sources of the streams named actually meet, and the Great Escarpment forming the watershed between them is deeply embayed toward the east. The

[2] On the map of the Sperrgebiet (13) the following levels are given: 757 metres, 833 metres, 836 metres.

Nasep Mountains also form the apex point of the Nama beds, which from here dip at a low angle respectively to the west and east.

In the folded belt along the coast the Schwarzkalk reaches sea level. On the east side of the Klinghardt Mountains its base already lies 400 metres above the sea. The Wittpuetz trough thus affords further confirmation of Penck's view (14) that South Africa is a warped surface of denudation (*Rumpfflaeche*), and that the Great Escarpment is quite independent of the nature of the rocks of which it is built and also, as we have seen, of the old tectonic lines intersecting it. On the other hand, it has been shown that the trough was already in existence when the escarpment came into being which, according to Rogers (2), was in late Cretaceous times.

The Folding Within the Wittpuetz Trough.

The Wittpuetz Trough, as previously stated, owes its origin to epeirogenic movements, *i.e.*, to the foundering of great strips of the earth's crust. And yet there is abundant evidence of folding within it. Apart from the folding along the coast there is the intensive folding within the limits of the bounding monoclines. Within the great eastern flexure itself, which is little disturbed by faults, the Schwarzkalk beds are strongly folded. But a few hundred metres away from its upper and lower extremities they are again found lying almost horizontally and quite undisturbed. (Plates I. and II.)

The folding along the southern flexure, which has cut up by faults into great wedges, is on a much more extensive scale (Fig. 2). In the Wittpuetz Horn, situated to the west of Wittpuetz, one of the highest eminences in the southern chain of table mountains, there is exposed a magnificent section of a fault-wedge that has been intensely folded. The folding is to be attributed to the lateral compression to which the detached wedge-shaped masses were subjected as a result of the subsidence of adjacent fault blocks.

The section is similar to that given by Lehmann (15) to illustrate the effects of compression and tension in the formation of great pits formed at the surface as a result of the caving of underground mine workings. Lehmann has shown that compression and stretching are not always mutually exclusive, and that, in certain circumstances, stretching and tension are a necessary consequence of the processes involved. He distinguishes in such great openings, formed by mine subsidence, between an outer zone of tension and an inner zone of compression; the former represented by a folded core and the latter by an outer zone of block-faulting. The zones of block faulting would correspond with those lying to the north and south of the Wittpuetz trough. Very important from our point of view is his observation that along the border of these two zones there has often been a slight updoming of the surface, because the ranges of table topped mountains bordering the trough undoubtedly show a slight uplift relative to the block-faulted areas lying to the north and south. This uplift may be ascribed to locally acting tangential compression which was also

evidently responsible for the crumpling of the Nama beds within the limits of the main flexures. We may therefore supplement Lehmann's observations by recognising that the slight updoming between his zones of tension and compression corresponds with our bordering monoclines.

There is no evidence of folding in the central part of the Wittpuetz trough. No considerable sections of the underlying strata are exposed in the Reck Vlagte, but the writer got the impression that they are unfolded and more or less horizontal in disposition. Observations at the western unfolded end of the trough between the Numitsoab and Verloren hills, east of the Klinghardt Mountains, confirm this inference.

Folding, that may possibly be connected with the formation of the Wittpuetz trough, was noted by the writer to the north-east of Huns, north-east of where the main eastern flexure has its beginning.

Travelling toward Huns from the farm Geigoab and the deserted police post Nuichas, situated respectively 35 and 50 kilometres south of Brackwater railway station, one notices that as the great trough is approached the Nama beds become more and more disturbed.

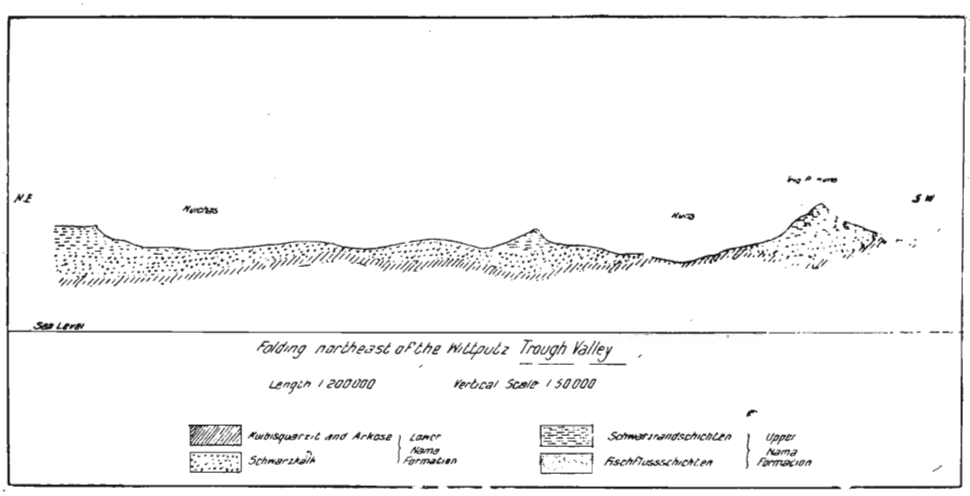

FIG. 2.

Halfway between Nuichas and Huns the first shallow synclines are in the Schwarzkalk observed, one such being surmounted by a conical hill with a capping of Schwarzrand beds 75 metres thick. South of Huns there follows the fairly deep syncline of the Hunsberge (Plate IV., Fig. 2), on which is situated the trigonometrical point Huns. One of them shows a capping of Fish River sandstone overlying Schwarzrand beds. These folds begin at a distance of about 20 kilometres from the great eastern flexure. Their genetic connection with the trough is proved by the fact that, as it is approached, there is a progressive increase in the intensity of the folding. It would appear therefore that

the trough is bordered on the north and south by zones of block-faulting and on the north-east by a well-defined folded belt. While the previously described folding within the limits of the bounding monoclines may, as suggested, be ascribed to locally acting pressure between the block-faulted zones and the great central sunk segment, or between adjacent fault wedges, the folding in the folded belt to the north-east of the trough is possibly a collective effect of the subsidence within the limits of the trough and the block faulted zones. It should be stated that the folding within this belt is nowhere as intense as that in the fault wedges previously referred to.

The third type of folding within the area under review, namely, that in the extensive folded belt along the coast is quite independent of the sunken area. We may proceed to deal with it.

IV.—The Folded Belt along the Coast.

Lotz (3) assumes the existence along the coast of South-West Africa of a belt of folding, and concludes from the route surveys of Range and Klinghardt that toward the interior the intensity of the folding steadily decreases, so that there is a gradual transition to the unfolded plateau tract. The so-called "folded table mountains" marked on the map of the Sperrgebiet (13, sheets 6 and 8) fall, however, within the limits of the Wittpuetz trough, the folding being an effect of local tangential compression due to the great east and west trough subsidence.

The folded belt proper only extends from the coast to the eastern edge of the Klinghardt Mountains, and has thus a width of some 50 kilometres. Beyond this there is a fairly abrupt passage, within the area embraced by the trough, to unfolded Nama beds. In the westward continuation of the trough, the folded Nama beds reach the coast. They first appear some 10 kilometres inland to the south of the Zweikuppenberg, situated east of Possession Island, and thence extend southward as far as Buntfeldschuh, a distance of 65 kilometres. The deepest syncline, in which the Schwarzkalk descends to sea-level, lies between Bogenfelsen and the Luderitz claims respectively the southern part of the Pomona area. West of the Zweikuppenberg the infolded Nama beds recede step-like farther and farther to the south, on the one hand, and to the north on the other, west of Buntfeldschuh, so that their extension in a north and south direction becomes progressively less and less. They are replaced toward the north by gneiss and toward the south by sedimentary rocks which the writer has assigned to the Konkip system. There is very considerable development of these pre-Nama rocks not only in the littoral south of the Wittpuetz trough, but also farther inland at Wittpuetz.

