THE FUNDAMENTAL COMPLEX
Of
WESTERN DAMARALAND,
SOUTH WEST AFRICA.

By

T.W. GEVERS, M.A., Dr. Phil.

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To accompany Geological Map of Southwestern Damaraland. Scale 1:100000.

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INTRODUCTION:

Enormous areas of South West Africa, particularly in its central portion, are occupied by very ancient gneissoid and granitic rocks, a great variety of schists and other more or less highly metamorphosed sediments. These ancient rocks, forming as they do the backbone or nucleus of our comtinent, on which all younger rocks repose as a veneer of varying thickness and continuity, are everywhere generally grouped together under the term Basement or Fundamental Complex.

For obvious reasons, chief of which are their invariably highly folded and metamorphosed nature and the entire absence of fossils, these ancient sediments and their intrusives have nearly always after the first initiation of geological surveys in most countries of Africa been somewhat neglected and also visiting geologists have generally preferred to devote their attention and limited time to less complex problems, for the solution of which detailed mapping extended over many years was not an essential or indeed a sine qua non. A notable exception, however, to this rule is the detailed early work of Rogers and du Toit in the northern Cape and of Hall in the eastern and north-eastern Transvaal.

In Europe and America, at a corresponding stage of the development of regional geology, conditions were entirely similar and to this day the space devoted to pre-Cambrian stratigraphy in most text books is in comparison to the fossiliferous Palaeozoic and later Systems exceedingly small. Natural and to a large extent unavoidable as this state of affairs may be, nevertheless it is apt to lead to entirely misguided

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conceptions in the mind of the novice and untravelled worker as to the relative importance of the pre-Cambrian and the post-Cambrian not only in building up the outer crust of our globe, but also as regards areal extent and particularly with reference to the geological time-scale. To the student growing up amidst the ancient sediments building up the plateau of southern and central Africa and trained to visualise the exceedingly old age of the African continent, that portion of a European text-book of stratigraphy dealing with the Tertiary conveys no intelligible message. The whole epoch is to him so incomprehensibly recent and short-lived, that the time-scale fixed in his mind allows of no comparison. To the student of pleistocene glaciation in the north German plains and the investigator of the "Litorina Sea", the praecursor of the present Baltic, the pre-Cambrian, even the Palaeozoic is equally incomprehensible. In the same way the present European and to a lesser extent American text-books on Stratigraphy produce in the mind of the ordinary stratigrapher and palaeontologist an entirely erroneous conception, particularly regarding the relative importance of the various Systems on the geologic time-scale. He fails to realise at what a late date in the history of our globe life of the more highly organised type really came into existence; that the Palaeozoic and later Systems in reality form but a thin veneer of sediment on the pre-Cambrian rocks; that the latter form the nucleus of all continents and, lastly, that they not only preponderate in bulk, but also that the length of time necessary for their formation is vastly in excess of the time expired since the beginning of the Cambrian.

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It is of course obvious that far greater difficulties attend the unravelling of the pre-Cambrian history of the earth, than that of the later periods. In the same way as hand-writings are rendered dim through age, so also the geological records backwards through the aeons become increasingly difficult to read. Above all, our mind and imagination entirely fail to appreciate the enormous intervals of time separating certain events, the visible records of which appear crowded together and in general have been more or less highly disturbed. Particularly is this the case with the oldest known sedimentary beds and with archean rocks generally. Fossils that might serve as indicators of time and horizon are entirely wanting. All the constituent rocks have been highly disturbed by intense folding and magmatic intrusion. The sediments are often metamorphosed beyond recognition. Unconformities, the main aids in assessing time-values, are more often than not completely obliterated by interfolding. Luck alone in discovering one or two localities more favourable for their preservation can offset this disadvantage. Even age-determinations by ordinary superimposition are very often rendered inapplicable by systematic overfolding. Indirect and more laborious methods have to be applied, such as the determination of the intrusive nature or otherwise of a certain widespread igneous rock into the various sedimentary groups, or the detailed study of pebbles, particularly with reference to their derivation, in conglomeratic zones. Very often results, which in the case of younger, less metamorphosed and less disturbed beds would have been apparent almost at once, can only be deduced after detailed mapping extended over years.

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In Europe Sederholm and his assistants in Finland have led the way in establishing a stratigraphy of pre-Cambrian sediments and in North America a large number of geologists, among them Walcot and Coleman, have been so successful in unravelling the pre-Cambrian history of their continent, that the major divisions of the North American classification of the older and most ancient rocks have practically become standard throughout the world.

It is obvious of course that investigations of these old sediments and their intrusives will be rewarded with most success and their results be of wider significance in regions, where the continental nuclei have been deprived of their veneer of younger sediments over great areas. The old, rigid landblocks of the earth's crust offer the most favourable opportunities in this respect. It is no wonder therefore, that the pre-Cambrian stratigraphy hitherto established and well-known is connected with two such land-blocks or continental nuclei: The Canadian Shield and Fennoscandia.

South Africa as a portion of one of these ancient landblocks, the largest of them all, offers particularly favourable facilities for studies in this field. With the exception of its extreme southern portion the surface veneer of younger sediments has by erosion become very disrupted and localised, an immediate result of the old age of the surface of our sub-continent. Ever since its consolidation into a continental nucleus in archaean times, our continent has weathered the ages as a firm and stable block, that only rarely subsequently was submerged beneath the sea. On the few occasions

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that this event did occur, apart from minor encroachments of the sea along portions of the coast, it was only a shallow and shortlived sheet of water that covered larger portions of the continent. South Africa, on the contrary, is characterised by a great wealth of non-marine, terrestial or at least continental shallow-water deposits. Among the continents of to-day, Africa of which the extreme northern part is a foreign entity only comparatively recently accrued and geologically in reality a portion of Europe, is the venerable "old man" and the very large areas of exposed pre-Cambrian rocks mark the progress of its senile decay.

As already stated, enormous areas of South West Africa are occupied by these ancient rocks. Magnificent exposures over large areas, partly the result of the general aridity of the country, invite to detailed studies. In the words of Wagner (6, p.33): "An almost bewildering variety of lithological types is represented, and with its unrivalled wealth of exposure the territory will, no doubt, eventually become one of the classic fields of petrographical research". To which Beetz adds (12, p.42), that not only petrographically, but also stratigraphically South West Africa promises to become, together with North America and Fennoscandia, a classic country for the study of pre-Cambrian formations in general.

The first step in this direction has already been effected by Kaiser and Beetz in the Luderitzbucht littoral, where their very detailed investigations have made this coastal strip one of the best known areas in the country. In connection with the Fundamental Complex a recent paper of Beetz (12) is of special importance, since it represents the first attempt based on detailed investigations in the south to classify the

Basement rocks of the whole territory.

Similar progress cannot be reported for the rest of the country. Although numerous geologists have from time to time described many of the most notable rock-species belonging to the Fundamental Complex, nevertheless the stratigraphy and tectonic structure of the latter have hitherto been neglected. Very useful work, however, in this direction was done by Rimann in the Rehoboth area, where an attempt was made by him to classify the Fundamental Complex in that portion of the territory (4). The most notable contribution towards our knowledge of the distribution of the various main rock-types of the Basement Complex was made by Reuning some years ago (7). His geological map of the Central Portion of South West Africa (scale 1:2000000) proved of great value in the mapping of the area to be described in the present paper. It conveys, however, very little information about the tectonic structure and none about the succession of beds in the sedimentary components of the Fundamental Complex. To Reuning we also owe very valuable investigations on many of the ore-deposits genetically connected with the old granite-intrusives (8 & 9).

The earliest description of part of the ancient rocks in the area under consideration was given by Gürich in 1889 (1). In 1911 Cloos collected information about these ancient rocks in the area of the Erongo Mountains. In 1916 Wagner published his compendium of the geology of South West Africa and briefly described some of the main rock-types (5). In 1921 he made a further contribution to our knowledge of the old granites and associated mixed rocks in the coastal area in the hinterland of Walvis Bay, (6). The recent paper of Beetz on the Stratigraphy of the Fundamental Complex has already been mentioned (12). In alluding to the central and northern portion of the territory he makes use of the information contained in the papers by Rimann, Reuning and Wagner.

(NOTE: The numbers in brackets refer to the bibliography at the end of this paper).

The area in which detailed mapping has been carried out by the Geological Survey of South West Africa since 1927 and briefly referred to as Western Damaraland is bounded by the 21° lat. in the north and 23° lat. in the south and by the 15° long. in the west and 17° long. in the east. The Lower Ugab river, or the line joining the Brandberg and Kompaneno Mts., north of Omaruru, denotes its northern limit, while the Tinkas Flats between the Kuiseb and Swakop rivers and the north-western corner of the Khomas Highlands mark its limit in the south. The railway from Windhoek to Walvis bay runs through the central portion of this area from Wilhelmstal to Arandis.

The northern portion of this area, i.e., north of the line joining the Little Spitzkopje, Usakos and Karibib, was jointly mapped by the writer and his colleague, Mr.H.F. Fromurze, in 1928, while the area between the Omaruru River and the Brandberg was mapped in 1927 by Dr.S.H. Haughton and Mr.H.F.Fromurze. The results of these investigations have in very brief form been jointly published in 1929, as well as a more detailed paper on the "Tin-Pegmatites of the Erongo Area", which were the main object of investigation (13,14 & 15).

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In 1929 and 1930 the writer mapped the southern half of the area, which proved vastly more instructive as regards the stratigraphy of the Fundamental Complex than the northern area had been. Not only were such deductions as were possible in the latter verified in the southern portion, but in addition such a wealth of unexpected new information became available, that the area between the lower Khan and the Swakop Rivers bids fair to become the classic region for the ancient stratigraphy of the central and northern portions of the territory. As a result, the present paper deals almost entirely with the geological structure as exposed in a remarkably clear way in the southern portion of the area. The northern portion conforms to this, except for certain changes in facies, and, except for the old granites and derived pegmatites, exhibits a fairly uniform monotony as far as the Fundamental Complex is concerned. Also the exposures cannot compete with those in the area between the Lower Kahn and Swakop Rivers.

II. PHYSIOGRAPHY.

(a) General Morphology: The area delineated above and briefly referred to as Western Damaraland embraces two very distinct types of country, there being a very marked difference between its western and eastern portions. While the latter is densely clad with bush and trees (in the main various forms of acacia) the former is an arid desert and forms part of the Namib, the extensive desert coastal tract of South West Africa. A stretch of country exhibiting intermediate characters separates the west from the east. The average rainfall rises from less than one inch in the west to 10-12 inches in the east.

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Plate 1

Photo Author

View of the highly dissected margin of the Khan-Canyon between Khan Mine and Welwitsch. In background on left hand: Rössing Mt, in centre Blauer Heinrich (cone-shaped hill) with portion of Khan Mts around the Khan Mine. Predominant rocks: Khan Quartzites, knotted schists (Khomas Series) and red aplitic granite (left hand foreground)

The vegetation of the Namib, which consists mainly of different species of Mesembrianthemum and Euphorbia, becomes progressively more stunted and scanty towards the coast, while the immediate coastal tract is almost destitute of vegetation.

The northern portion of the area is drained by the Ugab and Omaruru and the southern by the Khan, Swakop and Kuiseb rivers. None of these rivers are perennial, but only flow after heavy downpours in the interior. They are filled to varying depths with gravel and felspathic sand and already in their central courses very often are hundreds of metres in width. The underground flow in the case of each river, however, is considerable and open water occurs in all these rivers with the exception of the Khan, at several localities throughout the whole year. Water is everywhere obtainable in shallow pits and wells. The salinity of the water increases progressively from east to west. Along their courses through the Namib plain all of these rivers have cut canyons of varying depth into the rocks of the Fundamental Complex, the most impressive being those of the Khan River in the area of the Khan Mine (depth approximately 300 M.)and of the Swakop River from Husab to Birkenfels (average depth approximately 200-250 M.) Needless to say these canyons provide magnificent exposures, and, since they are of great length, unique sections through the rocks of the Fundamental Complex.

The latter builds up almost exclusively the entire area. Apart from the youthful surface-deposits, such as river-gravels, windblown sand, desert-rubble, etc., the only rocks of younger age occur in a few isolated localities of the northern area: The Brandberg, a circular dome of

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youthful Erongo granite, 25 miles in diameter, and surrounded by a narrow fringe of Kaoko-sediments and Lavas (Karroo); the Great and Little Spitzkopje, two smaller intrusions of Erongo-granite of striking shape; and the Erongo Mountains, a circular block of Kaoko-sediments overlain by a great thickness of lavas and intruded by granodiorite and the typical Erongo-granite in a most picturesque way. The Erongo is a volcano of Kaoko (Karroo) times. In addition there are a large number of Diabase and Olivine-diabase-dykes, which occur crowded together in the zone of crustal weakness continuing the big Waterberg fault in a NE-SW direction past the sites of the Erongo and Spitzkopjes to beyond Goanikontes and Birkenfels on the Lower Swakop river. The bulk of these dykes are no doubt Kaoko (Karroo) in age and represent the feeding fissures, from which the lowest basaltic lavas of the Erongo, Brandberg, Omatako Mts., etc.,were erupted. In the southern portion of the area, there occur two small, but morphologically very prominent outliers of these lavas and underlying Erongo (Kaoko) sediments on the farm Okongava south of Karibib: the "Sargdeckel" (coffin-lid) and Virgin Peak.

The whole area under discussion includes portions of three well-marked morphological entities.

In the south the map embraces the western edge of the Khomas Highlands (Khomas = Nama (Hottentot) for mountains), an exceedingly rugged and inaccessible region extending in a NE- SW-erly direction, parallel to the general strike of the sediments of the Fundamental Complex, from Windhoek westwards. Its north-western edge is followed by the valley of the Swakop river from Okahandja to Otjimbingwe. Its western edge marks the site of the Great Escarpment of Southern Africa, which as a purely

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erosional feature parallels the coast almost right around the sub-continent. As far north as the Khomas Highlands the escarpment in S.W.Africa is well-marked and represents an imposing morphological feature, there being a drop of about 500 M., down to the upper reaches of the Namib plain. North of this point the escarpment disappears as a well-marked feature as far north as the Central Kaokoveld, where it is again well-marked. In the area under discussion the larger rivers rising in that portion of S.W.Africa possessing the highest rainfall, i.e., the Swakop, Khan, Omaruru and Ugab rivers, have cut the escarpment far back into the interior of the country. The north-western edge of the Khomas Highlands, an imposing scarp several hundred metres high, marks the sudden inward trend of the Great Escarpment as far as Okahandja. The Khomas Highlands represent a highly dissected, very extensive peneplain possessing a general height of about 1800-1900 metres above sea-level. Its geological structure is very simple and its rock-composition very uniform. It is essentially composed of an enormous thickness of biotite-schists and is remarkably free from igneous intrusions. As a structural feature it will be discussed in more detail in the tectonic chapter of this paper.

The second morphological feature is the most extensive and represents the western extension of the Inselberg Region of Central and Western Damaraland. The latter exhibits extensive flats, for the most part deeply covered with sand and surface limestone, through which the underlying rocks project in the form of prominent mountainous areas, ridges and isolated conical hills. The mode of origin of this "Inselberg" landscape has often been discussed and need not be commented on here. Suffice

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it to say that the prominences represent particularly weather-resisting erosional remnants and that the intervening débris-covered flats are primarily due to the fact, that under the climatic conditions obtaining the accumulation of sand and rock-débris is in excess of their removal by running water and wind.

The Inselberg landscape is most typically developed in the northern portion of the area, where the general plain is surmounted by several very large mountain-blocks. The highest elevation not only of this area, but also of the whole of S.W.Africa, is the Brandberg, which rises to a height of 8550 feet above sea-level. The Erongo Mountains attain their greatest height along their western precipitous escarpment, where the Hohensteine tower 7670 ft. above sea-level. Another prominent range are the Kompaneno Mts., north of Omaruru, which in the Okongue Peak attain an elevation of 5800 feet.

In the southern portion of the area single, well-marked mountain blocks are rarer, their place being taken by mountainous tracts, separated by sand and rubble-covered plains and the valleys of the larger rivers, and by long continuous ridges formed by one or more weather-resisting horizons in the Fundamental Complex. The most important group in this connection is the Quartzite Series, the reddish-brown Chuos-quartzites of which form a large number of very conspicuous mountain-chains or large domes according to the tectonic plan. The highest elevation is reached by the Otjipatera Mountain south of Usakos (1910 M. = 6300 feet). Other quartzite ridges are the Chuosberg (1600 M. = 5300 feet), a long continuous red ridge forming the backbone of the area between the Khan and Swakop Rivers; the Gamgamchab Mt.(1706 M)south of Usakos; the Khan Mts., north of the Chuosberg, and the Langer Heinrich (1168 M) south of the Swakop River near Riet, while quartzite-domes are represented by the Rooiberg near Usakos and the Potberg (1406 M.) and the mountains along the southern bank of the Swakop River.

In places the Marble Series also assume morphological importance. In general the latter forms long low continuous ridges, which often stand out sharply, while the underlying quartzites have been entirely planed down. At several localities, however, e.g., around Karibib, south of the Otjipateraberg and at the Falscher Heinrich near Husab, it builds fairly high mountains. In the area south and west of the Langer Heinrich, i.e., in the northern portion of the Tinkas Game Reserve, the quartzites recede morphologically almost entirely and here the plain is surmounted by long, straggling stringers of low marble kopjes and ridges.

Along the western margin of the map, around the confluence of the Khan and Swakop rivers, the red Chuos quartzites morphologically become quite subordinate and their place is taken by the dark greenish-grey Khan quartzites, which near Rössing and around the Khan Mine form a number of conspicuous mountains. From a distance these have a bluish-black appearance and hence such names as "Blauer Heinrich" (Blue Henry).

The granites on the whole are morphologically unimportant. In places, however, very resisting types, generally of rather aplitic nature, build prominent domes, like the Tachub (1585 M.) south of Usakos, the so-called Sphinx (1075 M.) near the old Sphinx mines, a conspicuous needle of red, somewhat pegmatitic granite, and the granite mountains around Donkerhoek in the south, the highest of which is 1800 M. above sea-level. The constituent granite is nonporhyritic, rather poor in melanes and of whitish-grey colour. This rock very often gives rise

Plate 2

Photo Author

a side-valley of the Swakop-Canyon near the Ida Mine.

Marble-ridge on right hand; schists of Khomas Series intruded by red & white aplitic granite
In background plain of the Namib (Tinkas Game Reserve)

Photo Author

an overfolded schist-syncline near Welwitsch

Marble-ridges of Damara System on either side.
In background mountain ranges below Husab. On right-hand background surface deposits of the Namib plain.

to enormous steep and smooth slopes, that are reminiscent of the grandiose scenery formed by the youthful Erongo-granite.

Small domes and cupolas, the so-called "Banks" of South West Africa are exceedingly common, particularly on the debris-covered plain of the Namib. These "Banks" or small dome-shaped outcrops of granite projecting through the surface deposits very often mark the site of temporary water-holes and on this account are of great value in these arid tracts. The water either collects after a periodical or episodical downpour in cup-shaped hollows in the granite, but in this case is of very short duration, or it collects in sand-filled joint-fissures in the granite to form typical water-holes, which generally last for several months after one of the intermittent thunder-storm showers.

Along the western border of the area, between the railway and Omaruru river the numerous diabase-dykes give rise to low, but conspicuous dark parallel ridges, very often representing the only rock-outcrop in the débris-covered plain of the Namib. The contrast between the dark igneous rock and the glaring-white of the surface-limestone so widely distributed in this region, is a very striking one indeed.

THE ORIGIN OF THE COASTAL PLAIN OF THE NAMIB:

The third important morphological entity is the Plain of the Namib, which in the area under discussion reaches from the coast about 140 Km. (87 miles) inland. The Namib everywhere rises fairly rapidly towards the interior. The 100 M. contour in the coastal strip

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Plate 3

Photo Author

Pitching Quartzite anticline cut into by Tsaobis River, northwestern slopes of Potberg.

In ~~left~~ right hand background Valley of Swakop River. In foreground schists of Khomas Series with pegmatite-sills. Marble series inconspicuous.

Photo Author.