The step-like recession of the Nama beds from east to west in the folded coastal belt is the expression at the surface of the progressively deeper down-sinking of these beds as one proceeds from the zones of

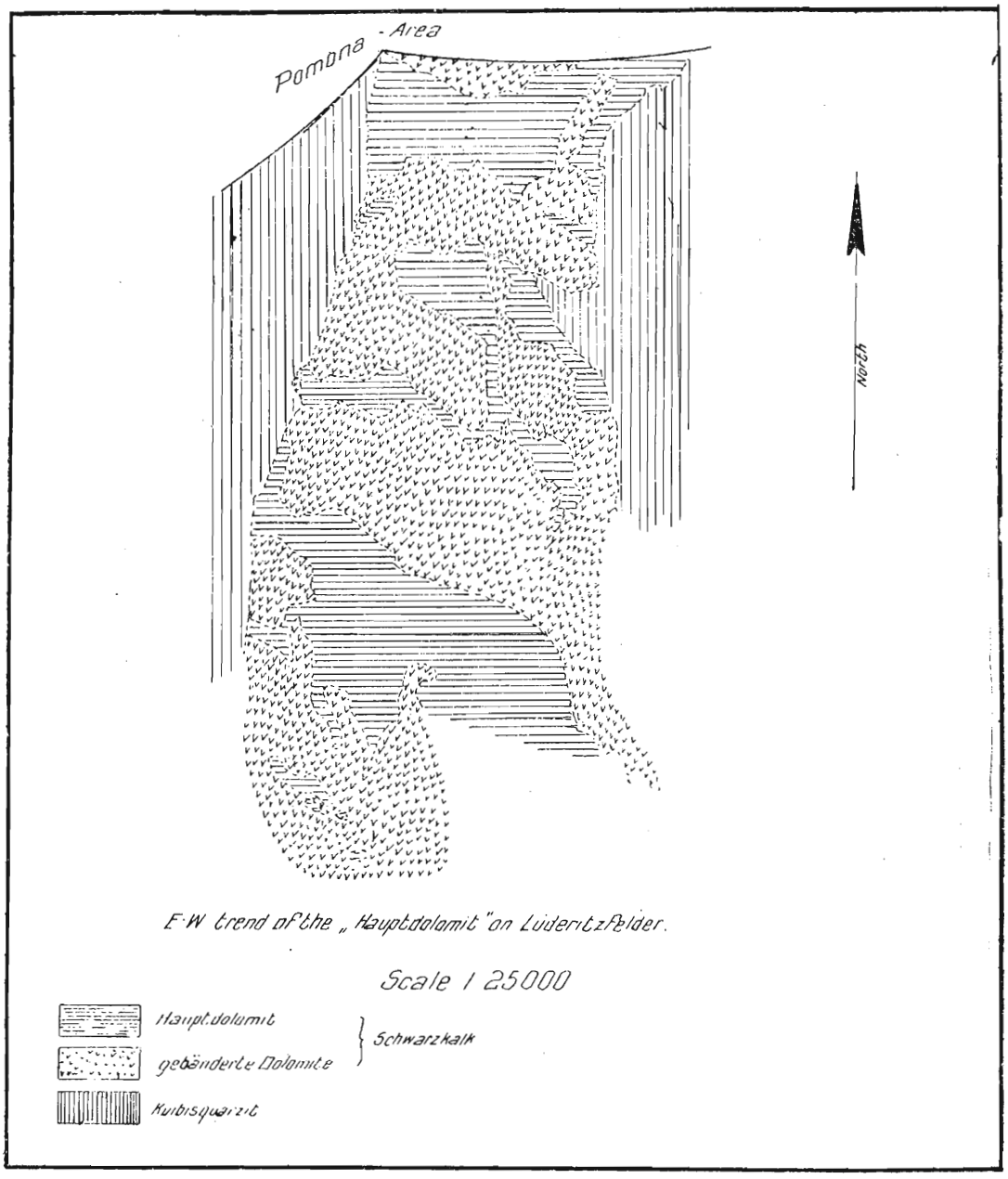

FIG. 3.

Shows east and west Trend of the Main Dolomite on the Lüderitz Claims.

block faulting toward the centre of the great trough. The bounding flexures themselves have been obliterated by the folding. It is possible, however, to make out in the Luderitz claims, and in the southern part of the Pomona area an abrupt drop in the level of the Schwarzkalk beds towards the Hexenkessel. From the Hexenkessel the Nama beds rise rapidly toward both the north and south.

Apart from the existence of the Nama beds at the coast, and their step-like recession toward the north and south when followed inland, there are additional facts pointing to the original extension of the Wittpuetz trough as far as the coast.

First, there are the considerable patches of Nama beds, with a regular east and west strike, found in different parts of the area, as, for instance, to the south of the Klinghardt Mountains. Then there is a phenomenon, an explanation of which was only rendered possible by the recognition of the existence of the great trough. It may here briefly be referred to. The Schwarzkalk series, as developed along the coast, is made up of a lower division consisting of thin-bedded dolomites and limestones interstratified with shales. This has been termed the " Banded Dolomite " (17). It is overlain by massively-bedded dolomite, to which the name " Main Dolomite " was applied. Now, whereas the Banded Dolomite is considerably folded, this is not the case with the Main Dolomite. At many points an unconformity is to be seen between the two divisions. The question whether we have to do here with a normal erosion-unconformity or with one due to differential folding has been fully discussed by the writer elsewhere (17). The massive dolomite hereabouts is often found lying like a beam with an east and west trend on other rocks trending in different directions (Fig. 3). Thus on the Luderitz claims it is found lying transversely on banded dolomite and Kuibis quartzite. The writer now finds an explanation of this unconformity, in that the less competent or more *mobile* banded dolomite, to use Stilles's term, lying below the Main Dolomite was folded, whereas the latter, owing to its greater rigidity, offered such resistance to folding that it remained lying in the original position and maintained its east and west trend. Such differential folding of superimposed strata possessed of different degrees of mobility has been described from many localities. Thus, for instance, from the Witwatersrand, and also from the dolomites of the southern Tyrol and the Malm and Dogger of the Bernese Oberland (16).

Finally, it is possible to recognise the position of the middle of the trough by the distribution of the Nama beds west of the Klinghardt Mountains. Here an anticline with a north and south trend can be traced from the Gabis Berg to the Mitte Berg. This is built up by a strip of gneiss which increases steadily in width both toward the north and toward the south, but immediately west of the Klinghardt range is overlain by a strip of Nama beds. This evidently marks the position of the deepest part of the original depression. For the same reason the Nama beds between Bogenfelsen and the Luderitz

claims extend westward down to the coast, the Schwarzkalk descending to sea-level, whereas when followed inland they exhibit the previously described step-like recession toward the north and south.

On the question of how far the strike of the basement gneiss has been affected by the coastal folding, and of whether or not certain inliers exhibiting an east and west strike are to be regarded as unfolded relicts, the writer does not feel justified in expressing an opinion. That, however, the gneiss is not as rigid and immobile as was formerly supposed, was clearly brought out by the detailed mapping of the littoral (17).

It is of interest to record that Rogers also ascribes the north and south strike of the gneisses on the coast of Little Namaqualand, and their east and west strike farther inland, to later folding at the coast (18). In so far as the folded belt in the area under discussion is concerned, it is not clear whether or not the intensity of the folding increases as the coast is approached. The more westerly of the two synclinoria that can be distinguished on the southern diamond fields is certainly the more strongly folded. This, however, may be due to its being the narrower, as it is generally found that the narrower an infolded belt of Nama beds the more intensely is it folded; and, further, that the intensity of the folding always increases with approach to the less mobile gneiss basement. In the main synclinorium, although it is on the whole less strongly folded, numerous overtilted folds are also observed as the gneiss is approached, and at its narrower northern end, situated south of the Zweikuppenberg, it is made up of three overturned folds.

The most easterly of the gneiss anticlines, which at the same time may be taken as the eastern limit of the coastal folding, lies immediately below the eastern escarpment of the Klinghardt Mountains. East of these mountains is a debris-covered plain which, in close proximity to them, is underlain by phonolite and gneiss. At a distance of from three to five kilometres farther east, however, only Nama beds are found. The strike of the ranges, capped with Nama beds, along the western end of the Wittpuetz trough is identical with that of the main monoclinal flexure at Wittpuetz, namely, W.38°N.

The gneiss-granite ridge, extending from the watering-place Aurus across Heioab to Gabusib, also follows the same direction, but along the eastern edge of the Klinghardt Mountains it apparently swings round more to the north, becoming involved in the most easterly of the anticlines of the coastal folded belt. This gneiss ridge is still clearly within the area affected by great trough subsidence. On its northern slopes are exposed great quartz veins up to several kilometres in length. On the Gabusib Berg the writer located no fewer than six such veins running parallel with one another. In the Heioab Berg, the highest eminence of the range, they are also very much in evidence.

The first syncline occupied by Nama beds, to the west of the anticline mentioned above, begins between Namiams and Namitzis,

and extends across the so-called Mittagskuppe, situated west of Kaukausib, to Zuelow Kop. In it Schwarzrand beds are still to be observed between the Klinghardt Mountains and Kaukausib. Their areal extent will have to be determined by further investigations. West of this the Nama system is only represented by its lower members up to and including the Schwarzkalk.

Very important and interesting from the point of view of the present investigation is the occurrence of alkaline rocks in the coastal folded belt. They are found for the most part within the extension of the Wiitpuetz trough toward the coast, being far less common between the trough and the gneiss horst, already mentioned, and apparently absent altogether on the latter. The widely-held view that there is a close genetic relation between alkaline rocks and epeirogenic crustal movements was discussed at some length by Professor Shand in his presidential address to this Society (22). Shand is inclined on the whole to reject the theory, and there can be no doubt that alkaline rocks do occasionally occur in folded tracts or owe their upward propulsion to folding. Professor Kaiser in his recently published paper (23) on the different forms assumed by injected bodies of syenitic rocks, designates the celebrated occurrence of the Sierra de Monchique a *phacolite*—that is, a body of igneous rock that owes its emplacement to injection into a cavity formed by folding. And yet the surprisingly frequent occurrence of alkaline rocks in areas affected by epeirogenic crustal movements is so striking that there appears to the writer to be ample warrant for further investigation and discussion of this very important subject.

In this connection we may first quote Eduard Suess, who states on p. 558, Vol. IV., of his great work *The Face of the Earth*:—

> " In 1902 Becke published the surprising observation that two types are to be distinguished in recent volcanic rocks, and that regions which in the main are folded tangentially belong to the one (Andes type), while regions with dominant radial dislocations (segmental fractures) belong to the other type of the Bohemian Mittelgebirge).
>
> " A few months later, in 1903, Prior arrived independently at the same conclusion, as a result of his investigations of East African rocks, and in the same year, 1903, Becke's more detailed work on this subject appeared, in which the two types are distinguished as Pacific and Atlantic."

The restriction of the alkaline rocks to areas affected by epeirogenic movements is only claimed by Becke in respect of Tertiary and post-Tertiary eruptives. He maintains that, before a definite law could be established, it would be necessary to ascertain whether the presumed connection also holds with regard to the earlier periods of igneous activity. In the Namib the intrusion of the syenitic and foyaitic rocks took place in pre-Tertiary times. Such intrusions include the massifs of the Granitberg with its satellites, the Schlueberg (Pomona), the Drachenberg (between Pomona and Kaukausib) and the Naras Hills (west of Namitsis, south of the Klinghardt Mountains).

The syenitic rocks of the last-named locality occur at the same level as the phonolites exposed in this area. It is to be concluded therefore that, between the intrusion of the syenites and the extrusion of the phonolites, there was an erosion interval during which a thickness of several hundred metres of rock must have been removed. The syenites are earlier than the early Tertiary or Cretaceous silicification (*Verkieselung*) of an old land surface that has been found in the littoral, and also earlier than the early Tertiary Pomona beds. The eruption of the phonolites probably began during or after the deposition of the Pomona beds in very early Tertiary or Cretaceous times, since at Swartkop, east of Bogenfels, the phonolites have metamorphosed quartzites belonging to the Pomona beds.

The phonolites in numerous separate intrusions riddle a large area. This embraces the entire width of the Wittpuetz trough, its eastern limit coinciding with the first of the folds east of the Klinghardt Mountains. The phonolite province includes the whole of the Klinghardt range and a strip of country, about 10 kilometres wide, lying to the west of it, so that the entire width, measured from east to west, is 30 kilometres.

The Pomona beds are also pierced in the Chalcedontafelberg, situated in the eastern part of the Luderitz claims by basic basaltic rocks (melilite basalt). A still more recent phase of the eruptive activity is represented by basic igneous rocks enclosing boulders of phonolite derived from the oldest pre-Miocene river gravels.

All these igneous rocks are practically confined to an area corresponding with the westward prolongation of the Wittpuetz trough into the folded coastal belt. There is thus strong presumptive evidence for connecting them genetically with it. In the concluding section of the present paper evidence will be adduced to show that the manner of injection of the syenitic and foyaitic rocks affords proof of their dependence on the great trough-subsidence and their independence of the folding. It will suffice here to draw the conclusion, substantiated by further argument that the subsidence, like the igneous activity responsible for the eruption of the alkaline rocks, was of long duration; and further that, while the great trough was already in existence before the folding along the coast began, the subsidence within it continued long after the folding.

V.—The Block-faulted Zones.

It was pointed out in the introduction that several areas characterised by block faulting may be distinguished. First there are those bordering the Wittpuetz trough on the north and south, while that of Kuibis, which ranks as the best known, must also be taken into consideration. It lies north of the great gneiss horst and belongs to the Koichab trough, to be presently referred to.

The block faulted area south of the Wittpuetz trough is the least known. Numerous faults were observed by the writer at Breckbout,

south of the great bounding flexure; also to the south of Wittpuetz in the neighbourhood of the watering place Harries, where some of the faults have evidently a very considerable displacement.

The area north of the great trough is better known, particularly along the Namib escarpment. It begins at Gubidaus, 17 kilometres south of Kubub and about 8 kilometres south of the trigonometrical point "Aar" (1,786 metres) in which the gneiss horst culminates. From this point the Nama beds dip gently toward the south, and the edge of the plateau juts out farther and farther to the west. Faults striking east and west and north and south are much in evidence, and cut up the area so as to make it resemble a vast chessboard. The faulting and the southerly dip of the sedimentary rocks become more pronounced east of the Arasab Berg, which is capped with an outlier of the Nama system. Powerful faults trending north and south are also to be seen east of Pockenbank, where a number of Nama-capped hills project westward into the Namib. This chain of table-topped hills is shown on Range's map (1). That author also shows a great north and south fault in this area and another to the east of the Great Escarpment, south of Aukam. A short distance south of Pockenbank the big northern bounding monocline of the Wittpuetz trough is itself exposed, its position being marked by a chain of table mountains running out into the Namib.

In the block-faulted area of Kuibis, lying north of the gneiss horst, Dr. Lotz observed dislocations striking N.-E. S.-W. in the table-topped mountains east of Kubub. Range (1) recognised W.-N.-W. E.-S.-E. faults at Kuibis, and on his map he also shows a fault trending at right angles to this. He makes no mention, however, of the fact that the whole of the Kuibis area is cut up into great fault blocks. As far as the writer's own observations go it is completely cut up by a network of faults striking east and west and north and south.

Range (1) was the first to call attention to the great east and west fault which at Kuibis station has brought the Schwarzkalk into juxtaposition with gneiss. This can be traced for a considerable distance along the railway. Other east and west faults were observed by the writer in the steep banks of the Aukam River, between Aukam (Bitterwasser) and Kuibis. Speaking generally, however, the north and south faults are the more important. One such is crossed by the road between Kuibis and Aukam, near the watering place Aukam. Owing to the lack of reliable maps of the area the writer is unable to say whether we have to do here with the same fault that farther south runs parallel with the Aukam River for a considerable distance on its eastern side, approaching in places to within a few hundred yards of the river. The throw of this fault is variable. At some points it has brought quartzite into contact with quartzite; at others, gneiss borders on Schwarzkalk. Two kilometres east of Aukam this fault can be clearly made out on the upper slopes of a range of hills (Plate III., Fig. 2). Its strike at this point is N.30°E.

A north and south fault which was first noticed 1 kilometre south of the homestead on the farm Heikoms was more carefully traced. This trends northward from the locality named past the trigonometrical Namisis. It can be followed for 20 kilometres. The strike varies from N.20°W. to N.10°E. The throw was found at one point to be 125 metres, measured by an aneroid barometer. The next north and south fault, situated some 6 kilometres to the west, is the one described above as running parallel with the Aukam River. The great fault block lying between these two dislocations consists of Kuibis quartzite dipping at a low angle toward the east. Nearer the Heikoms fault, however, the strata become more disturbed and the dips much steeper, with the result that for considerable distances the fault is bordered by Schwarzkalk brought into this position by synclinal folding, or as a result of drag (Schleppung) along the dislocation. (Plates III. and IV.)

All the faults referred to, as well as the great monoclines, find expression at the surface in escarpments, and are thus very easy to trace. The faults themselves are not simple dislocations but shalter zones. This is proved by their considerable width and by the fact that they are occupied by friction breccias, which may or may not be cemented by quartz. In the east and west fault exposed on the banks of the Aukam River the filling is in part milky white quartz, but in part also very closely resembles the adjacent quartzite. It exhibits a splintery fracture, and is at the same time interspersed with small patches of kaolin, which point to the original presence of fragments of the felspathic quartzite.

Particular interest attaches to the filling of the Heikoms fault. This takes the form of a body of friction breccia, 10 metres in thickness. The whole mass of the breccia is impregnated with silica, grey drusy hornstone, *eisenkiesel* and chalcedony being present in addition to quartz. Numerous angular fragments of country rock are in evidence. These are themselves silicified and traversed by quartz stringers of varying thickness. The quartzite and schwarzkalk bordering the fault are also fractured and veined with quartz, so that the limits of the breccia are none too clearly defined. At two points shows of oil were found in the breccia, the oil being contained in fractures and druses (12). The dark colour of the portions of the breccia, containing the oil, at once betrays the presence of enclosed masses of Schwarzkalk. It should be stated that in the area under review, as elswhere in Great Namaqualand, the Schwarzkalk often contains highly bituminous layers having the character of foetid limestone (Stinkkalk). The oil has thus evidently been derived by distillation from the Schwarzkalk, and the question arises: What has caused the distillation?