The dissected margin of Khan-Canyon north-east of Welwitsch.

between Walvis Bay and the mouth of the Omaruru River runs 8-10 Km. (5-6 miles) inland from the shore. 35 Miles from the sea the height of the plain is already 450 M. Below the escarpment of the Khomas Highlands (87 miles from the coast) its height is about 1100 M. above sea-level. The slope of the plain towards the sea therefore possesses a considerable gradient.

Furthermore the plain is not an absolute one. Particularly in the area between and around the lower Khan and Swakop Rivers it is surmounted by numerous ridges and hills of the Inselberg type. The Marble Series of the Damara System in this area plays a very conspicuous part in building up the latter. As already pointed out by Wagner (6 p.72), this would certainly not be the case if the Namib plain had been formed by marine planation, as is maintained in some quarters.

The plain is covered by all manner of surface deposits typical of weathering under arid conditions. The most predominant are: rock-débris of various grades, generally highly felspathic and either unconsolidated or lime-cemented; felspathic windblown sands and grits; surface-limestone. Around the Lower Khan and Swakop rivers, however, definite terraces of fluviatile gravels and grits are met with. The latter are best exposed along the southern bank of the Swakop from the Langer Heinrich (55 miles from coast) to the descent of the road into the Swakop valley at Nonidas. Between Haigamchab and the latter locality, they form an almost level plateau, cut into by a number of dry rivulets and overlooking with precipitous cliffs the canyon of the Swakop River, 200 M. deep.

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These youthful beds consist essentially of lime-cemented felspathic grits with a large number of conglomeratic layers and numerous isolated pebbles. The bulk of the enclosed pebbles are typically river-worn and well-rounded. A minority are flat and angular. Their thickness is very irregular (average near Goanikontes 12-15 M). They were laid down over an uneven surface. They fill depressions and overlap prominences, where they generally contain large rock-fragments and rubble derived from the latter. This feature is practically proof against the marine origin of these beds, as maintained by Voigt and Reuning. No fossils of any kind have so far been found in them. In addition the gravels become coarser and the pebbles still more numerous in an inland direction towards the Langer Heinrich.

Interbedded with these sediments occur several lense-shaped layers of rock-salt and gypsum, pointing to lagoon-conditions near sea-level. There is no doubt therefore, that formerly the niveau of the plain in general was much lower and since the cessation of lagoon-conditions in this particular locality the coast must have risen by approximately 350 M. or over a thousand feet. Along the shore north of Swakopmund very well-marked beach terraces were observed at heights varying from 10-12 and 20-25 ft. above present sea-level. They mark the most recent elevations of the coast.

The Namib Plain as such, however, was not formed by a marine transgression. The portion actually submerged before the main uplift just referred to, is nearly everywhere deeply covered by subsequent sand-dunes

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and thus hidden from view. From all the available evidence it appears, that at the time of deposition of these youthful salt-bearing sediments, there existed a low, wide plain below the escarpment possessing arid conditions of climate and formed mainly by aeolian erosion and sheet-flood action, as already suggested by Wagner (6.p.72). The plain lay approximately 350 M. lower than now and the immediate coastal tract must have been submerged.

The uniform and level fluviatile plateau-gravels around the Khan and Swakop rivers and their very wide distribution away from the present canyons prove, that the Khan and Swakop, and no doubt also the other rivers, at that time did not flow in well-established channels, but meandered over a very wide level area or, more probably, changed their shallow and wide channels very frequently with each "coming down" in flood and in this way spread a thick sheet of grits and river-gravels over a very wide area.

III. STRATIGRAPHY OF THE FUNDAMENTAL COMPLEX.

It is not proposed in this paper to deal exhaustively with the purely petrographical nature of the sedimentary rocks of the Fundamental Complex. The main types of these have at intervals been described particularly by Rimann, Reuning and Wagner. Only the main features will in each instance be briefly described. For fuller descriptions - always, however, of rocks collected over limited areas-the reader is referred to the Bibliography at the end of this paper.

All sedimentary constituents of the Fundamental complex have been more or less highly metamorphosed, as well as the oldest granites. Ortho - and para-gneises, as well as mixed rocks have a wide distribution.

Rimann, who investigated the Rehoboth area of Central South-West Africa (4) applied the term "Primärformation", i.e. Primary System, to these highly folded and metamorphosed ancient rocks in contradistinction to a less metamorphosed and less folded group, which he thought to have established and called by him the "Phyllite Formation". Recent work by the writer in the Windhoek district and by writer's colleague, Mr. de Kock, in the Rehoboth district, has, however, shown that the stratigraphic succession is ~~not as~~ ~~impart~~ ~~Rimann's supposed Phyllite Formation is in reality a~~ ~~simple as~~ very much more complex than depicted by Rimann. ~~part of his Primary System and can no longer be upheld.~~ The term Primary System is also misleading in that it implies, that ~~ist~~ its constituent sedimentary rocks represent the oldest sedimentaries formed after the formation of the original crust of the earth. The....

The occurrence of pebbles of quartzite and marble in conglomeratic zones of Rimann's Primary System, however, clearly proves that this is not the case and that a still older group of sedimentaries must have existed or still exists somewhere. Such an older group of highly metamorphosed sedimentary rocks has now been discovered by the writer in Western Damaraland and termed Abbabis System. It is separated from the overlying beds, equivalents of Rimann's Primary System in the Rehoboth area, by a well-marked unconformity. Still more recent work by de Kock in the Rehoboth district seems to indicate that also here there exists a group of sedimentaries still older than Rimann's Primary System, only that here the unconformity is very indistinct. The term Primary System can therefore be dispensed with.

A. The floor of the oldest sediments; the problem of the original crust of the earth.

In Western Damaraland the sedimentary constituents of the Fundamental Complex are, as already stated, divisible into two groups: The Abbabis and Damara Systems. With the exception of the Khomas Highlands both Systems have everywhere been intruded on a vast scale by a great variety of gneisses, granites and other intrusive rocks. The gneisses are partly ortho-gneisses, but to a large extent represent highly metamorphosed mixed-rocks of various ages and associated with a great variety of gneisses and granites. The orthogneisses on the other hand are in this area mainly associated with the older Abbabis System.

All of the orthogneisses everywhere in the investigated areas, however, have been found to be intrusive into the most ancient sedimentaries (Abbabis System) and no gneissose rocks representing the floor, on which the latter repose, were found. Conditions in this area of the globe's surface are therefore entirely similar to those on the Canadian Shield. Here the Laurentian gneisses and gneissose granites were for a long time held to be a portion of the original crust of the earth, on which the oldest sedimentaries of the Coutchiching and Keewatin were deposited. Later investigations and a closer inspection, however, showed that although in a mechanical sense the oldest sediments repose on the Laurentian gneisses, nevertheless the latter are intrusive into the former and stratigraphically are therefore younger.

The same has been found to be true for nearly all other parts of the world, where large areas of pre-Cambrian rocks are exposed. Sederholm in Finnland however, still is of opinion that the orthogneisses underlying his Ladogian represent portions of the original crust of the earth and in accordance he has designated them as katarchaic primary gneiss.

Also Beetz in his recent publication (12, p.45) considers certain basic and other gneisses of the Lüderitzbucht littoral, which do not appear to be intrusive into any of the ancient sedimentary rocks exposed here, to be primary gneisses. One of these gneissose rocks is a widely distributed greyish Augen-gneiss. Very similar rocks, however, also occur in Western Damaraland, but here they are intrusive into and younger than the beds of the Abbabis System, the oldest sedimentaries so far discovered. In the Luderitzbucht littoral these beds are apparently unrepresented,

only....

vertical and in addition both Abbabis and Damara Systems contain many similar rock-types. Unconformities are therefore of necessity highly obscured and exceedingly difficult of detection, particularly since the various successive tectonic phases have always observed more or less the same directions. Particularly favourable circumstances were therefore necessary to reveal the existence of a still older group of metamorphosed sediments below the universally distributed Damara beds, which together with the intruded Old Granites make up more than 95 % of the rock-surface of Damaraland. The locality of outcrop is situated west of Karibib and south of Usakos on the farms Abbabis, Navachab, Ubib, Schettler and Tsawisis.

In this area the beds of the Damara System are arched up into a wide, elongate dome with a maximum elongation of about 50 km and a width of 18 km. The elongation of the dome is directed parallel to the general strike of the Fundamental Complex, i.e. S.W. - N.E. Its margin is formed by very conspicuous high mountain-ridges built up by the red Chuos quartzites and to some extent also the marbles of the Damara System: the Navachab, Gamgamchab, Otjipatera, Chuos - and Khan Mountains. The core of this dome is taken up by the Abbabis beds and intrusive gneisses, amphibolites, granites and pegmatites.

Although similar domes and anticlines, though nowhere of the same size, are numerous throughout the entire area, nevertheless the Abbabis dome is the only one incontestably showing the existence of still older beds than the Damara in its core. This fact is due to several causes, the main one being the peculiar nature of the mechanism of granitic intrusion in Central S.W.Africa. The granite

bodies....

bodies exposed on the present surface are almost without exception laccolithic or phacolithic in nature and closely conform to the structure of the sedimentary skeleton. Next to phacoliths intruded along zones of torsion or bending, laccolithic bodies filling synclines or forming the core of domes and anticlines are most abundant. In the mapped area this feature is so well marked that the sediments merely form skeletal partitions between granite bodies of all shapes and sizes. The most resisting members of the Damara System are the Quartzite and Marble Series and intrusion has therefore mainly taken place below and above them. For this reason the softer, more schistose Abbabis beds are so very seldom exposed, being covered by laccolithic granite bodies. In the same way over a larger portion of the mapped area the soft and schistose Khomas Series overlying the Marble Series of the Damara System has been systematically displaced by similar bodies of granite intruded between the two groups.

In addition another feature must be noted in this connection. A large portion of the Abbabis beds consists of biotite and amphibole schists very similar to the schistose rocks of the Damara System. Where the two occur close together, as in the surroundings of Abbabis, where a well marked unconformity shows the former to belong to an older system, the schistose rocks of the Abbabis System are seen to possess a higher crystallinity, i.e. are metamorphosed to a still greater degree. At localities, however, where the very characteristic quartzite of the Damara System are not developed and their place is taken by normal biotite-schists conformably underlying the Marble Series, as in the northern portion of the area

around....

around the Omaruru and Ugab rivers, and vertical dips are in addition predominant, it is indeed very difficult or impossible to prove the presence of the Abbabis Schistose rocks.

Further, as already pointed out by Reuning (7), it is a noteworthy fact, that the degree of metamorphism of all the rocks concerned gradually increases from the interior towards the coast. West of the line joining Ebony, Jackalswater and the Langer Heinrich, this process becomes very rapid and along the western limit of the map and in the coastal tract in general all the rocks have suffered such changes and have been intruded by granites on such an intimate scale, that practically all schistose species can only be classed as mixed or hybrid rocks. ~~and~~ In the absence of more characteristic rock-types it is obviously impossible to distinguish between the two groups. The cause of this feature will be discussed in a later chapter of this paper.

In the area under discussion, however, there is a wellmarked unconformity between the two groups. This feature is most clearly exposed near the western termination of the Gamgamchab Mts. on the farm Schettler and on the northern slopes of the Otjipatera Mountain on Abbabis. At the latter locality there is a very thick conglomerate at the base of the Quartzite Series, which contains a selection of fragments of nearly all rocks making up the Abbabis System exposed in the core of the dome.

Immediately below the Otjipatera mountain-ridge there outcrop highly metamorphosed bedded rocks consisting mainly of sericite and quartz. These rocks ~~is~~ are extensively veined in lit-par-lit fashion by pegmatitic veins containing a salmon-red felspar and often crowded with black

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tourmaline. The basal conglomerate of the Chuos quartzites of the Damara System in this locality is everywhere crowded with fragments of this characteristic salmon-red felspar, as well as with fragments of the pegmatite with black tourmaline and of the sericitic rock.

In the vicinity of the Henderson and Ehler's Mine near the western termination of the Gamgamchab Mts. the unconformity is exposed in a very clear way. Here a band of quartzites interbedded with schistose rocks of the Abbabis beds striking approximately N - S can be seen disappearing under the Chuos quartzites of the Damara System striking more or less E - W.

Also the Chuos Tillite is packed with boulders derived from the Abbabis beds.

Where the Basal conglomerate and lowest quartzites of the Damara System are underlain by gneissose igneous and mixed rocks, the foliation in the latter generally conforms to the dip and strike of the overlying Damara beds. This feature indicates that the foliation was mainly developed by folding movements subsequent to the deposition of the Abbabis beds.

(b) <u>General description.</u>

The Abbabis beds appear to have undergone folding already prior to the deposition of the Damara beds. In addition they have been extensively invaded by ortho-gneisses with the production of mixed or hybrid rocks, now having the appearance of typical Augengneisses. Amphibolites are also very common and without a doubt in part represent ortho-amphibolites, i.e. highly altered

basic....

basic intrusions or flows. The numerous amphibolites and the abundance of amphibole-schists, together with the greater crystallinity, i.e. the higher degree of metamorphism of the schists and all the other rocks concerned, are among the main distinguishing features of the rocks of the Abbabis System in this area.

(c) The succession of beds and description of rocks.

Everywhere in this locality the Abbabis beds have been disturbed, confused and invaded by various gneisses with the production of large amounts of mixed-rocks to such an extent that it has been impossible up to the present to determine accurately the succession of the various beds. Mapping on a very much larger scale alone can solve this problem. It is only possible therefore to indicate in broad lines the probable succession and to describe briefly the various rock-types occurring. At this point the reader is referred to the sections I and II through the Abbabis System at the end of this chapter.

1. Original Sediments.

(a) Gneissose Arkoses and Quartzites.

On Abbabis and Schettler there is exposed a great thickness of highly gneissose arkoses and coarse felspathic quartzites, both with conglomeratic layers. They appear to represent the lowest horizon of the sediments exposed. The pebbles in the conglomeratic zones have been generally more or less deformed. They consist mainly of quartz, felspar (angular fragments) and gneiss. These rocks appear then to be followed by more fine-grained felspathic, phyllitic and more compact quartzites,

also.....

also in part conglomeratic. The colour of these arkosic and quartzitic rock varies from reddish-brown to yellowish and reddish-white. The bulk of them have been sheared and rendered highly gneissose, in particular the coarse arkoses.

At several localities and apparently in a higher horizon several layers of very dense and compact dark, greenish-black and brownish-black quartzites with garnets and epidote were found interbedded with biotite- and amphibole-schists.

Under the microscope these rocks invariably show undulose extinction of the quartz grains. Generally these latter also show signs of parallel elongation. The felspar consists predominantly of microcline, but decomposed orthoclase is also common. In most sections plagioclase is rare, but a few sections were examined in which it predominates. Muscovite is found in most sections and is often strongly bent and disrupted. Nearly all these rocks contain abundant sericite. Secondary quartz is common. Re-crystallisation, minerological changes, kataklastic structures etc., are most frequently observed in the gneissose arkoses.

Epidote is common in many of these rocks and it often gives a yellowish-green tinge to some of the fine-grained quartzites. On Habis, west of Karibib there is exposed a pale-greenish rock, which consists almost solely of grains of epidote and quartz and thus represents an Epidosite.

Pebbles, boulders and angular rock-fragments of the more compact and resisting of these quartzites are exceedingly common both in the Basal Conglomerate of the quartzite series and the Chuos Tillite of the Damara System.

(b)....

(b) Schistose rocks.

The Abbabis Beds embrace a great thickness also of these. Their bulk seems to belong to a horizon above the gneissose arkoses and main set of quartzites. Narrow layers of quartzite, generally epidotised and passing over into quartzose biotite- and amphibole-schists, however, also occur in these predominantly dark rocks. Their majority represent highly metamorphosed biotite-schists, but in contradistinction to the schistose rocks of the Damara-System in this area, they also contain abundant amphibole- schists, such as Biotite-Hornblende, Hornblende- and Actinolite-schists. In addition there occur Chlorite-schists and Biotite-garnet-sillimanite-Cyanite-schists. Under the microscope these rocks exhibit the usual features of lepidoblastic rocks and hence need not be described in detail. The Hornblende is mostly deep-green to greenish-brown in colour. Its needles generally exhibit parallelism and it is often poikilitically intergrown with quartz, with the production of sieve-structures. Epidote, Titanite and Magnetite are common in the Amphibole and Chlorite-schists. Occasionally Cyanite is present.

In addition to these rocks there occur quartz and epidote-bearing para-amphibolites, originally probably derived from calcareous shales.

Of petrographic interest are the dark contact-rocks building up the Black Hills north of the Chuosberg on Ubib and Tsawsis, which embrace very compact metamorphosed hornfelses containing abundant quartz, biotite, sillimanite, garnet and some cyanite and cordierite, together with apatite, zircon and magnetite. The sillimanite needles or fibres are very often helicitically arranged around icositetrahedra of red garnet.

(c)....

(c) Crystalline limestone.

On the farm Schettler and at a place between the Black Hills and the Chuosberg above a zone of fine-grained felspathic quartzites there were found narrow bands of highly metamorphosed limestone of a thickness varying between 30 and 60 feet. The colour of the limestone is generally brownish to yellow. Under the microscope the calcite is mixed in varying proportion with generally abundant Forsterite, Epidote, some Tremolite and here and there with a little secondary quartz.

2. Intrussive Rocks.

(a) Ortho-amphibolites.

Rocks of this description are very common in the Abbabis beds and occur mainly in sill- or sheet-form. On Ubib and Schettler, however, there also occur some dyke-intrusions of this rock. It is impossible to say to what extent the former represent contemporaneous flows.

The colour of these rocks is black to dark-greenish-black. Their main constituent is a dark-green hornblende, generally showing parallel orientation and often also poikilitical intergrowth with quartz. The mesostasis varies in quantity and consists in varying proportion of minute quartz-grains, abundant Titanite and Magnetite, as well as Epidote and Zircon together with indefinable, aggregate-polarising matter. Occasionally biotite is present. Hornblende, however, is always in great excess and very often together with some octahedra and grains of magnetite the only constituent. In the latter case the rock probably represents altered hornblendites or uralitised pyroxenites.

A....

A few sections still exhibit remnants of the ophitic structure of diabases and basalts, in which the pyroxene has been replaced by hornblende. The plagioclase - laths in this case show various degrees of saussuritisation.

Whatever their precise original petrographical nature, there is no doubt that these rocks represent altered basic intrusions and possibly also ancient lava-flows.

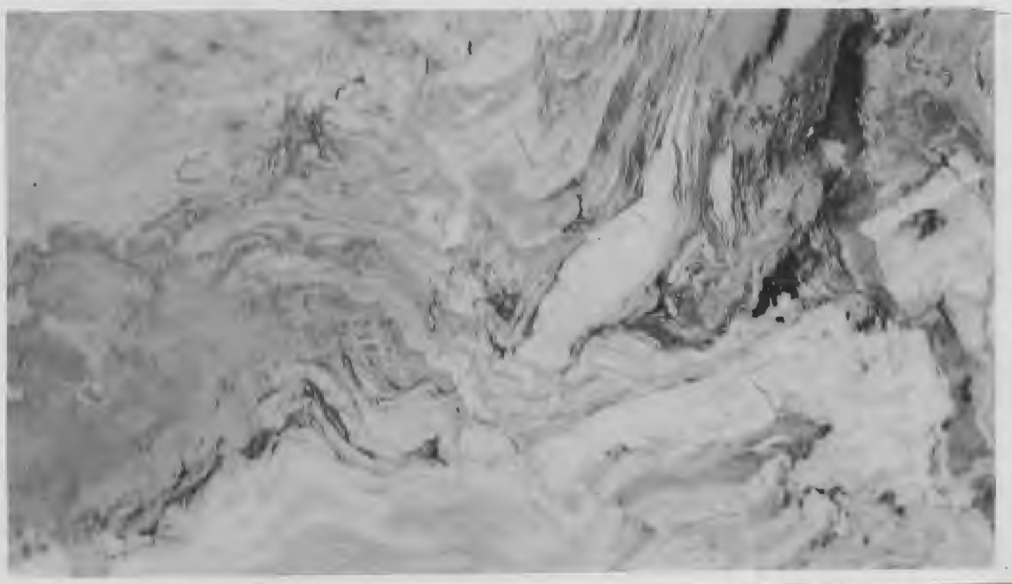
One of these rocks, containing, however, considerable amounts of quartz in small grains separating parallel needles of green hornblende, exhibits numerous rounded and elliptical spherules of quartz suggestive of amygdales. Under the microscope these spherules were found to consist of an aggregate of large quartz-grains, possessing fissures filled with fibrous,aggregate-polarising matter and some calcite.