Shows of oil have been found at many localities in the Union of South Africa, where it can be proved that the oil must have been distilled from bituminous Ecca Shales through the agency of dolerite dykes. A similar explanation could be offered of the oil occurrences under discussion, as, about 20 metres above one of them, a porphyrite

dyke cuts through the fault and the quartzite bordering it.[3] And yet the writer inclines to the view that the oil distillation was not caused by the dyke. In the first place no igneous rock has been found in the neighbourhood of the second oil show, situated some hundreds of metres from the first. Secondly, the Schwarzkalk shows no sign of alteration where cut by the dyke, nor has any oil been distilled from it. The writer regards the presence of the dyke at this particular point merely as a rather remarkable coincidence. According to his view, heat generated by friction due to the trituration of the material occupying the fault is sufficient to account for the distillation of the oil. He would like to call attention to a similar occurrence which he observed in the Poethen potash mine in Thuringia. One of the shafts of that mine is sunk in a crush-zone in the Zechstein dolomite. In fissures and cavities in the dolomite exposed in it, oil occurs in exactly the same manner as described above. The oil has evidently been derived from the " Stinkdolomit " of the Zechstein. There can be no question here of the distillation being due to an igneous intrusion. It might, of course, be assumed that the oil had been distilled from yet greater depths by heat of the earth, but, if that were so, the dolomite away from the crush zone should also contain oil, and this is nowhere the case.

At a number of points there is clear evidence to show that the faults with which we have been dealing have developed from monoclinal folds, or, in other words, that they represent torn flexures. Thus the east and west fault of the Aukam River is clearly a doubly fractured monocline with a steeply inclined intercalated fault segment. In the Heikoms fault the quartzites on the upthrown side are also at several points inclined toward the fault. Westward of, *i.e.*, below, the steep escarpment on which the trigonometrical Namisis is situated, a great block of quartzite is found lying on Schwarzkalk. This is shattered to such an extent that not a single solid layer of the rock could be found in it. It evidently owes its position and its present condition to the sliding down from the upper slopes of a great mass of quartzite which was favoured by the bending down of the beds of that rock above the fault.

The great fault blocks, lying between the N.-S. and E.-W. dislocations at Kuibis, exhibit a certain regularity of disposition which proves that they are related genetically with the Koichab trough. Not only are they all inclined toward the east and break off step-like along the north and south faults, but they are also inclined toward the north, as is proved by the considerable extent of country covered by the Schwarzkalk at Kuibis, south of the east and west fault. South of the gneiss horst, on the other hand, the fault blocks show a constant dip toward

[3] This dyke is the only igneous intrusion of post-Nama age that the writer came across in this particular area, though he carefully examined the escarpments of all Nama-capped hills for suspicious gaps. Provisionally the porphyrite may be assigned to the period of igneous activity that gave rise to the Karroo dolerites. Range (1) actually mentions porphyrite as occurring among the Karroo dolerites of South-West Africa.

the south, *i.e.*, toward the Wittpuetz trough. We have thus to picture to ourselves a tableland, broken up into fault blocks, dipping away to the north and south from a central horst, and forming a transitional stage between it and the great depressions of the Wittpuetz and Kuichab troughs.

The earthquakes recorded by Range (1) at Kuibis are proof, according to that author, that crustal movements are still in progress along the dislocations of the block-faulted area.

VI.—The Aus-Luederitzbucht Gneiss Horst.

A horst is a strip of the earth's crust left upraised by the foundered segments of the surrounding country. The portion falling east, at any rate, of the Great Escarpment, of the tract of country extending from Heikoms across Aus to Luederitzbucht comes strictly within this definition, as it is bounded both on the north and south by block-faulted areas falling away from it toward the Wittpuetz and Koichab troughs. But the broad belt of gneissic rocks (1, 2, 3, 4, 5) that extends westward from the Great Escarpment at the trigonometrical point Aar across the Aus Mountains to the peninsula, jutting out into the sea at Luederitzbucht, is also morphologically and probably genetically part of this horst. Little is known about the gneiss-granite horst lying south of the Wittpuetz trough beyond that areas of infolded pre-Nama beds are of fairly common occurrence in the gneiss. About 10 kilometres south of the bounding monocline at Wittpuetz is the great granite boss of Harries-Nudabib, which at Harries attains an elevation of 1,410 metres. A well-defined belt of granite and gneiss builds the Aurus-Heioab-Gabusib mountains. Its relations to the great trough have not as yet been established. The gneiss area of the Buchu Mountains almost reaches the coast. It is quite possible that in this Harries-Nudabib-Aurus-Buchuberge gneiss-granite belt we have the southern equivalent of the gneiss horst extending from Heikoms to Luederitzbucht.

A gigantic gneiss-granite ridge borders the Kuichab trough on the north. The Tiras and Awasib Mountains lying in the great sea of sand dunes, occupying this part of the Namib, form part of it. The writer knows very little about this area or of that lying south of the Wittpuetz trough. He proposes therefore to confine himself to a description of the Heikoms-Luederitzbucht horst.

This has its beginnings on the farm Heikoms, situated 35 kilometres south of Kuibis. The table-topped mountains so characteristic of this area are here interrupted by a strip of gneiss with an east and west trend. This is shown on Range's map (1). It is between 50 and 60 kilometres in length and has an average width of about 10 kilometres. Toward the east it appears to be cut off by a fault striking north and south, as the Nama beds, with which the table mountains are capped, make an abrupt appearance about 12 kilometres east of Heikoms in a steep escarpment trending north and south and covered

in great part with sand dunes. Toward the west the gneiss disappears below lofty table-topped mountains also capped with Nama beds. It is significant that the highest part of the Great Escarpment in this area, on which is situated the trigonometrical point Aar, lies in a direct line with the continuation toward the west of the gneiss ridge. From this point the edge of the escarpment falls away both to the north and south, without there being any corrrespoding decrease in the thickness of the capping of Nama beds; the increase in the elevation of the plateau edge being evidently due to a gradual increase in the elevation of the gneiss-Nama contact, or, in other words, of the base of the Nama. This can actually be made out with the aid of field glasses. From the trigonometrical point Aar, a ridge of old granite, building the Aarkop and Schettler Mountains, trends westward to the Aus Mountains, which stand out like a great bastion in front of the Namib escarpment, attaining the same elevation as the latter. Westward of this there follow in turn the Tsirub, Tschaukaib and Kowies Mountains and the Luederitzbucht peninsula jutting out into the Atlantic.

Before proceeding further with our description, it will be convenient to deal briefly with the several granites that play so important a rôle in the geology of the Namib. The systematic study of these rocks is still in its infancy. We propose here merely to point to certain conclusions in regard to their tectonic and age relations that may be drawn from existing observations.

Arranged in order of decreasing geological age we may distinguish between:—

(1) Plagioclase-rich Granite.
(2) Grey Granite.
(3) Red Granite.

The general geological relations between these several types may be briefly stated as follows:—A complex of very ancient orthogneisses, for the most part of rather basic composition, was intruded by stocks and injected in *lit par lit* fashion by the oldest recognisable granite. This is characterised by being rich in greenish-white plagioclase and by showing a tendency, in areas where assimilation has taken place, to develop a pegmatitic or aplitic facies. The basement complex thus intruded and injected by the plagioclase-rich granite was next subjected to intense metamorphism and crushing evidently caused by orogenic movements. These, the oldest rocks of the area, are in consequence more or less of the nature of mylonites. The original equigranular texture of the granites has only been preserved at the centre of the bosses, but even here they show marked evidence of metamorphism. Macroscopically the pegmatites are seen, as a rule, to consist of parallel lenticles of quartz in a granular matrix composed mainly of felspar. Other pegmatites show large felspar crystals or aggregates of such crystals in a groundmass exhibiting advanced cataclastic structures. Yet others have suffered complete granulation to a dense dull-looking mass in which with the naked eye it is barely possible to make out the individual quartz and felspar grains. The *augen-gneiss* that has such

a wide distribution at Pomona and Prince of Wales Bay appears to have developed as a result of such mylonitisation from a composite gneiss formed by *lit par lit* injection; there being every gradation between the *augen-gneiss* and typical "Zebra" (composite) gneiss. Breccia-like angular inclusions of the injected gneiss and patches of granite and pegmatite can, moreover, sometimes be made out in the *augen-gneiss*.

Under the heading Grey Granite are included two granites belonging to the second period of intrusion. One of them occurs in the littoral, the other at Aus in an area occupied predominantly by very ancient sedimentary rocks.

The granite occurring in the littoral is a medium-grained grey biotite granite which, at Luederitzbucht and in the Kowies Mountains, forms a number of large and small stocks. These cut the old gneiss and also the plagioclase-rich granite, previously referred to. The granite differs from the oldest granite in that, while it also is metamorphosed and gneissic in habit, it has not suffered granulation. It, moreover, as stated, exhibits a transgressive relation with regard to the rocks injected by the plagioclase-rich granite, and is free from the greenish-white plagioclase so common in that rock. A final point of distinction is that it shows less tendency to a pegmatitic development than the older granite. With this granite the writer would also group the older gneiss-granite of Aus. This forms the main mass of the Aus Mountains where it has injected in interlaminar fashion and in great part assimilated a complex of ancient sedimentary rocks. A characteristic feature of this granite, which it shares with that at the coast, is its richness in *schlieren* and xenoliths and its very variable composition. At Aus it is generally rich in garnet, which is to be attributed to the assimilation of ancient calcareous sediments. The Aus granite is best described as a gneiss-granite exhibiting well defined pseudo-bedding. It is surrounded by a broad aureole of composite- or zebra-gneiss which merges gradually into the intruded sedimentary rocks.