(b) Intrusive gneisses and gneisses derived from hybrid rocks.

The Abbabis beds are literally interwoven with large and small bodies of gneiss and granite. While the majority of granites including gneissose types are also intrusive into the overlying Damara beds, there are a number of typical gneisses, which while breaking through the Abbabis beds are no longer intrusive into beds of the Damara System. On the contrary the basal conglomerate of the Quartzite Series and the Chuos Tillite enclose a host of boulders and pebbles derived from them. It must once more be pointed out, however, that all the gneisses and granites found in this area are later than the Abbabis beds. There is thus no sign of the floor on which the latter were accumulated.

In this connection only pre-Damara gneisses will be dealt with.

Plate 4



Lit-par-lit intrusion of schistose rocks of Abbabis System by Pre-Damara Gneisses; west of Black Hills north of Chuos Mts.

Photo author

Schistose rocks (Khomas Series) of Damara System intruded by white aplitic & pegmatitic granites. On right hand dyke of diabase.

Photo author

The most widespread of these and outcropping over considerable areas on the farms Abbabis, Navachab and Habis is a coarse-grained greyish gneiss, which represents an altered biotite-muscovite-plagioclase granite. Plagioclase by far predominates, but microcline and occasionally also some decomposed orthoclase also occur. Biotite and muscovite are present in nearly equal proportion. The quartz invariably possesses undulose extinction and kataklastic structures are typically represented. The quartz partly occurs in micropegmatitic intergrowth with plagioclase and microcline. The degree of gneissosity varies. In general the rock is not a typical augengneiss, though irregularly distributed "Augen", consisting of a quartz-felspar aggregate surrounded by small grains of secondary quartz and abundant shreds of sericite, are present everywhere. In numerous places, however, this type passes over into a typical Augen-gneiss with large Augen of white felspar (plagioclase). This type obviously resulted from a porphyritic phase of the original biotite-muscovite granite.

In the Chuos Tillite on Navachab, west of Karibib, big blocks and boulders of this rock preponderate over other rock-fragments.

Similar greyish Augengneisses also occur in smaller bodies on Tsawisis and the area north of the Chuosberg in the vicinity of the Black Hills. On the road from Ubib to Tsawisis in this region there is exposed a greyish gneiss composed of large eyes of white plagioclase and quartz surrounded by dark brown biotite and containing abundant zircon. The very biotite-rich types of these Augengneisses no doubt represent altered hybrid rocks or migmatites formed by the lit-par-lit intrusion of the abovementioned original plagioclase granite into biotite-schists or less altered

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equivalents of the Abbabis beds.

West of the Black Hills small outcrops of a greyish gneiss were found composed of large Augen of quartz and white microcline or microcline and orthoclase set in a kataclastic mesostasis consisting of an interlocking aggregate of microcline, othoclase and quartz, together with small shreds of biotite and a little muscovite arranged parallel to the foliation.

In the northern portion of the farm Schettler a gneissose rock was found consisting almost entirely of kataclastic orthoclase, microcline and quartz, which in nearly all larger grains possesses a peculiar rectangular cleavage. Plagioclase is almost absent. In addition occur a little chloritised biotite; some quartz-vermiculé; a few shreds of muscovite; apatite and sericite. The rock probably represents an altered aplitic granite.

On the same farm occurs a very similar rock, but possessing plagioclase, biotite and muscovite, in greater abundance and also containing some epidote and titanite.

Fragments of these aplitic gneisses are very common in the Chuos Tillite near by.

In addition there occur gneissose pegmatites and highly sheared bodies of quartz.

Also reddish Augengneisses occur in fair abundance. In the Audawib- and Kuduhills representatives of these underlie the Damara-beds apparently with a sedimentary contact.

Below the Husabberg, on the road from Pforte to Husab, there are extensive outcrops of reddish ortho-gneiss and also below the Rabenrücken on the Tinkas Flats. At both localities they occur in juxtaposition with highly altered gneissose red felspathic and sericitic quartzites

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and...

and grits, which closely resemble them macroscopically and are part of the Quartzite Series of the Damara System. It is impossible to obtain fresh specimens of these reddish gneisses. A section of a specimen from the northern part of the Husabberg, besides exhibiting a high degree of infiltration with red iron oxides and even secondary magnetite, showed the identifiable felspars to be mainly orthoclase with subordinate microcline. In addition to highly kataclastic quartz, decomposed biotite and some epidote are present. The contacts are everywhere such that the intrusive nature or otherwise of these reddish gneisses into the beds of the Damara System could not be accurately determined. Nowhere, however, throughout the whole area, were they seen to be intrusive into the latter.

(c) Pegmatites with salmon-red felspar.

In discussing the unconformity between the Abbabis and Damara Systems, it has already been pointed out that on Abbabis highly altered rocks belonging to the former are extensively veined by pegmatitic stringers consisting of quartz, a salmon-red felspar, and often abundant black tourmaline. The fact that the basal conglomerate of the Damara System immediately covering these rocks is crowded with fragments of the very characteristic red felspar and also of the whole pegmatite, indicates the latter to be pre-Damara in Age. It is not, however, gneissose. It must also be pointed out that similar pegmatites of post-Damara age associated with the old granites are very common throughout the entire area.

(d) Correlation of the gneisses.

It is of interest to note that according to Beetz (12, p. 45 and 48) in the Luderitzbucht littoral the oldest granite-intrusion is represented by a characteristic mylonitised granite rich in plagioclase, which breaks through older basic gneisses. This rock appears to be comparable with the plagioclase-gneisses and the gneissose plagioclase-granite just described.

To what extent the older gneisses intruded by this granite in the Luderitzbucht littoral may be equivalents of the pre-Damara gneisses intrusive into the Abbabis beds in Western Damaraland, it is difficult to ascertain. Petrographically many types appear to bear a close resemblance to each other. No definite statements, however, can be made at this stage. The outcrops of these gneisses in Western Damaraland are too isolated and discontinuous to allow of any final conclusions at present. In addition in the coastal tract it is too difficult to separate them from the gneissose hybrid-rocks of a later age.

(e) I. Section through the Abbabas beds on farm Abbabis, from S. to N.

Approximate thickness in Metres.

Top	60 - 80	Basal Conglomerate of the quartzite series of the Damara System. Unconformity.
	± 40	Reddish gneiss (sericitic rocks veined by red-felspar-pegmatites)
	± 100	Greyish gneiss (biotitic schists - do-)
	± 200	Reddish orthogneiss with gneissose aplites and pegmatites.
	± 70	Greyish gneiss rich in biotite and highly metamorphosed biotite-schists Reddish gneiss, partly Augen gneiss.

Hundreds....

Hundreds of Metres)	dark biotite- and hornblende-schists with layers of Amphibolite and dark epidotic quartzites.
	Gap
	Muscovite-gneiss with drawn-out quartz-veins.
	Gap
12)	Yellowish-brown, felspatic quartzite with conglomeratic layers and clearage fragments of red felspar.
20	Reddish-brown metamorphosed quartzites, coaser in grain.
10	Gneissose conglomeratic arkoses and felspathic Grits.
8	Silicified white quartzite.
100 - 130	Gneissose arkoses and sericitic quartzites.
± 800 - 1000	Whitish sericitic, quartz-phyllites and quartzites, gneissose arkoses with intrusions of gneissose pegmatites and aplites.
40	Biotite-schists.
25I	Sericitic quartz-phyllites and gneissose grits.
10	Reddish sericitic, felspathic quartzite.
Great thickness	Gneissose arkoses and metamorphosed quartzites intruded by greyish gneiss.

II. Section through Abbabis Beds on Farm Schettler near Western termination of Gamgamchab Mts., from N. to S.

South of Aukas Pforte below quartzites and marbles of Damara System: gneissose arkoses interwoven with light-coloured gneisses (gneissose aplites and aplitic granites) and post-Damara reddish pegmatites.

Then at above locality:

Biotite and hornblende-schists.

Reddish intrusive Augengneiss.

Quartzose biotite- and Amphibole-schists

with....

with layers of Amphibolite and Metamorphosed dark epidotic quartzites with garnet.

Biotite and Amphibole-schists with layers of darker epidotic quartzite.

± 100 M. finegrained felspathic, light-reddish-brown quartzites.

dark biotite- and amphibole-schists with layers of dark epidotic quartzites.

C. THE DAMARA SYSTEM.

(Primary System: Rimann; Schist Formation: Wagner, Frommurze and Gevers; Karibib Beds: Beetz).

a. Historical.

Together with the Main Granites intrusive into them the beds of the Damara System are by far the most widely distributed rocks throughout the central portion of South West Africa. As a matter of fact, disregarding surface deposits, in the area stretching from the northern boundary of the Nama Beds, south of Rehoboth, to the southern limit of the Otavi beds near Outjo and Franzfontein, they constitute the exposed rock-floor almost exclusively.

The first attempt to unravel the stratigraphic succession of these beds was made by Rimann (4) in the Bastardland area of Rehoboth. As already mentioned, he applied the term Primary System to this ancient group of sediments. This term has become customary in the German geological literature dealing with S.W.A. As already pointed out by Beetz (12,p.46) however, there exist sedimentary beds still older than this group of sediments. He therefore proposed the term "Karibib Beds" for these rocks, since they are well exposed in the surroundings of that village.

Wagner (6), and following him Frommurze and Gevers (13, 14, 16) referred to these beds as constituting the "Schist Formation". Also this term, however, is apt to be misleading, since it lays too much stress on the petrographical nature and the distribution of only one member of the whole group, namely, the Schist Series. The term "Karibib Beds" in the author's

mind / .....

This, however, is not the case. Since the quartzites include terrestial, and in general represent shallow-water deposits, such a uniformity would indeed have been surprising. In addition it must be pointed out, that also in the Bastardland and Windhoek areas, as shown by recent work of the writer and his colleague Mr.de Kock, the stratigraphic succession of these ancient beds is considerably more involved than it would appear from Rimann's classification, and that there are several quartzite and limestone horizons separated by unconformities.

In Western Damaraland Rimann's Classification does certainly not obtain. Here a massive conglomerate forms the base of the whole system and is followed in succession by a quartzite- , a marble - and a mica-schist - horizon of enormous thickness. In the area between the lower Khan and Swakop Rivers the latter group has nearly everywhere been displaced by various granites filling the synclines of the very complicated tectonic structure. Only in the Khomas Highlands, where granites are absent, does the real enormous thickness of the mica-schist- group become apparent.

The succession of beds as exposed in Western Damaraland is as follows:-

Damara System.	Khomas Series (Schist Series: Wagner, Frommurze and Gevers).	
	Marble Series	
	Chuos Tillite	
	Quartzite Series	Khan Quartzites
		Chuos Quartzites
		Basal Conglomerate

Unconformity / .....

Abbabis System

Plate 5

Photo Author.

The Otjipatera Mt. as seen from Abbabis Station.

Quartzites dip to the south. Basal conglomerate covered by talus. In foreground gneissose rocks of Abbabis System.

Photo Author.

The Otjipatera Mt. from the south.

In the distance Quartzites. In foreground white ridge of overlying marbles.

~~Unconformity.~~

~~ABBABIS SYSTEM.~~

I. THE QUARTZITE SERIES:

This group consists essentially of highly resisting quartzitic rocks and as a consequence is morphologically of great importance. Nearly all of the more important mountain-chains in the southern portion of the area under discussion are built up by this group.

1. Chuos Quartzites and Basal Conglomerate:

In the eastern portion of the area between the lower Khan and Swakop Rivers the Quartzite Series is constituted entirely by these reddish rocks. The reddish colour and the comparative lack of alteration-minerals are the main features distinguishing them from the greyish-green Khan Quartzites. Basal Conglomerate.

On the northern slopes of the Otjipatera Mountain and well exposed on both sides of the Abbabis-Etusis gorge gneisses and highly metamorphic biotite- and amphibole-schists, as well as hybrid rocks of the Abbabis System, can be seen to be unconformably overlain by a massive basal conglomerate 80-100 M. thick.

The enclosed pebbles consist mainly of very abundant reddish felspar-fragments and ~~such~~ of a reddish pegmatite often with black tourmaline, as well as of numerous fragments of highly micaceous gneisses and hybrid-rocks, quartz, gneissose graphic granite and rarer of amphibolite, biotite- and amphibole schists. The ground-mass is exceedingly rich in felspar, mainly of reddish colour. As a matter of fact it is best described as a coarse granite-detritus and the conglomerate is obviously of terrestial origin. The parent rocks, from which the detritus and enclosed rock-fragments are derived, can be seen outcropping on the lower slopes of the mountain and the hills to the north as members of the Abbabis System.

The conglomerate is generally somewhat sheared and rendered gneissose to some extent, but not nearly on a scale comparable with that of the gneissose conglomeratic arkoses of the Abbabis System.

Such a well-formed and massive conglomerate is not everywhere present at the base of the Quartzite Series, where this is exposed. But everywhere the basal portion of the lowermost arkoses is particularly coarse in grain and generally also includes a few pebbles. ~~nearby~~. Also at the Otjipateraberg the massive basal conglomerate only represents a lens-shaped body, which rapidly decreases in thickness and finally dwindles away towards the east and west (vide section).

The Chuos Quartzites nearly everywhere comprise a basal portion consisting of more or less coarse arkoses, often with conglomeratic layers or isolated pebbles. In general these arkoses are either entirely unbedded or bedded only in a very irregular way. Invariably they are very rich in felspar, mostly of a reddish colour, and where metamorphosed to an appreciable degree, these rocks may easily be confused with reddish orthogneisses.

In an upward direction the grain of these beds gradually becomes finer and the bedding at the same time more regular and closely spaced, until the arkoses are finally replaced by very compact, fine-grained and well-bedded felspathic quartzites.

latter make up the bulk of the whole series and are exceedingly weather-resisting.

Petrography: Under the microscope the felspar is seen to be mainly microcline, but often also plagioclase is not rare. Orthoclase is nearly always highly decomposed. As far as recrystallisation-processes allow this feature to be ascertained, the quartz-grains are on the whole rather sharp-edged and not well-rounded in the lower, highly felspathic quartzites. Secondary quartz is most common in the very compact, fine-grained quartzites, in which the felspar is least obtrusive. Undulose extinction and kataclastic structures are generally common. Muscovite is very abundant, biotite less common. With the exception of some very compact, highly silicified beds, Sericite is universally distributed in great abundance, often together with secondary quartz to form large knots and even balls in the more metamorphosed, originally highly felspathic quartzites. In other highly sericitic specimens porphyroblasts of biotite and magnetite were found to occur, giving the quartzite a spotted appearance. Epidote as an alteration product of the felspars is not rare, but not nearly common enough to colour the whole rock. In addition the ordinary accessory minerals of granites, such as apatite and zircon are present.

The Thickness of these quartzites, particularly of the arkoses, is exceedingly variable. They were obviously laid down on an uneven surface and appear mainly to have accumulated in shallow depressions to form lens-shaped bodies. The lowermost coarse arkoses particularly appear to be solely of terrestial origin, representing mainly a granite-detritus

Plate 6

Pitching anticline of Red Chuos Quartzites (left hand) overlain by dark schistose rocks of Khomas Series intruded by white aplitic & pegmatitic granites. Marble Horizon inconspicuous. In back-ground anticlinal ridges of Red Chuos quartzite, the Swakop river flowing in intermediate schist-syncline.

Surroundings of Hudis, Tsaobismund & Dorstriviermund on Swakop river.

Photo Author

place or swept together in shallow basins. Where the thickness of the whole group suddenly decreases, the lowermost arkoses disappear first, while the upper, fine-grained, well-bedded quartzites, which represent shallow-water deposits, are most continuous.

In the Abbabis-Etusis gorge through the Otjipatera range it was possible to pace off the entire thickness of this group and fully 2000 M. or somewhat over 6000 feet were measured at this locality. Towards the main peak the thickness still further increases, till finally the outcrop of the steeply dipping quartzites is fully 4 km. wide. Beyond this point, however, the quartzites are sharply bent northward, so that probably also tectonic movements have helped to increase the thickness at this point by rock-flowage to the area of lowest stress.

In the Chuosberg range the thickness of these quartzites must be enormous. The width measured at right angles to the strike of the rocks, which dip vertical to 75° to the south, is 5½-6 Km. near the Chuospforte. At the northern limb of the anticline, in the Khan Mts. their thickness is already considerably less and east of Tsawisis and south of Aukas it is scarcely 25 M. To the south of the Kuduberge, between Goas and Ukuib, they locally disappear altogether. Great thicknesses are further attained by these reddish quartzites at the Great and Little Rooiberg, north-west of Usakos, and along the southern bank of the Swakop between the Potberg in the east and the Langer Heinrich in the west. Their northernmost outcrop lies approximately 20 Km. north of Usakos at the Kudukuppe on Goabeb (vide Map Fig. 4), but here the thickness is already very small. North of this locality the Quartzite Series appears to be unrepresented. The Marble Series is here underlain by prdinary biotite-and other schists. According to Reuning's Map (7) reddish quartzites make an appearance again only north of the Ugab River in the area west of Franzfontein and, since they are represented as underlying crystalline marbles, they occur most likely in the same horizon.

It appears, therefore, that the entire Quartzite Series disappears in a northerly direction and that in their stead the narrow band of biotite- and amphibole-schists, which in the normal area generally separates Quartzite and Marble Series, gradually increases in thickness and finally completely replaces the former. In how far schistose rocks belonging to the Abbabis System form the floor of the Marble Series in the northern area, it was impossible to ascertain on account of the unfavourable exposures and the highly folded nature of all the rocks concerned.

2. <u>Khan Quartzites:</u>

<u>Distribution:</u> In the eastern portion of the area, in which the Quartzite Series is represented, e.g., in the surroundings of Usakos and Karibib, the reddish Chuos Quartzites are normally followed either directly by the lowermost marble bands or by a varying thickness mainly of biotite-schists (maximum thickness about 120-150 M.), which separate the two types of rock. Towards the west, however, and beginning in the eastern portion of the Khan Mts., west of Tsawisis, and in the lower Chuos Range west of the old Sphinx Mines, a rapidly thickening wedge of a different type of quartzitic rock, greenish-grey in colour, separates the reddish Chuos Quartzites from the overlying Marble group.

In / .....

Plate I

The "Blauer Heinrich" (Blue Henry) (left) and associated hills consisting of Khan quartzite. In centre dyke of Karroo dolerite. Road leading from Khan Mine down to Khan-Canyon.

The Confluence of Swakops and Khan Rivers.

The rocks of the Damara System (Khan quartzites, tillite & marbles hybrid rocks & composite gneisses, as well as red & white aplitic Husab granites) are traversed by numerous dykes of Karroo dolerite. In background plateau of the Namib (coastal desert of S.W.A.)

In the surroundings of the Khan Mine and along the Swakop valley west of Husab, these rocks attain a great thickness, which often reaches several thousand metres. Since the red Chuos quartzites at the same time begin gradually to recede, the former morphologically entirely dominate over the latter and the colour of the mountain-ranges now changes from reddish to greenish-grey and, seen from a distance, dark-blue and bluish-black. Hence such names as Blauer Heinrich (blue Henry), a conspicuous peak towering above the canyon of the Khan river just south of the Khan Mine. The Rössingberg is another prominent mountain formed by the Khan quartzites and large portions of the canyon-walls both of the Khan and Swakop Rivers are built up by them.

In the Khan Mts. west of Tsawisis the thickness of these quartzites already ranges from 1000 to 1200 M. and rapidly increases still further towards the west. In this area the greyish-green Khan quartzites are again overlain by a band of reddish, normal quartzites from 70-80 M. thick, which in turn is followed by the Marble Series (Vide Section V). Also in the surroundings of the Khan Mine these red quartzites are still found to occur in the form of several narrow bands below the marbles. (Section VI).

Such alternations of the two types of rock are on the whole quite common in the area of transition. This feature is particularly noticeable in the mountainous area along the southern bank of the Swakop River in the neighbourhood of Salem and Gaub, where the main bulk of reddish quartzites, several thousand metres thick, is overlain by a number of alternating lenses of red and greenish-grey quartzites of varying thickness.

At / .....

At a number of localities in this area an uppermost lens of reddish quartzites overlying the greenish-grey Khan quartzites again swells out to a great thickness, as for instance to the north and south of Gaub. At other places in the same area this upper horizon of reddish quartzites is entirely absent. In the same connection it may be mentioned that the limestones of the Marble Series in this particular area are very inconspicuous and even wanting. Where present, on the other hand, they are in turn frequently seen to be overlain by an uppermost horizon of reddish quartzites, from 30-50 metres thick. The best exposures of this feature occur along the road from Sphinx to Jakalswater and north of the Rote Adlerkuppe west of Jakalswater. At the latter locality the total thickness of the entire Marble Series is only 20-25 M. and near Dieptal on the Swakop-river it is absent altogether.

The sedimentation in this area was therefore a rather irregular one.

Petrographic description:

The Khan quartzites are everywhere highly epidotic and hence their general greyish-green colour. The grain of the rock is on the whole fine, yet shows a number of gradations. Very compact and fine-grained types generally possess a beautiful pale olive-green or yellowish-green colouration. Other varieties are sugary and light greenish-grey in colour, no individual grains of epidote being macroscopically visible. The bulk of the rock, however, is somewhat coarser in grain with numerous macroscopically visible grains of epidote and slightly darker greyish-green in colour. Since in addition to quartz and epidote some varieties contain macroscopically visible felspar and the bedding of these rocks is in general very ill-defined, these somewhat coarser varieties frequently resemble a fine-grained greyish granite.

Under the microscope the rock is seen to consist of an interlocking aggregate of quartz and felspar in varying amounts and abundant epidote. The nature of the felspar varies. In general microcline preponderates, but in some specimens orthoclase (highly decomposed) and plagiclase are in excess. Many varieties, particularly the finegrained types, show a reddish-brown garnet to be a main constituent. In addition diopside is common in nearly all sections and scapolite in a great many. Sericite is on the whole inconspicuous. Titanite is abundant in nearly all sections. The accessory constituents of granites, apatite and zircon, also occur. In a few sections chlorite is present, but on the whole this mineral is not common. In one section a little sillimanite was found.

Of special interest is the fact, that all sections examined showed the presence of calcite as a sort of mesostasis. There is therefore very little doubt that these peculiar rocks originally represented marine calcareous sandstones. The position of their horizon between coarse terrestial conglomeratic arkoses and well-bedded shallow-water quartzites on the one hand and biotite-schists, para-amphibolites and crystalline limestones on the other hand is in complete accordance with this deduction. The depth of the basin, in which they were deposited, apparently increased towards the west, but still was a shallow one, as the occasional ripple-marks found in these beds show.

Still further west, at the Rössingberg and along the sides of the Swakop canyon between Haigamchab

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sparingly distributed and already at the Western Sphinx Mine they are rather rare, while the groundmass of the tillite is identical with the rock just described from further west, even down to numerous nests of epidote.

It appears therefore, that the rock in question, here described with the Khan quartzites, is in reality an equivalent of the Chuos Tillite to be described in the next chapter. This supposition is supported by the excellent exposure of this horizon on the northern slopes of the Langer Heinrich. Here the reddish Chuos quartzites are overlain by the rock in question, massive and entirely imbedded. In its lower portion erratics are entirely absent, but they gradually begin to appear, until finally the rock grades into the normal siliceous tillite containing numerous pebbles.

II. THE CHUOS TILLITE.

Introduction: One of the most notable developments of Geology during the last decades has been the slow and gradual recognition that ice-ages have at intervals chilled the surface of our planet long before the advent of the last Pleistocene period of glaciation, from the effects of which our earth appears to be just emerging. The remarkable exposures and excellent descriptions of the South African Dwyka Tillite have played an important rôle in furthering and finally establishing the general acceptance of world-wide pre-Pleistocene periods of glaciation.

An outstanding and somewhat unexpected result of the invigorated search for fossil glacial deposits down the geologic time-scale has been the

accumulating / .....

accumulating evidence to show, that they appear to be most abundant, even crowded, in the ancient sediments forming the surface of our earth. Thus in Canada, where the largest area of Pre-cambrian rocks in the world is exposed, according to Coleman[x] ice-action has been proved or shown to be probable in all the main subdivisions of Pre-cambrian rocks.

The amount of evidence of glacial work in these ancient periods is all the more surprising "when one considers the age of these rocks and all the possibilities of the destruction or permanent burial or submergence of the Tillite, or else of its complete metamorphism into schists". (ibid.p.240). While not very long ago it was generally held that the climate of our globe had experienced a gradual decrease culminating in the (then only known) Pleistocene ice-age, "it now appears probable that the Precambrian was the coldest part of the earth's history, with glaciers at work within every one of its main sub-divisions. Part of this effect may, however, be due to perspective, the more distant glaciations being apparently crowded together because we do not appreciate the intervals between them". (ibid.p.240).

Glacial action being mainly chronicled by land-deposits and the bulk of preserved and investigated sediments being deposited by the sea, it is obvious that we must look to the ancient, long-established, rigid land-masses, such as the Canadian shield and the South African sub-continent, for the most complete record of the ice-ages, which have affected our earth.

Having / .....

[x] Coleman, A.P. "Ice Ages Recent & Ancient". MacMillan, New York, 1926, p.239.

Plate 8

Photo Author

Southern slopes of the Chuos Mts: Red Quartzites on left, marble on right. In centre and left foreground Tillite.

Photo Author.

Siliceous Tillite, Navachab Hills, west of Karibib.

Having passed through the stormy stage of its development at a very early date of the earth's history, South Africa presents to the investigator a very long succession of continental and shallow-water deposits dating right back to Pre- and early Proterozoic times and only rarely interrupted by marine invasions. It is not surprising, therefore, that South Africa already now presents a formidable array of proved and well established ancient tillites. With the extension of geological research also into the more remote and lesser known areas this record, judging by past experience, will in all probability be still further augmented and make South Africa into what it is fast becoming: the classical country for investigations in ancient glaciology.

Extent of Occurrence: The Tillite was first discovered in the Navachab Hills, a few miles west of Karibib, and then found to extend interruptedly in a southwesterly direction past the Otjipatera or Etusis mountain and the Tachub to the southern slopes of the Chuos mountains, where its finest exposures occur and where it attains a great thickness. It was here, in the vicinity of the old Sphinx mines that Prof.R.B. Young had independently noted the resemblance of this rock to a tillite sometime previously (Verbal communication).

It was still found characteristically developed along the western margin of the degree-sheet at the Husabberg or Falscher Heinrich and on the northern slopes of the Langer Heinrich just south of the Swakop River, a distance of 70-75 miles to the south-southwest.

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At the latter point the tillite is overlain by a great thickness of banded rocks representing ancient varves and these stretch southwards through the Tinkas game-reserve, until they disappear beneath the surface-deposits of the Namib half-way between the Swakop and Kuiseb rivers. West of the mapped area the peculiar quartzitic rocks already described as closely resembling the matrix of the siliceous facies of the tillite, and occupying the same stratigraphic horizon, undergo a tremendous development along the lower Swakop beyond its confluence with the Kaln river between Haigamchab and Richthofen, as well as at the Rössing mountain, roughly 90 miles to the southwest of Karibib.

The writer's colleague, Mr.W.de Kock, has since then found the tillite also to continue into the Rehoboth district, some 80-90 miles to the south of Karibib, where the quartzite and marble series again reappear from under the massive body of schists and phyllites of the Khomas Highlands.

Recent work by the writer in the region south-east of Windhoek has shown the presence also in this area of peculiar quartzitic and schistose rocks containing a variety of pebbles distributed in a way strongly suggestive of glacial deposition in the same horizon, i.e., between the Quartzite and Marble Series.

It will be seen, therefore, that the glacial rocks occur over a wide area and it is evident that the glaciation responsible for them must have been a considerable one.

<u>Mode of Occurrence and Thickness:</u>

The distribution of the tillitic rock is very irregular and patchy and it is obvious that a

large / .....

Plate 9

Photo Author

Chuos Tillite

Southern slopes of Chuos Mts., near Chuos Pforte

Photo Author.

Chuos Tillite

Southern slopes of Chuos Mts., near Chuos Pforte.

large amount of rearrangement, complete or partial removal and scattering of the glacially deposited material must have been effected by the waves of the encroaching sea, for immediately after the deposition of this material the whole area was completely inundated. Partly as a result of the marine transgression the outcrop of the tillite is very intermittent and its thickness varies between very wide limits, though of course regularity in the deposition of its materials is never a characteristic of glacier action as shown by nearly all tills, ancient and recent. The approximate thickness in feet along more or less the same line of outcrop from N.E., to S.W. (75 miles) are as follows: Navachab 350-400; Etusis 70-80; Tachub 40-60; Chuospforte at least 1500-1600; Sphinx Mines 300-350; Husabberg 10. At the Langer Heinrich south of the Swakop river it is about 300-500 feet. Further west again in the unmapped area along the lower Swakop the thickness of the massive unbedded quartzitic rock containing occasional pebbles and identical with the matrix of the upper portion of the typical tillite and occupying the same horizon, around Goanikontes and Birkenfels, must be 2,000 feet and over.

In general it may be said that where the underlying quartzites are very thick and massive, the thickness of the tillite is also considerable. Thus at the Chuosberg the thickness of the former must be in the vicinity of 15,000 feet and more and here the typical tillite attains its greatest thickness. It is obvious that the basal conglomerate and the massive quartzites were collected mainly in depressions of the ancient landsurface before inundation by the sea, for

it / .....

Plate 10

Photo Author.

Siliceous Tillite,
Navachab Hills,
west of Karibib.
Rock fragments consist of
gneissose porphyritic granite.

it is not uncommon for the latter to narrow down and even pinch out completely over a distance of only a few miles. These same depressions must subsequently also have served as centres of accumulation and preservation of the coarse glacial deposits.

General description:

Apart from the metamorphosed state of its matrix, the tillite as typically developed at the Chuospforte bears a remarkable resemblance to that classical example of a fossil till, the Dwyka tillite, in spite of the enormous interval of time separating them. From a little distance their weathered surfaces present an almost identical appearance, as some of the accompanying photographs show.

The rock exhibits all the characteristic features of a fossil till. Its bulk is completely unbedded, the argillaceous facies at the Chuospforte being massive and showing no indication of stratification over 500-600 feet. There is not the slightest sign of assortment of the embedded pebbles and boulders, which are of all shapes and sizes as the accompanying photographs make clear. Angular pebbles by far predominate, though well-rounded ones are not rare. Both angular and rounded are very frequently facetted in a way typical of striated stones. This is particularly noticeable in rounded boulders and pebbles. The size of the boulders and pebbles varies within very wide limits: from the constituent particles of a grit to boulders over 3 feet in diameter. The largest were seen in the Navachab hills, where very angular elongate slabs of rock 3 to 5 feet long were found. On the whole, however, such very large masses of rock are rare and boulders exceeding 2-3 feet in diameter are not very common.

Although numerous facetted pebbles and boulders were found and even some still showing indications of striae on what once were polished surfaces, no uncontestably striated stones have so far been discovered. It is also very unlikely that such will be found in the future. In a rock of this age, it would indeed be surprising to have found the delicate striae surviving all the forces of destruction acting on them throughout countless years. Different types of rock are striated with very different degrees of readiness and even in recent tills and moraines of to-day, particularly where they do not comprise limestones, striated stones are by no means always very abundant and may even be rare.

But quite apart from these considerations it borders on the obstinate to demand the presence of striated stones in a rock of such age to prove its glacial origin, when all remaining characteristics are typically developed. Not only do the rocks of the Damara System belong to some of the very oldest sediments known, but in addition they have suffered tectonic stresses and metamorphic changes to a very high degree. In the words of Coleman (ibid p.226): "it is indeed surprising that striated stones and striated surfaces should have been preserved at all in so ancient a formation (Lower Huronian Cobalt Tillite of Canada). This can only be accounted for by the fact that the Laurentian Shield has been largely exempt from folding or faulting since it was deposited.

Wherever / .....

Plate II

Photo Author

Siliceous Tillite, Navachab Hills.

Photo Author.

Siliceous Tillite, Navachab Hills.

Wherever faulting and slickensides occur, as at Timigami, forty miles south of Cobalt, striated stones are wanting, the delicate polished and striated surfaces having been destroyed". Not only are the rocks of the Damara System in all probability still older than the Canadian Tillite mentioned, but they have been subjected to the maximum of tectonic stresses. When one takes such powerful factors as mechanical deformation of the pebbles, rock-flowage and surface-solution into account, the preservation of striae would seem impossible in such an ancient rock. In many instances the pebbles are surrounded by a film of sericitic flakes and present a pitted surface. Embayed contours due to solution can be seen macroscopically even in very large boulders. In other instances secondary silicification of the whole rock has been so intense, that pebbles and groundmass have been welded together and the boundaries between them obliterated.

The matrix of the rock varies both in macroscopic appearance and mineralogical composition. It may be classified into two types: an originally argillaceous matrix and one originally mainly arenaceous. The former has been metamorphosed into a typical biotite-schist, very often knotted and spotted, and macroscopically generally presents a dark-grey to dark greyish-blue appearance. The knots consists mainly of cordierte and secondary quartz. Under the microscope this matrix is seen to be composed of an aggregate of angular quartz grains and small flakes of biotite. The other, arenaceous type has been changed into a very peculiar greenish-black siliceous rock, very dense and

compact / .....

compact and exceedingly hard. Macroscopically no individual grains of quartz can be seen, secondary silicification having entirely obscured its original texture. Probably this quartzitic rock originally represented a very finegrained sandstone or silt. Gradations between these two types naturally also exist, shown mainly by the appearance and gradual increase of biotite.

Originally this type of matrix and its transitional stages must have been highly felspathic, now evidenced by the marked abundance of epidote. Some varieties, particularly the massive unbedded rock containing few or no pebbles at all, is characterised by veritable nests of epidote. The underlying Khan quartzites also contain this mineral in great profusion and it is a feature of the massive, unbedded dark siliceous rocks occupying the horizon of the tillite in the area around Goanikontes and Birkenfels.

Occasionally, particularly in the uppermost portions of the tillite, there occur beds of ordinary finegrained, light-reddish or whitish, only slightly felspathic quartzite also studded with angular pebbles.

The proportion of pebbles and boulders to the matrix in general stands in direct relationship to the mineralogical nature of the latter. Where the matrix is siliceous, the rock is generally packed with boulders, very often to such an extent, that the latter preponderate over the former. Very large boulders are most frequently to be found in this type of rock. The angularity and sharp contours of the embedded rock-fragments, although very marked throughout the whole tillite, is particularly pronounced in the siliceous rocks. The schistose, originally argillaceous type in general contains the pebbles and boulders more sparsely distributed and the matrix always preponderates. The bulk of the former are also smaller, although large boulders of 1-2 feet in diameter are also to be found. In short, except for the metamorphosed nature of its matrix, the schistose type very closely resembles the ordinary bluish-grey Dwyka boulder-mudstone.

All these features point to the greater activity of glacial action and the marked vicinity

Plate 12

Photo Author.

Block of Siliceous Tillite, Navachab Hills west of Karibib.

Photo Author.

Siliceous Tillite, showing bedding, Navachab Hills, west of Karibib.

to the actual area of erosion in the case of siliceous type. This is further shown by the superimposition of the two types. Almost everywhere the tillite begins with the schistose facies, that is to say, where this type at all occurs, it forms the bottom and the top layers, as the two characteristic sections given (p.) show. At the Chuosberg this type forms considerably more than half of the bulk of the whole rock and a massive unbedded bottom-layer of 600-700 feet thickness. Beyond this bottom portion alternation of schistose and siliceous types sets on, till the latter predominates and forms a massive horizon. Towards the top the two types again alternate, the schistose gradually increasing till it again forms the topmost-layers before the commencement of varves.

These features and the previously mentioned phenomena very clearly point to the gradual advance and retreat of the ice-front of the glacier or ice-sheet. The coarser siliceous material is deposited nearer the scene of active scouring, grinding and plucking of the glacier and the fragments deposited in it are on the whole larger, more numerous and more angular. Further away everything in general shows lesser dimensions, the sandy matrix changing into a clay or mud. These changes can be traced along the line of strike of the sediments in the lower portions of the tillite from Chuospforte to the Navachab Hills, as a comparison of the two sections given will make clear. The area of the Navachab Hills during the first advance of the ice was nearer the scene of active erosion than that of the Chuospforte 20 miles to the south-west, a fact to be referred to again later. Since, however, all the beds having been intensely folded and vertical dips being

predominant,/ ......

predominant, only a few narrow sections along the line of strike are available, there is very little scope for such investigations. With the advance of the ice coarser material came to overly the finer and alternations mark successive advances and recessions of the ice-front. The very thick and coarse siliceous tillite designates the farthest advance of the ice lasting for the longest period. Alternation of the two types in the upper portions of the tillite again demonstrate a fluctuating ice-front, while the ultimate preponderence of the schistose variety followed by fossil varves marks the final recession of the ice from this area and the formation of glacial lakes in front of the glacier or ice-sheet. The section at the Chuospforte shows 8-9 major advances of the ice-front.

The fact that the greatest thickness of the schistose variety occurs in the bottom portion of the tillite before the deposition of any coarse material and that in the upper portion after alternation it is relatively thin and quickly followed by varves, indicates a relatively slow advance of the ice and a comparatively fast recession after its furtherst extension.

Very similar features with regard to a sandy and argillaceous matrix have been noted by Beetz[ø] in the case of the tillite occurring at the base of beds stated by him to be Folded Nama, and by Haughton and Frommurze[x] in the case of the Dwyka Tillite in the southern portion of South West Africa.

The / .....

ø Beetz, W. Über Glazialschichten an der Basis der Nama- und Konkip Formation in der Namib S.W.-Afrikas Neues Jahrb.Min.etc Beilageband LVI, Abt B.1926, P.447.

x Haughton, S.H. and Frommurze, H.F.: The Karroo beds of the Warmbad district, S.W.Africa. Trans.Geol.Soc.S.A. Vol.XXX 1927, p.136.

Plate 13

Banded Rocks (Varves) overlying Chuos Tillite. Photo author
northern slopes of Langer Heinrich.

Photo Author

Chuos Tillite, southern slopes of
Chuos Mts. near Chuos Pforte.

The rock fragments enclosed in the tillite belong to a variety of types. At the Chuospforte the most abundant are: Vein quartz, brownish-grey quartzite (from the underlying Abbabis beds), whitish aplitic and microgranite and both para- and ortho-gneisses. Some of the latter have been found to be intrusive into the Abbabis beds, but on the whole their area of origin is so far not very apparent. Highly angular, slablike fragments of schistose and amphibolitic rocks from the Abbabis beds also occur, but are never abundant. In the Navachab Hills, where in the siliceous tillite the angular rock fragments preponderate over the matrix, a white, probably bleached, porphyritic gneissose granite predominates. This rock except for its marked white colour, resembles in structure and degree of gneissosity the plagioclase-gneiss intrusive into Abbabis beds of the immediate neighbourhood. In addition there occur fragments of vein quartz, somewhat gneissose types of graphic granite, microgranite, aplite, white pegmatite with tourmaline, amphibolitic rocks and whitish and brownish quartzites of the Abbabis beds. On the whole the enclosed rock fragments appear to be less highly metamorphosed and in the case of granitic rocks show a lessor developed gneissose structure, than the parent rocks in the vicinity, where the latter are known. Their isolated position in the yielding matrix apparently exerted a protective influence.

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I SECTION AT THE CHUOSPFORTE FROM TOP TO BOTTOM. DIP 90 – 75° S.E.

Thickness in feet:

Salem granite in contact with quartzose biotite-schists.