Among the granites of the third period are comprehended a number of granites having in common the following:—

(1) An intrusive relationship toward the Grey Granite.
(2) A fresh appearance with very little evidence of metamorphism; their texture being as a rule equigranular.
(3) A tendency to aplitic or pegmatitic development.
(4) Richness in quartz.

Other peculiarities, such as richness in tourmaline, alteration to greisen, etc., have so far only been noted locally. Among these granites may be included:—

(*a*) The younger granite of Aus. This forms a number of stocks cutting through the gneiss-granite. It is a very coarse-grained grey porphyritic granite with phenocrysts of felspar often exceeding 2 cm. in longest diameter. Sometimes the felspars exhibit a fluidal arrangement. South of the railway at Aus this granite is less frequently seen. It forms two

stocks near the watering place Gubidaus, 18 kilometres south of the railway, when it runs parallel with the edge of the escarpment. It is also met with in the Kubub Mountains near the so-called Radford Well and in the Bismarckkuppe. North of the railway it builds the Kanusberg and the Swartausberg.

(*b*) A reddish fine-grained granite of aplitic habit which frequently encloses schliers of pegmatite and shows a tendency to granophyric development. Granite of this type occurs at Gabusib on the south-eastern edge of the Klinghardt Mountains, in the Muenzenberge to the south-east of the watering place Kaukausib, at Harries, to the south of Wittpuetz and at Pockenbank. Other examples are the younger granite of the gneiss-granite ridge south of the Granitberg and also probably the red granite of Kunjas (12).

(*c*) A purely pegmatitic facies, such as is met with at many localities between Elizabeth Bay and Prince of Wales Bay, and in the Rote Bergen and in the Bokberg west of the watering place Kaukausib cuts through mica schists and older sedimentary gneisses.

As regards the correlation of the granites, which we have been describing, with those in other parts of South-West Africa, it may be pointed out that the plagioclase-rich granite is probably older than the oldest granite described by Cloos (6) from the Erongo area, namely, the Salem granite, as this is intrusive in sedimentary gneisses. The grey and red granites are probably the respective equivalents of the two older granites of Cloos, namely, the Salem granite and the pegmatitic granite. No equivalent of the Erongo granite has as yet been found in the southern Namib.

As regards the granites of the Walvis Bay hinterland described by Wagner (30), the medium-grained older granite of that author may be the equivalent of either the plagioclase-rich granite or of the grey granite. His porphyritic and red granites may be correlated provisionally with the Aus granite and the red granite.

Taking a broad general view of the granites of the area under review, the following facts emerge:—

(1) There is a progressive increase in acidity with decreasing age, the oldest being the most basic and the youngest the most acidic.

(2) The earliest intrusion, irrespective of the age of the granite, always take the form of a *lit par lit* injection, while later intrusions exhibit a transgressive relation to the intruded rocks.

(3) There is always a very considerable development of pegmatites and aplites where *lit par lit* injection has taken place, and also in connection with the younger granites.

These characteristics of the Namib granites illustrate world-wide conditions to be found everywhere where pre-Cambrian rocks have been invaded on an extensive scale by granite. In this connection the reader is referred particularly to the papers of Cloos (7, 8, 9, 10) and to the writings of R. A. Daly (25).

After this somewhat lengthy digression, we may return to our discussion of the structural geology of the Heikoms-Luederitzbucht horst to which the following facts are relevant: The entire horst between the two localities named is riddled with large and small stocks of grey and red granite. In its eastern portion, between Heikoms and Aukam, the granites at once attract attention by reason of the black colour they assume on weathering. They give rise to conspicuous "Felsen" and "Block Meere," which on closer examination are found to consist of granite boulders covered with lustrous crusts of black desert varnish. At Aukam a big boss of fresh red granite is exposed.

The Aus Mountains, as previously stated, are built up mainly of gneiss-granite and composite gneiss, which are intruded by younger coarse-grained granites. The gneissic rocks predominate south of the railway, while to the north of it the younger granites are more in evidence.

The Tschaukaib Mountains were first recognised by Range (1) as a great granite boss. In the same area the present writer came across big intrusions of granite west of the Halenberg. The Kowies Mountains also consist of granite enclosing big isolated masses of gneiss. The detailed mapping of the Luederitzbucht area has shown that the rocks of the basement complex are cut discordantly by numerous large and small intrusions of grey granite.

Turning now to the gneiss area lying between the horst and the Wittpuetz trough, west of the Great Escarpment, or, in other words, to the western part of the block-faulted zone, one is at once struck by the rarity of large granite intrusions in it when compared with the horst. Granites are present, but for the most part they build small stocks, and almost all of these consist of the youngest red granite. Some of the stocks actually reach the Wittpuetz trough. This applies, for instance, to the big stock at Pockenbank which stands out in relief from the northern bounding monocline like a mighty pillar bordered east and west by sunk areas of Nama beds. In how far the granite was itself affected by the great trough-subsidence the writer was unable to ascertain, but it must have been involved to some extent, as it has been brought into direct contact with the Nama beds for a distance of several kilometers along the presumed course of the monocline. The main mass of the granite was, however, clearly unaffected by the subsidence. The detailed examniation and mapping of this stock would probably afford valuable evidence in regard to the question of whether or not epeirogenic crustal movements avoid old granite stocks. Owing to the waterless character of the area in question and its inaccessibility, the writer was unfortunately unable to do anything further in this direction. He is, however, inclined to regard the high gneiss-granite ridge to the south of the Granitberg as

an old granite stock that remained standing in its original position in the middle of the Wittpuetz trough. It is made up of plagioclase-rich granite cut by the most recent granite. The folds of the coastal belt also appear to have avoided it (23).

The plagioclase-rich granite is mostly present where the oldest basement rocks occur in the neighbourhood of the coast. It also has a wide distribution in the folded coastal belt west of the Wittpuetz trough between Prince of Wales Bay and Bogenfels. Here it actually preponderates over the other varieties, the youngest granite being confined to the high gneiss-granite ridge, previously referred to. Farther north the youngest granite in its pegmatitic facies is much in evidence between Prince of Wales Bay and Elizabeth Bay. The grey granite has so far not been found at all in the section of the littoral here dealt with. It is probable, however, that it is present farther inland in the great trough. The writer came across grey granite along the eastern margin of the Klinghardt range which probably belongs to this category. Big stocks of grey granite have, however, not been found in this particular area.

It has already been pointed out that alkaline rocks are of very rare occurrence on the gneiss horst or absent altogether. A few camptonite dykes have been located in the neighbourhood of Elizabeth Bay, and some quite insignificant exposures of essexite—in part only a few square metres in extent—are exposed on the Albatross Berg north of Elizabeth Bay. We have thus strong support for the view that the alkaline rocks stand in genetic relation to the Wittpuetz trough.

Although an interval equal at least to that represented by the deposition of the whole of the Nama system must have elapsed between the intrusion of the granites and formation of the trough, the abundance of granite stocks on the gneiss-horst and their rarity in the Wittpuetz trough appears to have been the decisive factor in determining the position of the master flexures bordering the trough; the rarity or absence of granite stocks having evidently provided favourable conditions for the subsidence of this great segment of the earth's crust.

This view, however, necessarily involves the assumption that the old plagioclase-rich granite, of which there is such a considerable development in the coastal belt within the area affected by the trough, must, in consequence of the granulation it has suffered, have had its rigidity very much reduced as compared with that of the unaltered younger granites; or, in other words, that it must have been thereby rendered much more mobile, which, after all, is quite easy to understand. Furthermore, it might be concluded from this and from the fact of the Pockenbank granite being involved in the northern bounding monocline that the roots of the granite stocks lie not only below the portion of the earth's crust affected by the tangential movements that gave rise to the folds, but below that in which the epeirogenic movements originated.

It remains to enquire in how far the dislocations of the block faulted zone have affected the gneiss horst. No important faults have so far been located on the latter. At Heikoms, where this question was specially studied, there are to be seen on the eastern slopes of the Heikomskuppe, along the line of prolongation of the great north and south fault there exposed, a multitude of small quartz veins carrying subordinate amounts of galena and chalcopyrite. Many of these give out within short distances and they never exceed 1 metre in thickness. The country rock of the veins shows no evidence of faulting. The vein-zone can be followed for a distance of about 1½ kilometres. Beyond this the veins are found to split up more and more into narrow stringers and finally to give out altogether. The fault, with a throw of about 100 metres, is thus found to disappear altogether on entering the horst, the main fault fissure being replaced by numerous subsidiary fractures.

7.—The Koichab Trough (Graben) and other Tectonic Troughs of Great Namaqualand.