500 – 600'	White crystalline limestones (marble)
25'	(laminated amphibolitic and biotite-) schists alternating with narrow badds of (fine-grained black quartzite.
12'	white crystalline limestones.
130'	(laminated biotite schists with alter-) nating narrow bands of black quartzite ((suggestive of varves.)
4'	grey crystalline limestones
30'	(schistose Tillite, i.e. matrix=biotite) schist; pebbles small, abundant in some (layers, sparing in others.
150'	(biotite-schists with occasional small) pebbles, mostly unbedded, but containing (a few horizons of alternating laminated) schists and narrow bands of black quart- (zite (varves).
30'	whitish-grey phyllitic quartzites (serici-tic).
20'	Tillite; pebbles mostly small but abundant; matrix dark, semi-siliceous.
15'	(Yellowish-white, finegrained, felspathic) quartzite showing cross-current-bedding; (enclosed stones numerous and all angular.
6'	(very compact quartzite, less felspathic;) enclosed stones all angular.
3'	(dark siliceous tillite; pebbles and) boulders abundant; matrix somewhat (biotitic.
6'	(schistose tillite; pebbles sparingly) distributed.
15'	(ordinary dark siliceous tillite (Matrix) slightly biotitic) with numerous pebbles) and some very large boulders.
20'	) schistose tillite: pebbles abundant, but (not as numerous as in siliceous tillite.

/ ....

10'	(light grey quartzitic tillite; matrix) entirely siliceous; stones numerous.
12'	dark siliceous tillite.
15'	schistose tillite.
10'	(dark siliceous tillite packed with) pebbles.
35'	schistose tillite.
3'	dark siliceous tillite.
55'	(Schistose tillite with some very large) boulders.
200'	siliceous tillite, packed with stones.
15'	(schistose tillite; matrix knotted and) spotted.
65'	(siliceous tillite; matrix somewhat) biotitic; pebbles abundant, but small.
45'	Knotted and spotted schistose tillite.
35'	(siliceous tillite; matrix somewhat) biotitic.
250'	(ordinary siliceous tillite with numerous) and very large boulders.
600'	(knotted schistose tillite, weathering) yellowish-grey, pebbles numerous, but (less abundant than in siliceous tillite, (mostly small, with occasional large (boulders. Entirely unbedded.
	Very massive, fine-grained, pale reddish-brown felspathic quartzite with nests of epidote, resembling matrix of some types of siliceous tillite; no pebbles; followed by the ordinary well-bedded, finegrained, felspathic Chuos quartzites.

II SECTION IN THE NAVACHAB HILLS NEAR KARIBIB. FROM TOP TO BOTTOM DIP 40 - 50° S. E.

Thickness in feet (approximate only)

Crystalline limestones, partly amphibolitic and impure, with biotite-schists and para-amphibolites.

/ ....

±	45 - 50′	quartzitic tillite, crowded with boulders.
±	20 - 25′	impure limestone with narrow bands of dark quartzite.
	7′	greenish tillite, matrix quartzitic with epidote.
	15′	phyllitic micaceous quartzites.
	10′	greenish tillite.
	3′	phyllitic quartzites.
	2′	greenish tillite.
	15′	white, highly siliceous compact quartzite,
±	80 - 90	Main(greenish) tillite, crowded withh angular rock fragments, many very large.
	10′	gritty, schistose tillite.
	5′	greenish tillite.
	5′	tillite with amphibolitic schistose matrix.
±	80′	schistose tillite with numerous boulders of a bleached porphyritic gneissose granite
±	12′	greenish-black quartzites, the top layer containing rock fragments.
±	40′	hard, greyish-black indurated, fine-grained quartzites.
		ordinary reddish-brown, felspathic quartzites.

Ancient .....

Ancient varves: It has already been stated, that the laminated schistose rocks alternating with narrow quartzitic layers overlying the tillite at the Chuospforte are suggestive of glacial varves. Around the Langer Heinrich south of the Swakop River, in the area of Tinkas and stretching south towards the Kuiseb, banded rocks immediately overlying the tillite or its horizon undergo an enormous development. The northern slopes of the Langer Heinrich show the tillite ± 300'-500' thick) to be gradually grading into a great thickness of banded rocks, consisting of alternations of thin layers of laminated biotite-schists and thicker bands of an exceedingly compact greyish-black to greenish-black quartzite, which under the microscope also contains some dark green hornblende and diopside. This rock must originally have been a very fine somewhat calcareous siliceous silt. In some horizons these quartzites are ripple-marked, the ripples indicating the current that produced them to have come from the west. In some horizons both bands are siliceous, no doubt due to increase in the volume of the glacial streams, but whereas the narrower band is then dark and contains flakes of biotite (original argillaceous admixture), the wider band is light in colour and more purely siliceous. These banded rocks here attain a thickness well over 1000 feet, around Tinkas they probably approach 2000 feet. The thickness of the individual bands varies within wide limits. Sometimes measuring only a few centimetres, very often they are much wider and the light siliceous bands may be over a foot and even two feet thick. In this case the latter generally also exhibit a subordinate banding, i.e.

a few .....

Plate 14

Photo Author.

Banded Rocks (Varves) overlying Chuos Tillite.
Canyon on northern slopes of Langer Heinrich
note native-boy and dog.

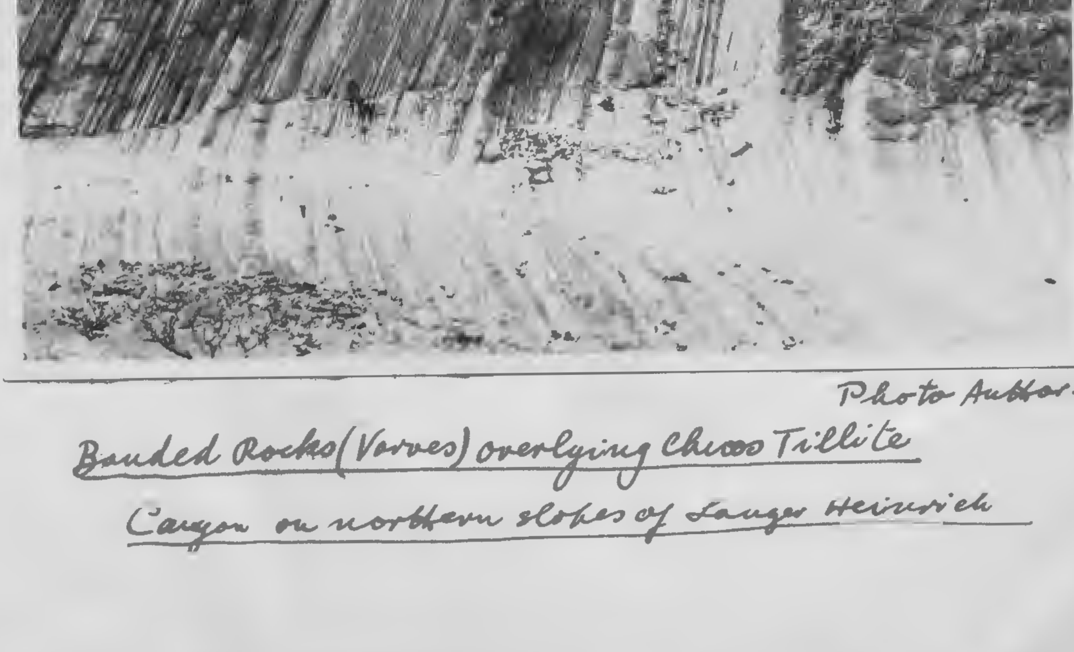

Photo Author.

Banded Rocks (Varves) overlying Chuos Tillite
Canyon on northern slopes of Langer Heinrich

a few darker layers, no doubt due to minor temperature variations during the summer.

It will be seen from this description and the accompanying photographs that these peculiar banded rocks agree very closely with pleistocene varves and also those described and pictured from the Squantum Tillite [x] and the Cobalt Tillite of America (Coleman ibid, p. 223). For a further comparison with recent varves, the reader is referred to: Kindle, E.M: Sedimentation in a glacial lake (Lake Cavell, Rocky Mountains); Journ. Geol. Vol. XXXVIII No. 1, p.81. The photograph of recent banded glacial sediments reproduced in this publication is almost identical with some of the more thinly banded rocks at the Langer Heinrich.

It is quite clear, therefore, that a fresh-water lake of considerable size must have existed in this area in the foreland of the glaciated region. The water must have been shallow as evidenced by the ripple-marks of some of the siliceous bands.

No attempt was made to follow in the footsteps of Baron Gerard de Geer, and to count accurately the number of varves and deduce the length of time during which deposition lasted at this locality. As already stated, the total thickness of these banded rocks south of the Langer Heinrich probably approaches 2000 feet, and on its northern slopes a thickness exceeding 1000 feet is exposed before being cut off by Salem Granite (it must be remembered in this connection that 40 miles north of this locality, at the Chuospforte, the thickness of the tillite itself exceeds 1500 feet).

x Sayles, W: New interpretation of the Permo- carboniferous Varves at Squantum. Bull. Geol. Soc. Amer. Vol. 40, No. 3, 1929, p. 541-546.

At ......

Plate 15

Photo Author.

Banded rocks (varves) overlying Chuos Tillite.
Southern slopes of Langer Heinrich near Klein Tinkas.
quartzitic layers weather out.

Photo Author.

Banded Rocks (Varves) overlying Chuos Tillite.
Southern slopes of Langer Heinrich near Klein Tinkas.
dip vertical; upturned edges of weather-resisting quartzitic layers.

At a place, where the individual bands are very narrow, 18 to 20 pairs were counted to the yard, and at another locality, where they were considerable wider, some of the light siliceous bands exceeding 1 foot in thickness, as many as 150 pairs over a thickness of 30 yards.
No reliable average can therefore be obtained by counting the varves over a limited thickness and it is left to the reader to arrive at his own conclusions as to the length of time necessary for these banded rocks to have been deposited.

Mode of Deposition. Although only a comparatively small portion of the Central Portion of S.W.A. has been mapped so far, nevertheless the outcrops of the tillite are already known to occur over a considerable area in accordance with the tectonic plan of the country. It may be said to have been proved over an area of roughly 5000 square miles. The writer feels confident that future mapping will still considerably extend the limits. Already now it is apparent that the tillite is not the result of a minor local glaciation. Its remarkable thickness at the Chuospforte together with that of the banded varve-rocks south of the Swakop still further stress this point. The thickness of both types of rock are considerably in excess of that of any known deposit of the Pleistocene and Dwyka periods of glaciation.

Unfortunately the highly folded nature of the sediments afford little scope for regional investigations of the tillite, except on a very limited scale. Much of the detail of its mode of deposition will therefore always remain hidden. The following points, however, are clear. The tillite represents the deposit of an ice-sheet of great extent and duration.

The ....

The thicknesses already commented on leave very little doubt about this point. In spite of the complex folding of the rocks of the Fundamental complex, it is fairly clear that the land-surface on which the Chuos quartzites were in process of deposition was gradually being worn down into a vast peneplain. It has previously been stated that the basal conglomerate and overlying quartzites were mainly deposited in wide shallow depressions, which were gradually filled. For while the basal beds overlying the conglomerate are mostly very coarse arkoses, towards the top they become progressively finer and the upper portions represent finegrained, well and usually rather thin-bedded quartzites. With the onset of the glacial period peneplanation must have been complete, for the uniform distribution of overlying marble-horizon shows the inundation by the sea to have taken place smoothly and comparatively quickly. Nowhere is there any evidence of mountains rising above the plain or a hilly character of the submerged landsurface. The latter, as shown by the uniform and very wide-spread development of the rocks of the Marble and Khomas Series over the whole of central S.W.A. must have been a very extensive one.

There is little doubt, therefore, that the tillite was deposited by an extensive ice-sheet occupying low-lying country. The floor of the ice in the area under discussion was formed largely by newly formed sediments (Chuos quartzites) and in part by a variety of older, already consolidated rocks. Glaciated pavements therefore could originally have been present on only a limited scale.

This ......

This fact also explains several differences in the development of the tillite, for instance at the Chuospforte and in the Navachab Hills. At the former locality the lower schistose tillite is very thick and contains mostly small pebbles and these in comparison with the siliceous tillite rather sparingly distributed. While the majority of pebbles are angular, rounded ones are also not rare. In the Navachab Hills the lower schistose tillite is comparatively thin, while the bulk is of the siliceous type and moreover so crowded with rock fragments, that the latter preponderate over the matrix. Nearly all fragments are here highly angular and very large ones are quite numerous. Some horizons of the siliceous tillite almost have the appearance of breccias. Although the tillite is here in part still underlain by quartzites, yet a few kilometres away the latter pinch out completely and the ice therefore ploughed over solid rocks, mainly a gneissose granite intrusive into the Abbabis beds. A large amount of plucking must have been effected by the ice, as shown by the great number of very large, slablike fragments of the former rock.

The tillite, as developed over the major portion of the area, constitutes a typical ground-moraine. The epidotic type containing very sparsely distributed pebbles or apparently none at all, in all probability represents the deposit from stagnant, inactive portions of the ice-sheet.

Extensive glacial lakes must have existed in the fore-land of the ice-front, probably formed mainly after its furthermost advance. The largest in the area examined was situated in the region of the northern Tinkas game reserve between the Swakop and Kuiseb rivers. The enormous thickness of the varve-deposits show the glaciation to have continued over a very long interval of time. The upper portion of the banded rocks at the Langer Heinrich show about half a dozen very narrow bands of marble (from 1 to 12 feet) to be interbedded with the varve-deposits. Generally the adjoining schistose and siliceous rocks are less regularly banded than those away from the layers of crystalline limestone in accordance with the fact that varves are not formed in salt-water. This interbedding shows that by this time epeirogenetic sinking had progressed to such an extent, that the surface of the area now practically lay at sea-level and the sea as a consequence was enabled to make a few brief inroads before the complete inundation of the whole area commencing with the deposition of the main marble horizon.

III.- THE MARBLE SERIES.

The main rock-constituents of this group are crystalline limestones, generally termed marbles throughout South West Africa. They are mostly coarsely crystalline and of a variety of colours. Although narrow bands of crystalline limestone also occur in the mica-schists of the overlying Khomas Series and occasionally also as small lenses in the Quartzite Series, this feature is nevertheless not too common in the area under discussion and all major bands of crystalline limestone belong to a well-marked and conspicuous marble horizon. Associated with the limestones occur as subordinate members of this group and mainly as intercalations of varying width :- dark biotite- and biotite-amphibole-schists, black and greenish-black para- -amphibolites and, occasionally in the lower portion of the group, narrow bands of finegrained quartzites, generally dark in colour and often containing needles of greenish hornblende.

The petrographic nature of the rocks of this series is therefore rather uniform, the number and succession of individual marble-bands within the group on the other hand very variable.

At the Great Rooiberg and the Gamgamchab range near Usakos for instance the uppermost finegrained reddish quartzites are immediately overlain by a very conspicuous band of brilliant- -ly white, sugary marble, which in turn is then directly followed by the normal greyish limestones. Almost everywhere else, however, the lowest major marble-band is separated from the quartzites by a varying thickness (40-150m) of biotite schists and amphibole-biotite-schists. While the first instance

yields /...

Plate 16

Photo Author

<u>The Tachub (Tiger) Mountain near Kubas.</u>

Salem granite cutting off red Chuos quartzites (remnants on top of hills). In background overlying Marble-ridge

Photo Author

<u>The Southern Slopes of the Chuosberg</u>

On right hand Red Chuos quartzites; on left hand marble-ridge. Saddle formed by biotite-schists, varves & Tillite.

yields a very striking colour contrast, the latter case is responsible for a very characteristic morphological feature as exemplified by the southern slopes of the Otjipatera and Chuos ranges : the limestones form a parallel mountain chain or ridge lower than that of the quartzites and separated from the latter by a deeply indented saddle formed by the interca--lated schistose rocks (vide Photo Plate 16).

In general the main bulk of limestones is united into one major marble band, in comparison with which any other bands that may occur are merely accessory. This is the case in the Kampaneno Mountains north of Omaruru, in the area between the Erongo and Brandberg, at the Otjipatera and Chuos Ranges, north of the railway from Ebony to Arandis and again around the lower Swakop at the Husabberg, Pforte and Witpoort. At other localities, however, the marble horizon is mainly made up of two bands of more or less equal dimensions and separated by biotite- and amphibole-biotite-schists as well as para-amphibolites, as for instance in the Khan Mountains west of Tsawisis. More rarely, e.g. in the neighbourhood of the Khan Mine, the whole horizon is constituted by several less conspicuous layers of varying width (vide Sections IV - VII)

Thickness: Accompanying this irregularity in deposition is a great variability in the thickness not only of individual layers, but of the whole horizon. Although as a whole the marble horizon is far more continuous and consistent than the underlying Quartzite Series, nevertheless the conditions of sedimentation must still have been somewhat unsettled.

The marble horizon attains its greatest thickness in the area of the Kampaneno Mountains north of Omaruru, where it is represented by a single band ± 700-900 M. thick, and in the neighbourhood of Karibib, where 650-700 M. were paced off at the Otjipateraberg.

The /...

The following table illustrates the variable thickness :-

Kampaneno ± 700-900 M; Karibib ±500 M; Otjipera(Etusis) at 650-700 M; Chuospforte ±400-450 M; Sphinx ±450-500 M; Pforte 200-300 M; Rote Adlerskuppe west of Jackalswater 22-25 M; Aukaspforte 0-5 M; Khan Mountains near Tsawisis ± 120 M; Khan Mine (several bands) ± 230-250 M; Audawib 0-100 M; Dieptal 15 M; Langer Heinrich 0-6 M.

Locally, e.g. between the Aukaspforte and Tsawisis, the marble horizon may disappear altogether. In general the total thickness is greatest in the northern and north-eastern portion of the area and decreases towards the west and particularly towards the south. In the former area the marble horizon is an important morphological factor, particularly since the Quartzite Series is completely absent.

Along the Swakop River from Otjimbingwe to the Langer Heinrich and south of this area the marble horizon is very inconspicuous or absent altogether over considerable distances, e.g. south of the Harebisspitze and around Tinkas. In this area one may speak of an argillaeeous facies of the Marble Series, in which the limestone-bands entirely recede and biotite-and biotite-amphibole-schists form the bulk of this horizon. At the Potberg for instance there is no conspicuous marble-bed at all and the quartzites are overlain by normal biotite-schists through which are scattered at intervals a number of narrow bands and lenses of limestone. On the northern slopes of the Potberg near Gamikaubmund twenty-three such bands, none exceeding 30 M. in thickness, were counted irregularly distributed throughout a thickness of 800-1000 M. of schists. Most of these bands and lenses are less than 2-3 M. in thickness.

At /...

At Grastal, near Palmtal (Pot-Mine) the following section through this horizon is exposed :

Section III.

Bottom.	Metamorphosed, highly sericitic, knotted quartzites. Lenses of a peculiar, brownish-weathering rock consisting in the main of Diopside rich in magnesia.
30 M.	quartzitic biotite-schists and quartzphyllites.
6 M.	conglomeratic biotite-schists (Tillite horizon).
25 M.	quartzitic biotite-schists and phyllitic quartz-ites.
32 M.	biotite-schists.
18-25M.	yellowish crystalline-limestone.
2 M.	biotite-schists.
.5 M.	crystalline limestone.
7 M.	biotite-schists.
1 M.	crystalline limestone.
1.3 M.	biotite-schists.
.7 M.	crystalline limestone.
1 M.	biotite-schists.
.6 M.	crystalline limestone.
1 M.	biotite-schists.
.5 M.	crystalline limestone.
1 M.	biotite-schists.
.3 M.	crystalline limestone.
1.1 M.	biotite-schists.
.3 M.	crystalline limestone.
50 M.	biotite-schists.
8 M.	crystalline limestone.
Top.	Several hundred metres of biotite-schists cut off by Goas Granite.

On /...

On the northern slopes of the Langer Heinrich there occur interbedded with varve-like, banded rocks overlying the tillite, 4-6 very narrow bands of crystalline limestone ranging in thickness from .3 to 4-5 M. South of this mountain, in the surroundings of Tinkas, limestones proper are absent altogether.

In this connection it may be mentioned that on account of the peculiar tectonic structure of the Fundamental Complex in this region enormous thicknesses of marble are sometimes simulated. Particularly is this the case in the northern area between the Khan and Ugab Rivers, where the underlying Quartzite Series is absent. In this region exposures of marble several kilometres in width are no rarity. Also at places of powerful torsion and bending great thicknesses of limestones are sometimes accumulated through rock-flowage into the areas of minimum stress, as for instance on Dorstrivier between the Chuosberg and the Swakop River. Very sudden attenuations of marble-bands are no doubt in many instances due to the same cause.

Petrographic description:

The predominant colour of the limestone is bluish--grey, but greyish-white, yellowish-white and pure white varieties are also widely represented. The macroscopic appearance of these rocks is entirely dependent on the degree of metamorphism, which they have undergone, particularly that of recrystallisation. In the vicinity of granite intrusions the latter has usually reached a very high degree. This type of rock lacks any weather-resisting qualities and disintegrates into rhombohedra of calcite of varying dimensions. The latter not infrequently possess a length along the face-edges of more than 5 cm. These calcite-rhombohedra may be greyish, greyish-blue, milk-white, pink or lemon-yellow in colour. Clear transparent rhombohedra of iceland-spar are exceedingly rare.

In areas, where large granite-intrusions are absent or large thicknesses of biotite-schists have protected the limestones, the degree of re-crystallisation has generally been high enough to produce a coarsely granular texture. At some localities, however, e.g. in the Etiro hills and the Dernburg Range (Marble quarries) near Karibib, a large portion of the rock is finegrained and even dense. The weathered surfaces of this type of rock often closely resembles the "Olifantsklip" of the Transvaal dolomite and other more youth-ful limestones. These finegrained types, however, nearly invariably show indications of originally colloidal argillace-ous, ferruginous and bituminous admixtures, which exerted a protective influence during re-crystallisation. The original banding of the limestones has on this account been most complete-ly preserved in the latter type of rock.

In many horizons the limestone is crowded with parallel bands of chert, now frequently rendered crystalline. These chert-bands are almost invariably highly interfolded and contorted, very often to an extraordinary degree. This feature testifies to the marvellous plasticity attained by these lime-stones during the intense folding movements, that affected them. In the area south of Neineis and Okombahe, the lower portion of the marble-horizon is particularly full of rusty-brown chert-bands and in addition highly ferruginous. The whole rock weathers with the production of a characteristic dark-brown colour and is a great aid to stratigraphic orien-tation.

In the same area a brilliantly white, sugary lime-stone forming the topmost layer of the whole group, forms an exceedingly useful marker-bed. As a result of its compact and resisting nature it forms a number of very conspicuous, snow-white hills. Its thickness varies from less than 1 M. to over 30 M. In addition the rock is everywhere crowded with small glistening flakes of graphite. This rock therefore originally must have been an impure bituminous limestone and also in this case the protective influence of colloidal admixtures during recrystallisation is very apparent. Even where this rock is in direct contact with intrusive granites, it still possesses the normal sugary grain and its compact texture, while the bulk of the underlying originally purer limestones, free of graphite, although further away from the granite intrusion, have been completely recrystallised and dis-integrated into large and small rhombohedra of calcite.

Under the microscope the finegrained limestones are seen to consist of an interlocking aggregate of calcite-grains and to contain very few alteration minerals. Occasionally secondary silicification is a notable feature. In areas in-vaded by granites, the texture, as already stated, is much coarser and the calcite ideomorphic to a greater degree. In this type of rock tremolite and actinolite, generally macro-scopically visible, are widely distributed. Frequently these minerals, particularly the former, form a major-constituent of the whole rock and on the Husabberg, west of Pforte, there occur lens-shaped bodies of pure tremolite several feet, occasionally yards in length, scattered throughout a particular horizon of the limestone. Although pegged, this occurrence from an economic point of view is valueless. In the area of Witpoort and Husab, south of the Swakop River, there occurs a rock, in which not only a large portion of the calcite has been altered to fibrous tremolite, but the remaining portion also so completely silicified, that a rock of remarkable tough-ness has been produced. In the same area, the limestone, silicified or otherwise, very frequently presents pink and greenish spots (diopside) and at Witpoort a highly silicified rock of this description in addition contains green beryls along a pegmatite contact.

Of/...

Of all rock-types represented in the Damara System, the limestones have offered the greatest resistance to the widespread granitic invasion. While the overlying schists very often have been displaced, disrupted and to some extent assi-milated, it is not uncommon for marble ridges to continue right through granite intrusions of considerable size (7 p.236).

In the southern portion of the area the overlying schists have almost invariably been displaced or partly assi-milated and granite-bodies show a marked predeliction for intrusion between the marbles and schists to fill synclinal basins. Granite-limestone contacts are therefore exceedingly common and a large portion of the ore-occurrences are connected with them (Gamikaubmund-, Ida-, Saddleback-, Henderson Mines, etc.). Calc-silicate rock is therefore very abundant and includes : Almandine, Andradite, Grossular, rarely Uwarowite, Diopside, Epidote, Wollastonite, Forsterite, Tremolite, Acti-nolite, Scapolite, Titanite, Apatite and Fluorite. Deposits of massive garnet are very common and in the neighbourhood of Husab and Palmtal there exist veritable hills and ridges of this mineral, the calcite having been almost completely ~~used up or removed~~ replaced. Unfortunately, although to be expected, the garnet is mostly rich in CaO and Andradite appears to be most common. Pure almandine, mostly used for the manu-facture of garnet-abrasives, while present in considerable quantity, is only subordinate in bulk.

Near Omburo, northeast of Omaruru, there is a large deposit of Fluorite in limestones of the Marble Series. At a number of these granite- or pegmatite-limestone-contacts metasomatic replacement of the calcite by metallic sulphides is conspicuous, but nowhere has a really first-rate ore-deposit been discovered. On Otjimboyo Ost the marble is veined by Galena and Copper pyrites, which carry small amounts of gold.

Graphite /...

Graphite is very widely distributed in these ancient limestones, generally in the form of small flakes irregularly disseminated throughout certain layers. Occasionally also massive graphite occurs, as for instance in the neighbourhood of Otjiwarongo. Part of the original limestones therefore must have had considerable amounts of bituminous and carbonaceous admixtures. In this respect the Damara limestones bear a marked resemblance to the highly graphitic archeozoic limestones of the Grenville Series of North America.

Where excessive recrystallisation has not destroyed this feature, a great many of the limestones are beautifully banded. The marble-quarries near Karibib - unfortunately almost entirely dormant - exhibit a remarkable wealth of different patterns and designs highly suitable for ornamental and general architectonic purpose. Apart from rocks of uniform grey, greyish-blue, black, pale-reddish, yellow and sugary-white colour, there are spotted and above all banded types. Of the latter there are varieties possessing either straight or contorted banding with almost every conceivable colour-combination. Of great beauty are also types, in which the originally banded and variegated rock has become intensely brecciated and the multi-coloured fragments have been recemented by a white or greyish secondary calcite.

Caves and subterraneous caverns are of common occurrence in these limestones, particularly in the regions of higher rainfall. Some of them contain considerable quantities of bat-guano and in Karibib an unsuccessful attempt has been made to utilise the latter economically.

The biotite-schists separating the limestones from the Quartzite Series are of the normal type, with the exception that in the neighbourhood of the former they frequently become amphibolitic and pass over into black and greenish-black <u>para-amphibolites.</u> Under the microscope the latter are seen to consist of a dark-green, strongly pleochroic hornblende,

numerous/...

numerous quartz-grains and generally also some biotite. Titanite is nearly always present as an accessory. Prior to the intense metamorphism the rock originally no doubt represented impure argillaceous limestones and calcareous shales and mudstones.

IV.- THE KHOMAS SERIES (Mica-Schist Series: Rimann and Wagner).

Where granite-intrusions have not displaced them, the Marble Series is everywhere conformably overlain by a great tyickness of crystalline schists, in which biotite-schists by far predominate. It has already been stated, that in the region of the lower Khan and Swakop rivers these rocks have generally been displaced by granite intrusions filling syn--clinal basins underlain by crystalline limestones. Where this is not entirely the case, the schistose rocks are general--ly interwoven with lenses of granite and pegmatite, frequently with the production of mixed-rocks and composite gneisses. In the extreme western portion of the mapped area and to a still greater degree west of 15° long. these rocks are to be found almost entirely in the latter form.

Also in the northern portion of the area, i.e. between the Khan and Ugab rivers, where the scale of granitic invasion is less intense, these rocks are mainly found in the form of more or less narrow strips and wedges separating granite massifs and generally swarming with pegmatites. It is impossible therefore to arrive at a reliable estimate of these schistose rocks in these regions.

The southeastern corner of the mapped area, however, includes a portion of the Khomas Highlands. As far as could hitherto be ascertained this rugged mountainous tract is built up entirely by rocks of this group. Together with his colleague Mr. de Kock, the writer therefore proposes the name "Khomas Series" for the mainly schistose rocks overlying the Marble Series. The old term "Mica- Schist Series" is misleading, since typical mica-schists occur also in other ... often in considerable thickness. South /...

Plate 17

Photo Author

Schist-syncline surrounded by white marble ridge near Welwitsch overlooking Khan-Canyon. In background mountains near the Khan Mine formed of Khan Quartzites.

Photo Author

The same schist-syncline (overfolded) showing bend of marble ridge. In background mountains of the surroundings of the Khan Mine formed of Khan Quartzites.

South of the prominent quartzite ranges along the southern bank of the Swakop river from the Potberg to the Langer Heinrich, a large body of granite has been intruded between the quartzites and overlying lowermost schists on the one hand and the main bulk of schistose rocks on the other and thus separated the latter from the other rocks of the Damara System. The succession, however, can be shown to be a continuous one. The Marble Series is practically absent in this region, but the varvelike, partly schistose, partly quartzitic rocks overlying the tillite on the other hand undergo a tremendous development. They consist of narrow alternating bands of normal biotite-schists, often amphibolitic, and of a dark, very compact and finegrained black to greenish-black quartzite, often with visible porphyroblasts of green hornblende. Under the microscope these quartzite-layers generally not only contain dark-green hornblende, but also some diopside. The rock originally no doubt represented a very finegrained somewhat calcareous siliceous silt, alternating with very fine clay or mud.

In the range of hills between Audawib and Anawood, west of Otjimbingwe, there occur in the same horizon very similar banded, quartzitic rocks, which here weather to a rusty--brown colour, but on fresh surfaces are greenish-grey in colour and generally spotted green and brown. The main bulk of these rocks has remained on the lower, i.e. northwestern side of the large granite intrusion, but on Blohmtal and Donkerhoek identical rocks form the southeastern margin of the intrusion. The banding, however, soon becomes less regular and the intercalated beds of dark quartzite become somewhat thicker, but after a thickness of about 1000 M. gradually recede.

On Blohmtal these very resisting rocks pass over into the normal crystalline schists of the Khomas Highland, biotite--schists by far predominating. On Quabis and Changas the rocks closely resemble those of the vicinity of Windhoek.

Steelgrey/...

Steelgrey graphitic schists, as well as Staurolite- and Cordierite-schists also occur in this region. Also narrow bands of white to greyish quartzite with conspicuous "Garben" of radiating hornblende needles are also to be found. On Quabis there occur, moreover, several narrow bands of an impure, finegrained reddish limestone.

Thickness. On account of the great uniformity of rock types and the absence of variety and marker-beds, it is impossible to make out the detail of the tectonic structure of this part of the Khomas Highlands and to arrive at a reliable estimate of the thickness of the rocks of this group. The beds all dip parallel to the S.E. The thickness, however, must be an enormous one, running into tens of thousands of metres. In the Windhoek area between the Auas Mountains and Okahandja where the tectonic structure is very simple, the figure of 30,000 metres does not seem to be excessive.

Petrographic Description.

The main rock-types of this group have often been described, in most detail by Reuning from the area of the Natas Mine near the southeastern edge of the Khomas High--lands (9 p.199). Since the various rock-types are to be found scattered everywhere throughout central South West Africa, it is not proposed to describe them in detail. Only the main features will be briefly mentioned.

The structure of all schistose rocks of this group is typically lepidoblastic. With the exception of the coastal area, where a higher degree of metamorphism prevails, most of them may be said to belong to the meso-zone of Grubenmann-Niggli.

Dark biotite-schists by far predominate. In addition there occur biotite-muscovite, biotite-muscovite--chlorite-, biotite-hornblende-, hornblende-, chlorite-, talc- and graphitic-schists, as well as sericitic phyllites. In

In the biotite-schists dark biotite with deep-brown to light-yellow and more rarely light-green pleochroism is the main constituent together with quartz in various proportions. By an increase of the latter the rock often passes over quartzose and quartzitic biotite-schists into biotitic quartzites. Acid plagioclose is not rare and as accessories there occur epidote, zoisite, chlorite, calcite, zircon, titanite and apatite.

The amphibole-schists generally show the green hornblende to be poikilitically intergrown with quartz and accompanied by biotite in varying proportions.

Spotted and knotted schists are widely distributed and porphyroblasts in general are common. The knots consist to a large extent of cordierite and quartz. More rarely they contain andalusite. Staurolite-schists, ~~often~~ frequently containing also long crystals of Cyanite, are very common and often form continuous horizons hundreds of metres thick, as for instance at the Garob Mine and the northern margin of the Khomas Highlands near Osona. At the former locality Staurolite crystals 10 cm. long and 4 cm. wide are no rarity and the mineral is so abundant, that the weathered surface of these rocks is covered with crystals packed closely together.

Occasionally there occur small lenses of valueless chrysotile in bands of talcose schists.

Garnet, generally of a deep-red to a brownish-red colour (Almandine-Andradite) is widely distributed in the mica schists, of which it very often is a main constituent.

V.-/....

V.- SECTIONS THROUGH THE DAMARA SYSTEM.

Section IV.- Section along the old wagon road from Habis to Nekhoes, 25 Km. southwest of Karibib.

Top.	Thickness in metres.	Goas Granite with remnants of biotite-schists of Khomas Series.
	45	White crystalline limestone.
	30	Quartzose biotite-schists.
	2	White crystalline limestone.
	4	Greyish phyllites.
	2½	White crystalline limestone.
MARBLE SERIES.	25	Sericitic quartzphyllites.
	160	White crystalline limestone.
	18	Biotite-schists.
	300	White crystalline limestone.
	85	Dark-green amphibole-schists and dark phyllites with narrow lenses of fine-grained, dark, rusty weathering quartzites.
	16	Bluish-grey crystalline limestone.
	14	Quartzose biotite-schists.
	2	Grey crystalline limestone.
	18	Greenish quartzose amphibole-schists and quartz-phyllites.
TILLITE HORIZON.	8	Arenaceous biotite-schists and schistose quartzites with pebbles.
QUARTZITE SERIES (CHUOS QUARTZITES).	40	Platy, reddish, sericitic quartzites with lenses of arenaceous biotite-schists.
	70	Coarse, reddish, conglomeratic arkoses, gneissose.
	5	Arenaceous mica-schists and brownish-grey phyllites.
	8	Coarse conglomeratic arkoses, gneissose.
	1	Arenaceous mica-schists with pebbly layers.

UNCONFORMITY.

Greyish micaceous gneiss, mixed rocks and gneissose aplites and pegmatites.
Abbabis System.

Section V.- /...

Section V.- Section along the Abbabis-Etusis Gorge in the Otjipatera Range.

Top.	Thickness in metres.	Goas Granite with remanants of biotite-schists of Khomas Series.
MARBLE SERIES	650-700	Sugary-white and grey and greyish-blue coarsely crystalline limestones.
	12	Amphibote-schists with narrow lenses of dark quartzites and impure limestones.
	20	Impure, brownish, cherty crystalline limestones.
	30	Amphibolitic biotite-schists with narrow lenses of dark quartzite.
	2½	Greyish-white crystalline limestone.
LLITE HORIZON	70	Arenaceous biotite-schists with several quartzitic layers carrying angular rock-fragments.
	30	Biotite-schists with narrow bands of greenish-brown quartzite and a few very narrow lenses of impure limestone.
	10	Greyish crystalline limestone.
	11	Arenaceous biotite-schists.
	50	Gap, rocks covered by rubble.
	10-11	Siliceous tillite.
ARTZITE SERIES	15	Yellowish-brown finegrained well-bedded quartzite.
	10	Conglomeratic layer, pebbles well-rounded
HUOS QUARTZITES	2100	Finegrained reddish felspathic quartzites
	70	Coarser, whitish felspathic quartzites.
	80-100	Massive conglomeratic arkose and coarse conglomerate.
		Groundmass : reddish arkose.

UNCONFORMITY.

Micaceous gneiss, mixed rocks and reddish pegmatites.
Abbabis System.

Top.	Thickness in metres.	
	55	Quartzitic schists with narrow lenses of sericitic quartzites.
	25-28	Coarsely crystalline limestone.
	8	Greyish sericitic quartzites.
	13	Coarsely crystalline marble.
	125-150	Pale-reddish seritcitic quartzites, partly phyllitic.
	12	Coarsely crystalline limestone.
	16	Pale-reddish phyllitic quartzites.
	48	Coarsely crystalline marble.
	10	Whitish phyllitic quartzites.
	42	Dark quartzitic biotite-schists.
	1¾	Coarsely crystalline marble.
	2	Dark-green epidotic quartzites.
	10	Pale-reddish sericitic quartzites, partly phyllitic.
	2	Dark-green epidotic quartzites.
	2/3rds.	Coarsely crystalline limestone.
	3	Whitish sericitic quartzites,
		Great thickness (over 1500 M.) of greyish-green epidotic quartzites (Khan quartzites) interwoven with swarms of pegmatite of Khan Mine type.

In the southern limb of the anticline, close to the canyon of the Khan river, dark para-amphibolites inter--bedded with the limestone-bands are far more conspicuous.

D. POST-DAMARA IGNEOUS ROCKS OF THE FUNDAMENTAL COMPLEX.

The ancient sediments of the Fundamental Complex have been invaded by granites and other deepseated igneous rocks on an enormous scale and a very considerable proportion of S.W.A. is underlain by them. In certain portions of Central S.W.A., particularly in the area enclosed by the Khomas highlands in the south, the Erongo mountains in the west, the Omaruru river in the north and the Sandveld in the east, they by far preponderate over sediments and form very extensive coherent massifs. Generally, however, and this is particularly so in the area under discussion, very large bodies of granite are wanting and the latter merely form the material filling interstices in a sedimentary skeleton of exceedingly complex structure. Laccoliths, phacolithic bodies and sheets of varying dimensions are the normal forms of intrusion. In the Khomas Highlands granite-outcrops are conspicuously absent, a fact to be again referred to in the tectonic portion of this paper. Everywhere else, however, the sediments are intimately interwoven with granites of various types with the production of widespread hybrid-rocks and composite gneisses.

The pre-Damara gneisses intrusive into the beds of the Abbabis System have already been discussed. The rest of the granites, forming part of the Fundamental Complex and constituting by far the larger portion of its igneous rocks, are post-Damara in age and in the area investigated all belong to one grand cycle of igneous intrusion, which is without parallel both in the preceding and subsequent geological history of this part of the earth's crust. Reuning (7, 8 & 9) has on this account made use of the collective term "Main Granite" (Hauptgranit).

Since these rocks however, not only include a great variety of different types of granite, but also widespread dioritic and subbasic rocks, this collective term is misleading. The rocks belonging to this vast cycle of igneous intrusion may more adequately and conveniently be referred to as constituting

THE MAIN PERIOD OF GRANITIC INTRUSION.

The various rocks of this epoch form an excellent illustration of cyclic igneous intrusion and the progressive differentiation of a magma of large volume. It has already been mentioned, that the granites and associated rocks in the area under discussion do not occur in very extensive bodies of batholythic type, but mainly fill interstices in the sedimentary skeleton and thus occupy a large number of separate compartments. Everywhere in the central and northern portions of S.W.A. the available evidence indicates that this main period of granitic intrusion accompanied a vast tectonic upheaval, during which the beds of the Damara System were folded into high mountain chains. Even the pegmatites, the very last phase of the cycle, still clearly exhibit this tectonic control. These questions will be more fully dealt with in a later chapter of this paper.