In looking for similar structural troughs in the Namib the following features of the Wittpuetz *graben* were specially borne in mind:—

(1) Its demarcation at the surface by a well-defined depression trending E.-S.-E. W.-N.-W.
(2) The preservation of Nama beds within it far out in the Namib and actually right down to the coast, *i.e.*, far beyond the recognised western limits of these rocks.
(3) Its delimitation to the north and south by zones of block-faulting.
(4) Its ultimate delimitation by gneiss horsts trending parallel with it.
(5) The occurrence near the coast of alkaline rocks within the limits of the sunken area.
(6) Its continuation westward across the Great Escarpment, which evidently came into being after the down-sinking occurred.

These features appear to be reproduced by two strips of country lying some distance north of the Wittpuetz trough. One of them embraces the deep depression between the Aus and Tiras Mountains, which is traversed lengthwise by the dry bed of the Koichab River. This the writer has named the Koichab Trough. The other has its beginning along the coast between Spencer Bay and Conception Bay, whence it extends inland.

The Koichab Trough.—North of the Heikoms-Aus gneiss horst lies an extensive block-faulted area in which the individual fault-blocks show a tendency to be tilted toward the north. It corresponds with the block-faulted area to the south of the horst in which the blocks are tilted toward the Wittpuetz trough. East of the Great Escarpment powerful faults have been located at Bethany. These strike

W.-N.-W. E.-S.-E., *i.e.*, parallel with the Wittpuetz trough and gneiss horst. Range (1) in referring to them states: "Dass die Verwerfungen im westlichen Namalande meist W.-N.-W. O.-S.-O., streichen giebt schon Dr. Lotz an. So streicht diejenige welche die Quellen von Bethanien bedingt rechtwinkelig zum Verlauf des Schwarzrandabfalles." If, as appears not unlikely, these faults mark the position of the eastward continuation of the Koichab trough, it would mean that this, like the Wittpuetz *graben*, cuts across the Great Escarpment, and is thus earlier than the latter.

Between the Aus and Tiras Mountains which attain approximately the same elevation, the level of the land sinks between Neissib and the Little Loewenberg to 960 metres. The great depression having a width of over 30 kilometres is floored with desert waste and sand dunes, its deepest portion being occupied by the so-called Koichab dunes, notorious among travellers for their impassibility. Between the Springbok Flats (12) and the Great Loewenberg the writer encountered dunes 150 metres in height, and it is probable that the combined thickness of the debris and sand occupying the depression exceeds 200 metres. North of this belt of sand dunes is the great range of the Tiras Mountains which, like the Aus Mountains, is built of granites belonging to the intermediate and later periods of intrusion (12). In the course of the journeys that he has so far made into the Koichab depression, the writer has unfortunately not been able to visit the few exposures of rock within it. The foremost authority on the Namib, G. Klinghardt, who has rendered such invaluable assistance in the exploration and mapping of that remarkable tract of country, has, however, given him some data with regard to the occurrences of Nama beds within it. According to Klinghardt there are considerable outcrops of Schwarzkalk west of the Koichab Pan. These can be followed for some distance into the sea of sand dunes, the strike of the Schwarzkalk being in the direction of the watering place Anichab. Other rocks of sedimentary origin and dark igneous rocks are also said to be exposed in the area named. Further he remembers having seen bedded rocks at other points, such, for instance, as the Rechenberg, but thinks they are gneisses. We also know from this area the essexite occurrence of the Magnettafelberg, to the north-east of the Great Tigerberg (Dicker Wilhelm), described by Kaiser. The upper portion of the very high Great Tigerberg itself consists of limestone. This and the limestone occurrence to the north of Tschaukaib described by Range (1) possibly represents outliers of the Nama system in a deeply eroded block-faulted zone bordering the Koichab trough on the south to the west of the Great Escarpment.

As regards the westward extension of the Koichab trough toward the coast, Klinghardt states that the Blauberg, which projects from the sea of sand east of Hottentot Bay, is built of limestone. The writer's own journeys have up to the present taken him only as far as Hottentot Bay itself. Along the edge of the sand dunes east of Great Anichab and also on the Oldenburg diamond claims along the

dunes south of Hottentot Bay gneiss only is exposed. It is, however, worthy of remark that in the Bremen claims lying along the coast south of Hottentot Bay opposite the guano island of Ichabo numerous camptonite dykes are in evidence. An occurrence of norite and other igneous rocks were also observed. At Douglas Bay there were found many large pebbles of agate which have very probably been derived from an occurrence of chalcedonised limestone lying among the sand dunes (*cf.* 26).

The existence between the Aus and Tiras Mountains of a great tectonic trough (*graben*) may thus be said to be indicated by:—

(1) The deep E. and W. depression between these ranges, the actual depth of which is greater than is indicated by the levels, previously given, as its floor is covered with a thickness of some 200 metres of desert waste and sand.
(2) The probable presence at several points within the depression of outliers of Nama beds.
(3) The existence north of the Heikoms-Aus gneiss horst of a zone of block-faulting in which the individual blocks are tilted toward the north, *i.e.*, in the direction of the presumed eastward extension of the trough; and the presence of faults with an E.-N.-E. W.-S.-W. strike at Bethany, north of this block-faulted area.
(4) The E.-N.-E. W.-S.-W. trend of the great gneiss-granite ridge of the Tiras mountains.
(5) The occurrence of alkaline rocks within the depression inland as well as at the coast.

The Sylvia Hill Trough.—Even more meagre are the data that can be brought forward in support of the assumption that there is another great trough extending inland from Sylvia Hill on the coast past Duwisib.

There are, however, at least two points in its favour, namely:—

(1) The occurrence along the coast between Spencer Bay and Conception Bay of rocks belonging to the Nama System.

At Easter Cliffs, to the north of Spencer Bay, the dunes along the western edge of the great coastal sand belt recede from the shore, exposing a strip of land about 5 kilometres wide. This is built of gneiss overlain by quartzites, sandstones and limestones (1). Voit (27) records the occurrence of quartzites and quartzitic shales, and states that these are overlain by beds of dolomite which in Sylvia Hill attain an elevation of 280 metres above sea-level. Of igneous rocks mention is only made of dykes of basalt and dolerite. Harger (35) expressly states that he came across no monchiquite dykes in the Conception Bay area. There are, however, other occurrences of sedimentary rocks in this area. Reuning (28) states that the Easter Cliffs consist in their lower portion of quartzitic and phyllitic rocks, and in their upper portion of crystalline limestone. Toward the south there follow conglomerates, sandstones and limestones, assigned by him to a very

ancient geological formation; also thin-bedded quartzites and crystalline schists cut by dykes of a dark igneous rock. These rocks are succeeded at Boat Bay by gneiss.

(2) The structure of the Duwisib and Kleinfontein areas south of Maltahoehe.

If we imagine the strip of Nama beds lying between Spencer Bay and Conception Bay to be prolonged inland across the great sand belt, it would pass through the Duwisib and Kleinfontein areas to the south of Maltahoehe. At Kleinfontein is exposed[4] a peculiar east and west anticline in the Nama bed, in which the rocks of the Konkip system and even those of the Basement complex appear below the Schwarzkalk in the Minenkuppe and other hills. This anticline can be traced for a considerable distance toward the east and toward the west. In the same area there were located ore-bearing, brecciated quartz lodes with an east and west trend. These apparently occupy faults in the Schwarzkalk. They are in places over 20 metres in width, and the main lode has been traced for a distance of nine kilometres. It is evident from the foregoing that the main trend-lines governing the structure of this particular area have an east and west direction. The writer has, however, unfortunately no other data concerning it.

As bearing on the question of the existence in this part of the Namib of another great tectonic trough, it is also worth recording that from the so-called "Blutpuetzer Faecher," which occupies a dominating position south of its presumed position, there can be made out with the aid of field-glasses a chain of table-topped mountains extending westward from the Duwisib area into the sand desert of the Namib. The writer was originally inclined to regard them as being built of rocks belonging to the Konkip system, but they may possibly consist of Nama beds.

Before concluding the present section it will be convenient to refer to some observations of Rogers (18) in Little Namaqualand. They relate to a peculiar tilting of the Nama beds at Nababeep, which is best described in his own words: "The base of the Nama system sinks in a north-easterly direction from 3,000 feet to under 400 feet above sea-level in the course of 17 miles. This slope is due to the tilt of the synclinal axis in the same direction, for the general structure of the Nama beds here, as in the Schaap River basin, is that of a shallow syncline. The axis rises again north of the Orange River, which appears to have cut its way across the syncline where the bend of the axis lies. That this tilting of the axis is of post-Karroo date, like some of the faulting, is very probable, for on the south side of the river the Dwyka beds drop in level in the same direction and rise again to the north."

It would appear from this that on the Nababeep plateau the Dwyka beds are also involved in movements of faulting and subsidence,

[4] *cf.* Beetz (12).

which are thus clearly of post-Dwyka date. If we are justified in assuming that these crustal disturbances were coeval with those responsible for the formation of the Wittpuetz trough, then the latter must also be of post-Dwyka age. We have seen, however, that it is earlier than the porphyrite dyke which cuts through the big fault at Heikoms and is regarded as belonging to the Karroo dolerites. The main subsidence would appear thus to have taken place in post-Dwyka times during the Karroo epoch.

It is of interest to record that in the coastal belt bordering the Nababeep plateau there occur strongly folded rocks, regarded by Rogers (18) as being the equivalents of the unfolded Nama beds of the interior. Within the area occupied by them alkaline rocks occur at a number of localities, some of the occurrences being of considerable magnitude.

8.—General Considerations and Conclusions.

(a) *The Wittpuetz Trough in Relation to the Geological Structure of South Africa.*

The Wittpuetz trough in its narrower sense, *i.e.*, including only the portion that falls within the bounding monoclines, has an area of 7,700 square kilometres If the block-faulted zone to the north of it and the corresponding portion of the littoral be included, this would be increased to 15,000 square kilometres. The probability of there being a similar graben (the Koichab trough) and the possibility of there being yet another with the same strike (the Sylvia Hill trough) render this particular form of trough subsidence one of the most important features, if not the most important, in the structural geology of Great Namaqualand. This raises the question of whether similar sunken crustal segments with an east and west trend enter into the structure of other parts of South Africa. From the consideration involved the writer will endeavour to draw further conclusions in regard to the age and duration of the movements.

Apart possibly from Rimann's observations on the Chapman graben in the area occupied by the Khauas Hottentots and the cauldron subsidence on the Bullsport Flats in Bastardland, described by the same author (4, 5), neither of which agree in direction with our troughs, nothing has so far been made known concerning the existence of such troughs in the interior of South-West Africa. According to a verbal communication from Dr. A. Stahl, who travelled through the Kaoko Land, in the north-western part of South-West Africa, during 1922 and 1923, *graben* with an east and west trend appear to be present in the southern portion of that territory.

Epeirogenic movements on a great scale have also been recorded from the area in which the Great and Little Kharas mountains are situated (1). These ranges are bordered by faults which pass into great monoclinal flexures (11). Here again the movements have been

shown by Wagner to be of post-Dwyka age, but the direction of the faults and flexures is N.-N.-E.—S.-S.-W. The relation of the horsts of the Great and Little Kharas mountains to the evidently existent intervening sunklands remains to be more closely studied. Brief reference may also be made to the trough-subsidences mentioned by Suess (19) as occurring along, what he terms, the Cameroon Line.

The best anologon to the great tectonic troughs of the Namib is in the writer's opinion the Cape geosyncline (29), and yet this is so much bigger, both as regards areal extent and the amount of the subsidence involved, that a comparison appears hardly justified. It is worth noting, however, that its direction agrees fairly closely with that of the Wittpuetz trough, that it is of roughly the same age, and that in both instances the subsidence extended over a considerable period. The formation of the Cape geosyncline went on from Devonian to Triassic times, and there were local recurrences of the down sinking during the Upper Cretaceous period. The oldest sedimentary rocks directly involved in the Wittpuetz trough-subsidence are the Fish River beds. The age of these rocks has not been definitely established. They have been correlated with the Zwart Modder Series and are certainly much older than the Dwyka Series. That the epeirogenic disturbances responsible for the formation of the trough were of very long duration we have indirect proof, if it may be assumed that the alkaline rocks occurring within its presumed extension owe their eruption to the down sinking.[5] Thus the syenites and foyaites are considerably older than the phonolites and the younger basic rocks. The dyke rocks satellitic to the syenites and foyaites do not cut the tertiary or late cretaceous Pomona beds (17). After the intrusion of the foyaites and syenites there must have been a prolonged erosion interval, since these plutonic rocks are now exposed at the same level as the younger phonolites (Narasberg, south of the Klinghardt mountains). The phonolites are younger than the quartzites of the Pomona series. They are found overlying them in the hill known as Zwartkop, east of Bogenfels. Here they have, moreover, metamorphosed the Pomona beds. The sandstones of the Pomona series are also cut by melilite basalt in the Chalcedontafelberg, east of Bogenfels. Even younger is a pipe occupied by tuff which breaks through early Tertiary or Cretaceous river gravels containing phonolite boulders. If the assumption made above be correct, it is thus quite evident the subsidence that gave birth to the trough must have extended over a very considerable geological period. It is probably still in progress, since Range (1) between 1909 and 1912 recorded a number of earthquakes in the interior of Great Namaqualand at Kuibis, Bethany, Chamis and elsewhere, which he attributed to movements along faults in the block-faulted zone bordering the Wittpuetz trough on the north.

While the subsidence within the trough must thus have continued long after the cessation of the folding along the coast, it evidently began

[5] The facts supporting this assumption will be enumerated later.

and was in great part completed before the folding took place. When this occurred the Nama beds must already have been more or less in their present position. They could only have reached their low level at the coast as a result of subsidence, otherwise one would expect to find similar occurrences of Nama beds in this part of the littoral.

Reasons have already been given for assuming that the main part of the subsidence occurred during the Karroo epoch in post-Dwyka-times. Be that as it may, it follows from what has been said above that it must have taken place between the close of the period represented by the Fish River sandstone and the folding along the coast.

(b) *The Folded Belt along the Coast in relation to other Belts of Folding in South Africa.*

Under this heading it is proposed to discuss three important questions, namely:—

(1) Is the coastal folding related to the origin of the coast line?
(2) Is it related to any other folding in South Africa?
(3) What is the date of the folding?

Lotz (3), basing his conclusions on the folding along the coast and in the so-called folded table mountains of Wittpuetz, and on the undisturbed disposition of the Nama beds in the interior, states that "one must distinguish in the southern part of South-West Africa as in the Cape Colony between two structurally contrasted zones, namely, an inner zone, a region of level unfolded upland plains—Great Namaqualand proper, which corresponds with the Karroid plateau of the Cape Colony—and a folded belt which runs along the coast."

This view cannot be upheld, as there is no folded belt along the coast of the Cape Colony. The Cape ranges, as developed in the Cedarbergen and in the east and west ranges of the Cape Colony, lie far inland, and between them and the coast is a tract of unfolded or only slightly folded country (18 and 26).

Furthermore, there is no northward continuation to the Cedarbergen, which represent a north-westward extension of the Cape ranges. Followed toward the north their folds "gradually flatten out" (29). Along the coast of Little Namaqualand, however, there appears rather abruptly a belt of pronounced folding with a north and south trend, in which the rocks of Malmesbury, Ibiquas and Nieuwerust series are involved (18). North of the Orange river the northward continuation of these folds builds the Schakalsberge and the Obibberge at Sendlingsdrift. These ranges when followed northward recede farther and farther from the coast. A short distance south of the mouth of the Orange there begins a great plain which becomes wider and wider as it is followed northward across the river. Of the rocks underlying this plain nothing is known, as they are almost completely hidden under a thick cloak of desert waste. The first considerable outcrops are met with south of the Buchuberge. These are of strongly folded

gneisses and ancient sedimentary rocks which the writer regards as being of pre-Nama age. Nothing is known of the direction of folding, and on account of their great age these rocks, moreover, fall without the scope of the present discussion. The Nama beds themselves apparently only appear in the neighbourhood of the watering place Buntfeldschuh, where they are disposed in regular folds trending north and south. The folded belt which from here extends northward along the coast is thus neither a direct continuation of the "Cape" folds in the Cedarbergen nor of the folded coastal belt of Little Namaqualand; nor is it parallel with the coast, but cuts slantingwise across it.

In discussing this point, Kaiser (23) states, "Die Faltenzuege selbst stossen im allgemeinen diskordant an der Kuesteab," and further: "Richtiger ist es, die Vorgaenge so zu trennen, dass man Faltung als unabhaengig von der Kueste ansicht, wie vir dies ja auch von anderen grossen Teilen Suedafrikas bereits wissen, dass der Kuestenabbruch erst nach der Faltung erfolgt."

It would appear from the foregoing that the folding of the Nama beds on the southern diamond fields of South-West Africa is not related in any way to the origin of the coast line. On the other hand, the folds are on the whole parallel with those of the Cedarbergen and with those along the coast of Little Namaqualand. While they do not, as we have seen, form a direct continuation of the latter, they are none the less evidently congenetic with them, just as the folds along the coast of Little Namaqualand, though discontinuous with the northward flattening parallel folds of the Cedarbergen, are without doubt congenetic with these.

We are here evidently dealing with an arrangement of folded belts in oblique coulisses.[6]

There is every reason for regarding the folding in the littoral of Great Namaqualand as being coeval with that of the Cape Ranges. It is later than the formation of the Wittpuetz trough (post-Lower Karroo) and earlier than the present coast-line (early Tertiary). The earliest of the more recent sedimentary rocks on the southern diamond fields, the early Tertiary or possibly the late Cretaceous Pomona beds, are not involved in the folding. Furthermore, the earliest intrusions of syenite and foyaite are later than the folding, and it is evident that a considerable interval must have elapsed between the intrusion of these plutonic rocks and the deposition of the Pomona beds, since they were already exposed by denudation when the Pomona beds were laid down. The time limits of the folding are thus narrowed down to Lower Karroo and Cretaceous, which are the same as those assigned to the Cape folding.