It is clear, however, that such a mode of intrusion, i.e. the gradual filling of compartment by compartment, offered unique opportunities for the preservation of individual fractions formed during the progressive differentiation of the magma in one or more larger unexposed chambers. Each fraction as it arrives and is emplaced, except for a more or less narrow adit, is cut off practically entirely from the main bulk of the magma and subsequent resorption processes on anything like a large scale are ruled out.

It is not surprising therefore to find the intrusive cycle particularly complete and the various fractions particularly well-marked in the area investigated. In regions on the other hand, where conditions of intrusion were such as to result in only a few bodies of granite of much larger dimensions, the cyclic succession is far less marked and it is generally only possible to make out a few main types, as for instance in the large granite area between Okahandja and Omaruru and in the area southwest of Rehoboth. § In this connection the point must be stressed, that the rate and extent of differentiation depends largely on the rate of cooling of the emplaced magma and this again is mainly regulated by the size and depth of the magmatic chamber, as well as the addition or otherwise of fresh supplies of magma from below. Identical or closely similar fractions can therefore be formed in separate magma -chambers at widely different intervals, particularly when far removed from one another, and thus complicate the cycle. § In the investigated area the withdrawal of the various fractions from the parent-magma -chamber and their emplacement in a compartment of the sedimentary skeleton appear to be mainly the result of tectonic stresses. In this region at least there is very clear evidence indicating, that tectonic stresses were the main controlling force and that they made use of the plastic magmatic material in filling potential cavities and moving it into areas of minimum stress. It cannot be stressed strongly enough however, that this only applies to the upper portion of the crust, which is exposed for investigation in this region, down to the depth of the sedimentary skeleton and down to which lateral stresses operated. Deeper horizons are not exposed. Generalisations are as misleading and harmful in this case as in any other.

A great variety of conditions govern any large-scale magmatic intrusion from place to place and it would be futile to suppose, that the cycle of intrusion as established in western Damaraland experienced no deviation in other parts of S.W.A. The country is far too large for such uncritical generalisations.

The peculiar mode of intrusion, i.e. the emplacement of different fractions generally in separate compartments of the sedimentary skeleton, is responsible for a great dearth of mutual contacts. Very often a strip of marble or knotted schists no wider than a few hundred metres may separate two types of granite and yet no evidence for their relative ages be exposed anywhere. This feature very often greatly prolonged the time required for actual mapping.

Fortunately, however, a diligent search throughout the area of 7200 square-miles was rewarded by the discovery of quite a number of mutual contacts of all the different types with only one or two exceptions. The order of succession of the various rocks belonging to the Main Period of Gramitic intrusion, as put down in the following pages, is therefore based on actual exposures in the field. Unfortunately it was impossible to have full analyses of the main rock-types made, but the careful microscopic investigation of a large number of slides entirely support the deductions made in the field.

In Western Damaraland the earliest phases of the intrusive cycle are diorites and associated hornblendites, diorite-porphyrites and anorthosites. The diorites frequently grade into granodiorites. These are followed by more typical granodiorites and hornblende-granites. The rocks listed here possess a considerable distribution, but are in toto very subordinate to the succeeding granites proper. The earliest of these are mostly porphyritic biotite-granites, of which the so called Salem Granite is the most conspicuous member and at the same time the most wide-spread granite of all. It is followed by a number of more acid and less biotitic types, grouped together as Post-Salem Phases. They grade from normal greyish-white and red granites, still with a fair proportion of biotite, to highly acid aplitic and pegmatitic granites, the final products being aplites and pegmatites proper, as well as bodies of pegmatitic quartz.

Before proceeding with their description, the writer wishes to stress the point, that all the available evidence indicates that all these various types of dioritic and granitic rocks do not belong to widely separated periods of intrusion, but are merely successive phases of one grand intrusive cycle.

There is, however, one type of granite, referred to as Habis Granite, of which this is not certain. While definitely post-Damara in age, it is possible that it belongs to an earlier epoch than the main period of granitic intrusion. It will be described under the heading Salem Granite, which it most closely resembles.

I. DIORITE, HORNBLENDITE AND ANORTHOSITE.

There are quite a number of laccolithic bodies of dioritic and allied rocks in the area west and south of Karibib. The largest is of irregular shape and, almost encircled by marble-ridges stretches from Navachab over Habis on to Okongava Ost, which is underlain mainly by these rocks, and continues from there into Audawib Ost and West. The two prominent mountains on Okongava, the "Sargdeckel" (coffin-lid) and Virgin Peak are built up by diorite, but possess a capping of Erongo sediments and diabases. Another fairly large body occurs on the lower portion of Goas and is cut into by the Gamikaub river. A smaller body is to be found on the farm Kubas, just a few miles to the north-west. On the Tinkas flats, finally, a few miles north of the Tubabasberg, a prominent white marble mountain, there occurs a peculiar quartzite-breccia, in which the cementing material is rich in green hornblende and dioritic in nature. Some distance away there is a body of altered dioritic ~~in nature~~ rocks near Husab on the Swakop river.

The constituent rocks show a fair amount of variation, both macro- and microscopically. The extreme edge of the laccolithic bodies generally consists of very dark rocks, which often grade into hornblendites and form an endomorphic marginal facies. These marginal hornblendites are best exposed along the road from Karibib to Otjimbingwe on the slopes leading up to the Otjimbingwe Pforte. From the margin inwards the rock gradually becomes lighter in colour and its bulk has the normal greyish-blue or steel-grey colour of most diorites.

On Navachab and most extensively on Audawib Ost and Audawib west the diorites further grade into <u>granodiorites</u> and even <u>hornblende-granites</u>. These rocks are most abundant in the inner portions of the laccolithic bodies.

The macroscopic texture of all these rocks is typically granoblastic.

According to mineralogical composition the bulk of these rocks consists of normal <u>Biotite-hornblende-diorites</u> and <u>Biotite-hornblende-quartz-diorites</u>. In the former quartz is rare or sparingly distributed, in the latter it is quite conspicuous, part of it often in vermicular intergrowth with plagioclase. The plagioclase in the typical diorites is mainly andesine and labradorite, in the quartz-diorites mainly oligoclase and andesine. The most abundant femic constituent in both types of rock is biotite, very often with pleochroic haloes around zircon-inclusions. Many of the darker varieties of diorite, rich in melanes, macroscopically show numerous large flakes of golden biotite. Green, strongly pleochroic hornblende, as ideomorphic crystals or in hypidiomorphic aggregates, is invariably also very abundant, but generally less so than biotite. Some types, however, e.g. from Audawib Ost near the Otjimbingwe Poort, contain the former in excess and are therefore Hornblende-biotite-diorites. All varieties contain abundant sphene or titanite, very often as idiomorphic crystals or as large allotriomorphic grains. Apatite is invariably also abundant and most sections also contain epidote and occasionally secondary calcite as decomposition products.

Near the Natmaakbank 6-7 miles north of Usakos, there occurs a small outcrop of a dark rock surrounded by schists and isolated from any other occurrence of diorite. Under the microscope it is seen to consist of plagioclase; idiomorphic augite, often twinned; quite abundant hypersthene with characteristic black inclusions of ilmenite; very abundant biotite; abundant apatite and some irregular aggregates of Pyrite, partly decomposed and recrystallised to magnetite. Quartz is comparatively rare. The rock therefore represents a Biotite-hypersthene-augite-diorite.

At Husab on the Swakop river, best exposed in the river-canyon near the open water and along the road them. At least a portion of these pegmatites, however, are probably derivatives of later granitic phases.

On the north-eastern slopes of the Potberg, between Grastal and Ukuib on the Swakop river, there occurs a single dyke of a white Anorthosite studded with grains of pyrite. The rock consists almost entirely of acid plagioclase. Quartz is present, but very subordinate. There are abundant crystals of Sphene and some large idiomorphic individuals of colourless garnet. The latter are no doubt derived from the limestones of the Marble Series, into which the rock is intrusive. Most likely this anorthositic rock is a derivative of the dioritic rocks outcropping 6-7 miles further north.

II. GRANODIORITE.

As already stated, the dioritic rocks just described, in places pass over or grade laterally into granodiorites. Thus on Navachab the ordinary grey quartz-diorite of the interior of this portion of the laccolithic body through a gradual transition passes into a light-grey granitic rock, which the microscope shows to be a granodiorite. Near the western termination of the laccolith this rock again grades into the normal greyish diorite and this in turn into a very dark marginal diorite, very rich in melanes.

Under the microscope acid plagioclase is seen to be still considerably in excess, but phenocrysts of microcline are also quite numerous; biotite is abundant; a little muscovite is present; quartz is abundant, partly in granophyric intergrowth with felspar (micropegmatite). Hornblende, while present, is not abundant in the rock from this locality.

The most extensive outcrops of granodiorite associated with dioritic rocks occur on Andawib Ost between

Okongava and Otjimbingwe. Also in the rocks from this area ferromagnesian minerals have receded and hornblende is generally less abundant than biotite. The predominating felspar is still an acid plagioclase, but orthoclase, partly in granophyric intergrowth with quartz, is no longer rare, but quite conspicuous. Some types, in which the plagioclase on the one hand and orthoclase and microcline on the other are practically equally abundant, should perhaps already be classed with the biotite-hornblende-granites. In all these rocks sphene and apatite are abundant and epidote common as an alteration product.

III. GOAS GRANITE : BIOTITE-HORNBLENDE- AND HORNBLENDE-GRANITE.

On Goas and portions of the adjoining farms, as well as on Ukuib, Komandibund and Audawib there are extensive outcrops of a generally finegrained granitic rock, which in addition to its bluish-grey colour is characterised by considerable amounts of ferromagnesian minerals. Before contacts with typical Salem Granite were found and microscopic sections of the rock were examined, the writer mapped the rock as a non-porphyritic variety of Salem Granite. At a later date, however, contacts were found on Goas showing, that the typical porphyritic Salem Granite is intrusive into this rock and a microscopic investigation revealed considerable deviations from the former.

While thus representing an older phase than the Salem Granite, field-evidence seems to indicate that in part at least these rocks grade into the granodiorites and diorites by a gradual endomorphic transition. Locally, however, as is to be expected, also intrusive contacts occur.

Where good contacts are not exposed, it is admittedly difficult macroscopically to distinguish this type of granite, particularly where the hornblende is not conspicuous, from some finegrained varieties of Salem Granite, in which the normal and characteristic porphyritic structure is not well developed. The microscope, however, reveals considerable differences in minerological composition. The writer wishes to point out, however, that while in this particular region the granite referred to as Goas Granite is demonstrably a precursory phase of the Salem Granite, in other regions the one may pass into the other without intrusive contacts.

Under the microscope it is seen, that the content of acid plagioclase (albite-oligoclase) is still very considerable and in some sections acid plagioclase on the one hand and orthoclase, microcline and microperthite on the other are present in nearly equal proportions. Generally, however, the latter predominate. Sometimes the acid plagioclase is present in idiomorphic zonal crystals showing both albite and Pericline twinning. Orthoclase generally preponderates over microcline. Microperthite is not rare, Micropegmatite common. Most varieties still contain apatite and particularly sphene in considerable abundance. The amount of ferromagnesian minerals varies, as well as the relative importance of biotite and hornblende. A rock from the vicinity of the Pot-mine near Palmtal contains abundant hornblende, but hardly any biotite. It is therefore a <u>Hornblende Granite</u>. In one section of this rock a few grains of Scheelite were seen. In a similar rock from the Gamikaubmund Mine (limestone-contact : Cuprites, Bornite Molybdenite, Garnet, Epidote, etc.) a brownish-green hornblende, poikilitically intergrown with quartz, is associated with abundant diopside. The latter obviously resulted from the limestone-contact.

With this group must also be classed some of the rocks associated with the altered diorites and grano-diorites near Husab, in which microcline and to a lesser extent orthoclase preponderate over the acid plagioclase. The biotite also in this rock has been almost completely altered to chlorite.

The northern portion of Goas is underlain by a rock of this group, which contains far less ferro-magnesian minerals (biotite) than normally is the case. Acidplagioclase, however, is still very conspicuous and present in nearly equal proportion with orthoclase and to a lesser extent microcline.

IV. DYKES OF HORNBLENDITE-, QUARTZ-HORNBLENDITE AND DIORITE-PORPHYRITE INTRUSIVE INTO GOAS GRANITE.

On Goas and the adjoining portion of Etusis, in the immediate vicinity of the Neikhoes waterhole, there is exposed a ramifying network of dykes composed of Hornblendite, Quartz-Hornblendite and subordinately Diorite-porphyrite. The dykes are closely spaced, but possess no great length. A number of prominent dark hills are formed by them. They are intrusive into Goas Granite and partly also into limestones of the Marble Series. A large dyke of diorite-porphyrite cuts right accross the latter and the quartzites of the Otjipatera ran range.

The Diorite-porphyrite is a compact dark greyish rock, to which numerous large rounded phenocrysts of felspar and smaller ones of quartz lend a spotted appearance. Under the microscope large corroded sphaerulitic and often zonal phenocrysts of plagioclase, as well as a few highly corroded ones of quartz are seen to be embedded in a dense, fibrous, aggregate-polarising matrix. In one section the latter was seen to enclose minute laths of plagioclase and grains of quartz. A few large phenocrysts of decomposed biotite are generally also present. The felspar phenocrysts are frequently epidotised. In addition occur apatite, magnetite and chlorite (decomposition of biotite).

The Hornblendites present a variable macroscopic appearance. They are all dark rocks, but while some of them are almost black and consist almost entirely of parallel hornblende crystals with very little interstitial plagioclase, other varieties possess a fair abundance of the latter and the rock then assumes a peculiar speckled appearance on fresh surfaces: Polygonal and rectagonal sections of black hornblende set in an always subordinate matrix of white plagioclase.

Under the microscope large idiomorphic, oriented crystals of green hornblende, often poikilitically enclosing small grains of quartz and laths of plagioclase are seen either to constitute almost the entire rock or to be separated by an interstitial aggregate of acid plagioclase. Apatite is very abundant and sphene common. In some sections epidote is abundant as decomposition product. Quartz while rare in some varieties, is quite conspicuous in others. In the dark types, consisting almost entirely of hornblende, it is generally rare.

The area of occurence of these peculiar dyke-rocks is surrounded practically on all sides at varying distances by bodies of diorite, quartz-diorite, often possessing a marginal facies of hornblendite and quartz-hornblendite, as well as of granodiorite. One may assume ~~It is not improbable~~, therefore, ~~to assume~~ that these dykes probably represent a differentiate from more deepseated portions of the same dioritic magma and hence were intruded, after the differentiation in higher regions had already progressed somewhat further. None were found intrusive into phases later than the Goas granite.

V. SALEM GRANITE:

This porphyritic biotite-granite is the most widely distributed granite throughout the central portion of South West Africa. Together with the succeeding more acid phases Reuning (7,8,9) has therefore termed it "Main Granite".

It was first desdribed by Gürich (1) from the neighbourhood of Salem on the lower Swakop River and its name has become firmly established in the geological literature dealing with S.W.A. An excellent petrological description of the rock was given by Wagner (5).

As typically developed the Salem Granite is a grey porphyritic biotite-granite, with tabular phenocrysts of orthoclase and microcline. Generally the rock is very coarse-grained, particularly at ~~the~~ Salem and other localities, where the rock fills narrow synclinal basins and has assimilated considerable amounts of schists with the production of an abnormally high biotite-content. In the interior of larger masses the grain very often is less coarse and sometimes the texture is of the ordinary granoblastic type and the porphyritic structure indistinct. The high content of femic constituents (biotite), however, still distinguishes also this type of rock from the more acid, non-porphyritic later phases. The high content of femic minerals is one of the main characteristics of the Salem granite. A direct result of this feature is its almost universal grey colour.

The felspar phenocrysts usually exhibit flow structure, i.e., a parallel orientation, which is invariably strictly conformable to the structural plan of the sedimentary skeleton. The flow-structure is particularly noticeable in smaller massifs and in the

marginal / .....

marginal portions of larger bodies.

While generally coarse-grained, there are also types in which the felspar phenocrysts are much smaller. Flow structure is a particularly marked feature in this variety. It is well represented in the rock of the "bank" at the Sandamab water-hole, between the Erongo and Great Spitzkopje.

In this connection another feature may be discussed, namely the large amount of assimilation effected by the Salem Granite, when intruded into the schistose rocks of the Khomas Series. There exist a large number of excellent exposures, which demonstrate this fact very clearly. One of the best illustrations is afforded by a narrow elongate body of Salem Granite intruded into schists, south of Aubinhonis on the Omaruru river.

At the edge of the Salem Granite massif it is difficult to distinguish between contact-altered schists and the dark grey, highly micaceous Salem Granite. There is a wide zone of transition, several hundred metres in width, from the normal biotite-schists, to the typical porphyritic granite.

Beginning from the schist side, the latter exhibit the usual phenomena of contact alteration (spotted and knotted schists). Then follows a zone of minute and intimate lit-par-lit intrusion of the schists by the granitic magma. The granitic veins at first consist predominantly of white felspar crystals with their axis of elongation arrayed parallel to the micaceous bands (strike of the schists). Individual felspar crystals entirely surrounded by altered, highly micaceous schists are very common.

Further / .....

Further towards the actual granite, such felspar crystals become more numerous and begin to form coherent bands separated by narrow strips of altered schists. The latter are finally reduced to thin lamellae of biotite separating long rows of parallel felspar crystals. Finally these alternating bands become disrupted and the individual flakes of biotite are scattered about within the granite and the felspar crystals are no longer in their entirety parallel to one another, though both the latter and "schlieren" of biotite still exhibit a marked parallelism to the strike of the adjoining schists.

It is highly unlikely that individual felspar crystals already formed within the magma were squeezed into the altered schists and there is little reasonable doubt that they were formed in place. Not only the high femic content of the Salem Granite in small bodies and marginal portions of larger massifs, but also its porphyritic nature appears to be at least in part due to assimilative processes, during which, with progressive assimilation and enlargement of the space occupied by the magma, the newly formed felspar crystals gradually drifted from the sides of the body of the magma into its interior. Being the first granite intruded on an extensive scale and in close conformability to the tectonic plan, the Salem Granite had a far better opportunity to effect assimilation than the later phases, which were intruded after the sediments had already been consolidated to a very much higher degree.[1)]

That a large amount of assimilation actually took place, is further shown by the following feature.

Wherever / .....

writer's attention to this mode of origin of part of the nocrysts of felspar was first directed by Prof.A. Young of e Town, who pointed out very similar features in case of Cape Granite and its contacts.

Wherever the Salem Granite is intruded as smaller phacolithic lens-shaped bodies into biotite schists or as somewhat larger lacolithic bodies into narrow synclinal basins originally filled by schists overlying the Marble Series, that is to say wherever tectonic stresses brought the granite into intimate contact with biotite-schists the granite invariably has a much higher biotite-content and to some extent is also coarser in grain. The rock as a result has a *very much darker colour* and frequently is also somewhat foliated. It is obvious of course that subsequent tectonic stresses could become effective much more easily in such a highly biotitic rock, in which the scales and flakes of biotite provide easy gliding-planes, than in ~~the~~ a very massive granite of interlocking grains and crystals of felspar and quartz.

This feature is particularly well-marked in the large body of Salem Granite around Jackalswater and along the Swakop river in that region. The bulk of the rock, well-exposed at the large "bank" at the Jackalswater waterhole, is a very massive rock, typically porphyritic and biotitic, but of very uniform and highly resistive texture. In the vicinity of Gaub the main massif sends off a large and narrow subsidiary branch, which fills a very narrow trough, originally occupied by biotite schists, between parallel anticlines formed by the Quartzite Series. The Swakop river follows this narrow trough from Palmtal to Gaub. The granite reaches from the latter place past Salem as far as Horebis as a long narrow tongue. The rock composing it is exceedingly coarse-grained, with large felspar-phenocrysts and highly biotitic with abundant biotite-schlieren. In places it is somewhat sheared and foliated.

One / .....

One may therefore distinguish a highly biotitic marginal facies from the normal type of Salem Granite. At Salem itself the rock is of the former variety.