We may next enquire how these facts fit in with Wegener's hypothesis (31). Wegener imagines the continents to be drifting like

[6] *cf.* Suess, E., "*The Face of the Earth*," vol. iv., p. 380.

great ice-floes and ascribes the folding of the Andes to the westward drifting of the American continent. The folding in the littoral of South-West Africa cannot thus be explained. The folds do not run parallel with the coast line and are not related in any way to its formation, which, according to Arldt (32), took place in Oligocene times. Now the Pomona beds, as stated previously, are early Tertiary or late Cretaceous. The intrusions of syenite and foyaite, though much older than these beds, are themselves later than the folding. Hence, if Arldt be correct, the folding is considerably older than the coast line.

According to Penck (14) the coast line is not a faulted one. He describes South Africa as a bent surface of denudation (*Rumpfflaeche*) and goes on to say that this bending "sich um die Leitlinien des Geologischen Baues nicht kümmert. Diese Verbiegung war maasgebend für den Umriss Suedafrikas. Wir haben es also nicht nur mit Kuesten zu tun, die sich an Faltungszonen und Verwerfungen knuepfen, sondern auch mit solchen, die ihren Verlauf jenem Vorgang danken, den wir heute Verbiegung, den aeltere Forscher Kontinentale Hebung und Senkung nennen." Range (1) concurs in the views of Penck. According to him a glance at the geological map of South-West Africa will convince anyone that the origin of the coast line is not due to faulting.

We have learned that the coast line south of Luederitzbucht is in no way related to the folding to which the Nama beds in this area were subjected. The detailed geological mapping of the southern diamond fields has, however, brought to light the existence, in the old gneiss and also in the rocks of the Nama system, of a number of great brecciated quartz lodes ("Buck" reefs), which in part run roughly parallel with the coast. Some of these quartz impregnated zones have been found to occupy fractures following the axial planes of small steep anticlines in the Nama beds. Others in gneiss occupy faults, the breccias being here evidently of the nature of friction breccias. South-west of the Pomona area they occur in two's arranged behind one another and trending roughly parallel with the coast. These particular "Buck Reefs" are, however, older than the coast line. They are cut by camptonite dykes and are thus of earlier origin than the intrusions of alkaline rocks previously referred to. Moreover, the most considerable of the "Reefs," which builds the Albatross Berg, south of Luederitzbucht, strikes N.-W.—S.-E. and is thus more probably connected with the formation of the Wittpuetz trough than with that of the coast line. A possible alternative to this explanation is that the requisite conditions for the severance of South America from Southern Africa in Oligocene times[7] were established long before the severance actually occurred by founderings on a large scale, and that these founderings gave rise to the faults and fractures above referred to.

[7] According to Arldt (32).

(c) *Alkaline Rocks in Relation to the Wittpuetz Trough.*

One of the most important results of the present investigation has been to establish that the alkaline rocks of the Southern Namib are practically confined to the Wittpuetz trough, being far less common in the zones of block-faulting previously dealt with, and absent altogether on the gneiss horst. Here we touch on one of the fundamental questions of geology, namely, whether or not there is a casual connection between alkaline rocks and epeirogenic crustal movements? There can, as already pointed out, be no reasonable doubt that in some places alkaline rocks owe their present position and their upward propulsion to folding (23). This, however, is not the case with the alkaline rocks of the Namib, the relation of which to the rocks they intrude has been worked out in detail at the Granitberg and also at the Schuleberg (in the Pomona area), having been described by Kaiser (23 and 24). Kaiser designates the Granitberg a transgressive "Durchschmelzungskörper," and states that it is on the whole independent of the folding that has affected the surrounding rocks; further, that the magma itself was largely responsible for the creation of the openings that it occupies.

The foregoing conclusions, reached as a result of a special study of the assimilation and contact phenomena along the edges of the Granitberg massif, and of the detailed mapping of the folded Nama beds of the Namib, indicate clearly that the magna must have been squeezed up from below. As the alkaline rocks are evidently related to the Wittpuetz trough it is difficult to escape the conclusion that the foundering of the sunk area was itself responsible for this upsqueezing. In other words the energy, by virtue of which the magna made room for itself, was derived from the pressure exerted on it by the great subsiding crust block. Kaiser evidently had something similar in mind when he wrote that the syenite injections and fissure fillings are perhaps related to the origin of the present coast line (*Kuestenabbruch*).[8] As we have seen, however, the coast line is of more recent date than the syenite intrusions.

The final impetus to the upward propulsion of the alkaline magma was probably given by the opening up, as a result of the folding in the coastal belt, of the bedding surfaces and other divisional planes of the already much fractured sediments occupying the Wittpuetz trough. The consequence of this was the riddling of the folded belt with intrusions of igneous rock.

Analogous assimilation phenomena, to those described by Kaiser for the Granitberg, were noted by the writer in the Drachenberg boss which is also to be described as a "Durschsmelzungskörper." Here again the more or less assimilated strips of the invaded rocks have retained their original north and south strike at the centre and along the margins of the intrusion, which has thus evidently reached its present position by a process of magmatic replacement.

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[8] *cf.* (23), p. 261.

Igneous rocks have so far only been found in the portion of the Wittpuetz trough affected by the coastal folding. It is to be concluded from this that the subsidence was in itself insufficient to cause the eruption of the magma and that the loosening process due to folding, previously referred to, was necessary to bring it about. The main arguments supporting the view that the alkaline rocks are related genetically to the Wittpuetz trough may be summarised as follows:—

(1) The main mass of the alkali rocks is confined to the folded portion of the trough.
(2) The igneous rocks themselves are obviously not responsible for the folding, since they cut across the folds.
(3) The syenitic-foyaitic magma made room for itself, the propelling force being the pressure exerted on it by the great foundering crustal segment.

Arising from the foregoing discussion we may finally raise the question whether kimberlite pipes, from which were derived the diamonds found in the littoral of South-West Africa, may not also be present among the igneous rocks of the Wittpuetz trough. The writer's own view is that, while this hypothesis may prove of value as a basis for further investigations as to the source of the gems, it is advisable, having regard to the numerous theories of origin that have already been discredited, to proceed here with extreme caution, and not to draw any premature conclusions.

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Explanation of Plates.

Plate I.—The northernmost part of the great monoclinal flexure bounding the Wittpuetz Trough on the east; view looking south. The photograph shows the horizontal disposition of the Schwarzkalk (forming the scarp on

the left) to within quite a short distance of the flexure. It takes in some six kilometres of the latter. At the southern (far) end of the visible part of the flexure this ends abruptly, but appears again in a similar scarp lying farther east. Within the limits of the flexure the Nama beds are locally much folded. Such folding is to be seen in places in the photograph.

Plate II., Fig. 1.—First beginnings of the great eastern flexure; view looking south-east from the banks of the Huns River. In the background the portion of the monocline, of which a nearer view is given in Plate I., can just be made out. The monocline begins with a slight downwarping of the Nama beds which rapidly increases in intensity.

Plate II., Fig. 2.—The great northern monoclinal flexure bounding the Wittpuetz trough. The photograph is taken from the Reckvlagte (Reck Vlaakte) which is floored with Schwarzrand beds. Toward the north these rise in a monoclinal fold to the level of the top of the hills seen in the middle distance. The Anus Mountains are seen in the background. They are capped with Fish River Sandstone.

Plate III., Fig. 1.—The north and south fault at Heikoms, seen from the north. The fault has a throw of 125 metres. To the left of it is gneiss overlain by Kuibis quartzite; to the right of it dark Schwarzkalk, and, in the ravine in the foreground, Kuibis quartzite. The bed of the ravine is formed of gneiss. The oil show, referred to in the text, is in the fault-breccia seen in the middle of the picture.

Plate III., Fig. 2.—The north and south fault between Aukam and Heikoms seen from the south. The breccia occupying the fault builds the small knoll on the edge of the scarp. The downthrown side on the left shows Kuibis quartzite resting unconformably on gneiss. The section on the right is similar and here the unconformity is clearly visible.

Plate IV., Fig. 1.—The fault-block between Heikoms and Aukam seen from the south-east. In the deeply incised bed of the dry river gneiss is exposed. This is overlain by Kuibis quartzite which forms the main mass of the block. The Schwarzkalk is only exposed along the near fault. It is seen in the foreground on the left. The surface of the block rises gradually westward and south-eastward to the next N. and S. fault at Aukam, the scarp of which is seen in the middle distance Bounding the horizon on the left is the Heikoms-Aukam gneiss horst.

Plate IV., Fig. 2.—Part of the syncline in the Nama beds, view from the north. The rock seen in the foreground is Kuibis quartzite. The hills in the background building the Hunsberge (on which is situated the trigonometrical point *Huns*.) consist in the main of rocks belonging to the Schwarzrand series which in this area is characterised by the presence of beds of dark quartzitic sandstone. The hill on the extreme left has a capping of Fish River sandstone.