Under the microscope ~~the~~ very acid plagioclase, mostly albite and acid oligoclase are seen to be still quite abundant. In a section of a rock from Wilsonfontein it even predominates over orthoclase, microcline being rare in this specimen. In a few specimens from Paukwab north of the Omaruru river also andesine is present. In nearly all specimens, however, orthoclase, with very well-marked Karlsbad twinning, sodaorthoclase and microcline by far predominate over the acid plagioclase. Microcline is universally very abundant and very often predominates over orthoclase and even replaces it almost entirely. This is particularly so in the case of the large phenocrysts. The orthoclase is to a large extent intergrown with albite to form microperthite. Various types of micropegmatite occur, but generally subordinately.

The quartz frequently shows strain-shadows.

Biotite is always present in considerable abundance, often largely altered to chlorite (pennine), In one specimen also green pleochroic hornblende was seen to to be present, mostly poikilitically intergrown with quartz.

Muscovite is occasionally visible as an accessory constituent. Of the latter zircon is always abundant, but apatite and titanite are less common than in the previously described diorites, granodiorites and hornblende-granites. Black tourmaline is occasionally present, as well as fluorite and topaz. Epidote, as an alteration mineral, is common. Metallic ore-minerals are rare, though magnetite, pyrite and molybdenite were noticed in a few sections. Sericite as an alteration

product / .....

product of the felspars is not uncommon.

Along the contacts of pegmatite dykes, cutting through the Salem granite, the phenocrysts of soda-orthoclase and microcline sometimes assume a beautiful pink colouration. In the Otjimboyo area and particularly well exposed on Okapaue, there outcrops a coarsely crystalline porphyritic granite entirely identical with the ordinary grey Salem Granite except for the salmon-red and pink colouration of its felspar phenocrysts. This rock fringes the outer edge of the normal Salem granite, is of considerable width and, where contacts are exposed (e.g. near the homestead of Okapaue) it is intrusive into the former. This porphyritic granite with pink felspars at this locality thus appears to represent a slightly younger phase of the granite intrusion.

HABIS GRANITE:

It has already been stated, that there exists one type of granite of which it is not certain whether it belongs to this intrusive cycle or whether it represents an older post-Damara intrusion. The rock indicated outcrops in considerable bulk on Habis and small portions of the adjoining farms, 6-9 miles west of Karibib. It here forms several prominent hills and underlies mainly the Marble Series, into which it is intrusive.

The rock is dark grey in colour and throughout markedly porphyritic, greyish-white felspar phenocrysts being set in a dark biotitic matrix. In addition it is generally faintly gneissose in appearance. Under the microscope its mineralogical composition was found to vary, for while most slides

show / .....

show microcline to predominate and plagioclase to be very rare or almost completely absent, in one section acid plagioclase, ranging from albite to andesine was found to preponderate over microcline and orthoclase. Biotite is generally abundant, in some specimens more so than in others. Muscovite, while sometimes present, is inconspicuous.

Macroscopically the rock bears a considerable resemblance to the highly biotitic, marginal facies of Salem Granite. The latter outcrops some two miles to the south at the Undas bank, but here is of the less biotitic, normal type. Nowhere else, however, was the Salem Granite seen to possess such a degree of foliation. Under the microscopic crush-structures in the quartz and felspar are very marked and there is a distinct parallelism of the biotite flakes and zones of coarser and finer aggregates of felspar and quartz. The phenocrysts of microcline are not infrequently seen to be somewhat deformed.

No contacts with Salem Granite and the closely neighbouring diorite are anywhere exposed and the question as to the age of this type of granite must provisionally be left unsettled. It is possible, however, that it merely represents a facies of Salem Granite intrusive into schistose rocks of the Abbabis System, the foliation being due to the absorbtion of biotite and particularly intense tectonic stresses.

VI. POST-SALEM PHASES:

The intrusion of the Salem Granite was followed probably at varying intervals by a number of other granitic rocks belonging to successive phases of differentiation and solidification of the same parent magma.

It / .....

It so happens that, in this portion of South West Africa a number of several very clear exposures demonstrate the later age of these granites and that here the successive differentiation of the magma is manifested in a very clear way. But, as already stated, conditions naturally vary from place to place and the same complete sequence cannot, of course, be expected everywhere.

Cloos (2 and 3) has collectively designated these related granites as "Normal Granite". They present, however, widely differing aspects not really typical of ordinary normal granite.

Their distribution is a very wide one, but taken over the whole area, less than that of the Salem Granite.

For the classification of these various granitic rocks their petrographical characters and mode of occurrence will be taken as a basis. Naturally a large amount of variation occurs within the several, groups.

A. <u>RED GRANITES:</u>

Granitic rocks of red colour are widely distributed throughout the area investigated. They are particularly abundant along the Ugab river around Sorris-Sorris, Anichab, Davib, etc.; along the Khan river around Wilhelmstal, Claustal and Treuenfels and further east, and in the area around Ebony and Trekkopie as well as in the neighbourhood of the confluence of the Khan and Swakop rivers.

Macroscopically the rock varies from coarse-grained, even porphyritic types to ordinary hypidiomorphic granular and fine-grained aplitic varieties.

Only / .....

Only typical granitic types will be described in this connection. Aplitic varieties will be discussed in the chapter dealing with aplites. The division is of course somewhat arbitrary, since very often the aplitic varieties merely represent marginal facies or the chilled rock of small bodies. There is thus a large amount of gradation. On the other hand numerous exposures show the aplitic varieties to be later phases and intrusive into the ordinary red granites.

Wherever contacts are exposed all these rocks are intrusive into Salem granite.

With the macroscopic appearance and grain of the rock also varies its content of ferromagnesian minerals. Thus a coarse-grained variety from Richthofen on the Swakop River contains abundant biotite with numerous zircons and pleochroic haloes. Muscovite is absent in this rock. Orthoclase and soda-orthoclase by far predominate and acid plagioclase is rare in it. Titanite is absent and there is also very little apatite. Other similar varieties show microcline to be practically the only felspar present, e.g., from near Okatib on the Khan river.

The red granite from south of Trekkopje, where it forms numerous small bodies, contains biotite more sparingly and the felspar is also almost entirely microcline. A little orthoclase and microperthite also occur. Plagioclase is almost entirely absent.

South of Husab there are large outcrops of a finegrained and compact reddish granite containing considerable quantities of biotite mostly altered to pennine with lavender-blue interference colours. The predominant felspar is microcline, but orthoclase is also quite abundant. Plagioclase is very rare. In

addition / .....

addition occur a little muscovite and varying amounts of secondary sericite.

Summarising, these reddish granites are characterised, apart from their colour, by the abundance of microcline, the paucity, even absence of plagioclase and the comparative scarcity of minerals containing appreciable amounts of calcium, such as Sphene and apatite, in general. Most of them are already rather acid and biotite is never nearly as abundant as in the Salem Granite. The quartz frequently shows signs of corrosion and in the western area invariably exhibits strain shadows and other kataclastic phenomena. Compared with the reddish aplitic granites muscovite is rare.

b. GREYISH-WHITE NON-PORPHYRITIC GRANITE:

Of all granites later than the Salem Granite granite, this has the widest distribution. It somewhat resembles that type of Salem Granite in which the typical porphyritic nature of the latter is not very distinct, but may be distinguished from it by its considerably more acid nature and the far lesser content of femic minerals.

The main constituents of this granite are quartz, soda-orthoclase and microcline. In the sections examined by the writer plagioclase (albite-oligoclase), while usually present, is quite subordinate. Biotite is not nearly as abundant as in the Salem Granite and is generally accompanied by muscovite, which occasionally predominates over biotite. Of the accessory minerals zircon is always abundant, apatite much rarer and sphene generally absent. Epidote is often present as an alteration product.

Pneumatolytic / ....

Pneumatolytic minerals, such as muscovite and black tourmaline are far more abundant than in Salem Granite and gradually increase in importance as the differentiation of the magma proceeds. Occasionally schorl is present in such excess that this type of granite passes into a tourmaline granite (Kakausib).

The very large body of granite extending from east of Otjimbingwe along the northern foot of the Khomas highlands past Tsaobis, Donkerhoek and the Arichadamab Mts. far into the Tinkas Game Reserve consists mainly of this type of granite. Around Donker-hoek it forms a very rugged and imposing mountain-land with sheer faces many hundreds of feet in height. Here the granite is of a very light, almost white colour. It is of medium grain, but contains numerous irregular bodies of coarse pegmatite. A highly pneumatolised representative of one of these represents the well-known Tantalite occurrence of Donkerhoek. Microscopic sections of specimens of this granite from Onanis, west of Donkerhoek, show biotite, with pleochroic haloes around zircon inclusions, to be rather sparing. Muscovite in some sections is more abundant than biotite. Most of it metasomatically replaces the felspar. This is particularly clear in the not uncommon micropegmatite, in which the muscovite has often completely replaced the felspar, leaving the quartz as wormlike inclusions. Microcline is by far the predominating felspar, but orthoclase and soda-orthoclase are also abundant. Plagioclase is quite subordinate. The quartz very often exhibits corroded edges and not infrequently also ~~either~~ kataclastic phenomena. Apatite is rare; sphene absent. In one section a very large scale of muscovite encloses numerous parallel needles

of / .....

of sillimanite cutting across its cleavage with about 75°.

At Ubukhoes, along the northern edge of this large massif, the biotite content of the rock is considerably higher, but not hearly as high as in the Salem Granite.

Frequently this type of granite is markedly garnetiferous, also away from marble contacts. Since the garnets are frequently aligned along joint-cracks in the granite or in well marked parallel zones, they are most probably mainly pneumatolytic in origin.

c. APLITIC GRANITES AND APLITES:

With progressive differentiation of the parent magma, the granitic intrusions become more and more acid and at the same time more scattered, less coherent and less extensive.

In addition to typical dyke-aplites there occur numerous bodies, generally of comparatively small extent, of aplitic granite and aplite of varying acidity. Generally these rocks are fine-grained, compact and highly weather-resisting. Hence they frequently form eminences of the Inselberg type.

While most of these rocks consist almost entirely of quartz and alkali-felspar, some varieties still contain varying amounts of biotite, generally with a large number of zircon inclusions. As the acidity, however, increases, biotite becomes more and more inconspicuous and in its stead muscovite very often assumes importance. With the exception of Zircon, accessory minerals are very rare. Quartz is always present in great abundance and no syenitic varieties were met with. In most rocks the surface of the

quartz / .....

quartz-grains is markedly corroded. Of the felspars microcline invariably by far predominates, but orthoclase and soda-orthoclase are also abundant and microperthite also occurs. In many types plagioclase is entirely absent and generally the felspar in this case is almost entirely microcline. In others acid plagioclase (albite-acid oligoclase) is present, but always very subordinately. Granophyric intergrowth is common around larger felspar individuals, but no typical granophyres were found.

These aplitic rocks may be divided into two groups according to the colour of the felspar: Red Aplitic granites and aplite and White aplitic granites and aplite.

Red Aplitic Granites and Aplites.

Rocks of this description are very common in the southern portion of the mapped area. On Ukuib a deep-red aplitic rock, macroscopically resembling a granophyre, but showing no granophyric intergrowth under the microscope and consisting practically entirely of quartz and felspar (mainly microcline), is intrusive into Goas Granite.

South and west of Karibib red aplitic rocks are rather widely represented. The very conspicuous dome-shaped hill, a few miles west of the village, is built up by a rock of this type. It is finegrained and in the hand-specimen resembles a sericitic and felspathic quartzite very closely. It contains fair amounts of muscovite replacing felspar (mainly microcline, then orthoclase and microperthite). In the sections examined secondary sericite is very common,

the / .....

the sericitisation beginning along cleavage-cracks of the felspar with the production of narrow parallel films or even in the form of a grid. Numerous dyke-derivatives of this type of rock occur in the same area and at other localities. Many of them so closely resemble reddish felspathic quartzites, that they have more than once been mistaken for such. Where they have been intruded into Chuos Quartzites as narrow dykes parallel to the bedding, a very close inspection indeed is necessary before they are recognised as aplitic dykes. In some cases of this description the microscope alone can decide the question.

Their greatest distribution, however, these reddish rocks experience in the surroundings of the Lower Swakop and Khan Rivers from Husab and Welwitsch westwards. Here they grade into pure-white or yellowish white aplitic rocks and together with the very dark Khan quartzites and a host of dykes of black Karroo-dolerite produce very striking scenic effects. The canyon-walls of the Khan and Swakop rivers in the area of their confluence at Haigamchab represent some of the most striking scenery in South West Africa. (Photos Plate 7) Specimens collected from the Ida Mine near Husab show practically no femic minerals at all and consist entirely of corroded quartz, with marked strain-shadows, and microcline, orthoclase, microperthite and quite subordinate acid plagioclase.

These aplitic rocks are nearly everywhere intersected by numerous irregular bodies and dykes of pegmatite.

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These aplitic rocks are nearly everywhere intersected by numerous irregular bodies and dykes of pegmatite.

White / ....

<u>White Aplitic Granites and Aplites:</u>

In the northern portion of the area under discussion white aplitic rocks are quite common, particularly in the surroundings of the Erongo Mts. It is a peculiar fact that reddish aplitic rocks are almost absent in this region. They have the same mineralogical composition as the rocks just described, the felspars, however being white. This white variety of aplitic rock seems to be considerably more weather-resisting than the reddish type and forms a number of prominent eminences, such as the Okongue Peak (5,800 feet) in the Kompaneno Mts. north of Omaruru, the two mountains known as Grober Gottlieb I and II and the Giftkuppe, a few miles east of Erongo station. At the latter locality the highly acid rock is very white in colour and, owing to a large number of parallel joints dipping at a rather low angle and frequently made use of by subsequent somewhat darker pegmatites, from a distance resembles a stratified crystalline limestone.

Numerous later intrusions of pegmatite are also a feature of these white aplitic bodies.

It has already been stated, that in the area of the confluence of the Khan and Swakop rivers the very widespread reddish aplitic rocks very frequently grade into equally wide-spread white aplitic rocks. The latter are in places pure white in colour and when intruded as sheets closely resemble bands of coarse crystalline limestone, even at a close distance. This rock may be referred to as <u>White Husab "Granite"</u>. It is rather coarse in grain and, except for a few isolated small flakes of chloritised biotite and very little muscovite, consists entirely of quartz and

white / .....

white felspar (microcline, orthoclase, microperthite and very subordinate acid plagioclase). All sections examined exhibit pronounced kataclastic features, such as marked strain shadows of the quartz and fracturing of quartz and felspar. In the neighbourhood of marble bands this rock is frequently garnetiferous.

d. PEGMATITIC GRANITES:

Apart from the innumerable pegmatite-dykes that have invaded the enveloping schists on an enormous scale, there occur numerous bodies of granite highly pegmatitic in nature. They are found as irregular and broad dyke-like bodies, usually along the edge or in the vicinity of earlier intrusions. Very frequently the types of granites already described as Post-Salem Phases are intruded by such irregular and dyke-like bodies to such an extent, that the pegmatitic material by far predominates, and the whole rock is best described as pegmatitic granite.

The rock is always of very coarse grain and presents many of the features of typical pegmatites. Owing, no doubt, to the greater volume of residual magma, the enclosed fugitive constituents did not alter the rock to the same extent as in well-defined pegmatite dykes or smaller bodies, with the result that their pneumatolytic effects are not as concentrated. The rock is, however, usually traversed by additional pegmatite dykes or sheets, which exhibit the usual pneumatolytic phenomena in more concentrated form.

In / .....

In addition to large quartz grains and crystals of alkali felspar, the characteristic mineral of these rocks is muscovite, which frequently occurs in large well-formed books. At several localities it grades into or is replaced by lepidolite. In addition black tourmaline (schorl) is widely distributed. The slopes of hills formed of this type of rock are frequently thickly strewn with fragments and well-formed crystals of schorl, some of exceptional size. Occasionally such crystals exhibit a central core of corroded crystalline quartz, showing that the crystals were formed by the replacement of the latter. Garnets, often in the form of large icositetrahedra aligned in zones parallel to the strike of the pegmatitic bodies, are also very abundant in these rocks, not only when they have invaded marble bands (grossular and andradite or melanite), but also away from the latter (almandine-spessartite).

A very ~~typical~~ characteristic feature of these pegmatitic granites, which necessarily vary greatly from place to place, are abundant feathery and stellar aggregates consisting of cookeite and quartz. Very often a large proportion of the whole rock is altered in this way.

Similarly to the aplitic granites and aplites also the rocks of this group may be divided into White and Red types.

White pegmatitic granites and pegmatites are again most common in the northern portion of the area in the surroundings of the Erongo mountains. Here some of them assume considerable proportions and, on account of their weather-resisting nature, form conspicuous eminences. The most prominent of these

are / .....

are the Omaruru Kop and the Great and Little Kainachab below the western excarpment of the Erongo.

<u>Red Pegmatitic Granites</u>, with pink or deep salmon-red alkali felspars, undergo a marked development in the area south and south-west of Karibib on Okongava, Otjua, Audawib, Neu Schwaben and Habis, and still further south on Anawood and Otjimbingwe. They here form a number of conspicuous hills and ridges, which from a distance closely resemble quartzite ranges. In the Audawib hills rocks of this type are intrusive into the gneisses underlying the Quartzite Series of the Damara System apparently with a sedimentary contact.

Everywhere these rocks are highly pegmatitic and full of muscovite and schorl. They are traversed by innumerable dykes and lenses of more typical pegmatite, which occasionally carry coloured tourmalines, as on Neu Schwaben. The large deposits of lepidolite on Okongava are also situated in a rock of this description.

<u>e. PEGMATITES:</u>

Naturally there is no sharp dividing line between the type of rock just described and typical pegmatites. For the sake of convenience and on account of their economic importance however, dykes and dyke-like bodies of typical pegmatite, which generally intersect the former type of rock in great abundance and often make up a large proportion of its total volume, have been reserved for separate description. They exhibit the usual pneumatolytic phenomena in more concentrated form.

With such a wealth of various types of granite, it is not surprising to find pegmatites to

have / .....

Plate 18

Photo Author

Massive dyke of granite & narrow dykes of pegmatite in schists of Khomas Series, southern edge of large granite massif along Swakop river & foot of Khomas Highlands. Farm Donkerhoek.

Photo Author.

Numerous dykes of pegmatite, partly tin-bearing, in narrow strip of schists, between Carsie Mine & Ebrechts "Mine". Davib Ost, western foot of Erongo Mts.

On righthand margin of photo in background large dyke of Diorite-porphyrite (Erongo). In central background Little Kainachab Hill (pegmatitic granite and intrusive dykes of Granite porphyry + Diorite-porphyrite (Erongo).

have an enormous distribution throughout the Fundamental Complex of South West Africa. As a matter of fact, with the exception of the copper-lead-zinc-vanadium deposits of the Otavi area, the diamondiferous gravels of the southern coastal area and a few unimportant minor deposits, nearly all other known occurrences of minerals of economic value are associated with contacts and pegmatitic derivatives of the granites belonging to the Main Period of intrusion. While a very large number of ore and mineral occurrences has been found, unfortunately the bulk of them are of value only to the mineral-collector. From an economic point of view they have proved very disappointing.

It is not the purpose of this paper to discuss fully the various types of pegmatites and mineral-occurrences associated with them. Only their main features are here indicated in mere outline in order to complete the picture of the main period of granitic intrusion. For fuller information the reader is referred to Wagner (5), Reuning (8) and the detailed description of the tin-bearing pegmatites by Frommurze and Gevers (14 and 15).

Most bodies of Salem Granite and its succeeding phases are accompanied by swarms of pegmatite-dykes. While a great number of pegmatites usually also occur in the parent granite-bodies themselves, particularly in their marginal portions, they attain their greatest development in the enveloping schists. It is a noteworthy fact, that pegmatites are rare in the crystalline limestones so widely distributed throughout the whole area, even when these are in direct contact with the parent granite. Within the schistose rocks, however, they occur in vast numbers, generally in distinct swarms or

groups, / .....

groups, and the presence of these can usually be ascribed to one or more structural features, which will be discussed in the tectonic chapter of this paper. Briefly they are most abundant in narrow strips of schist and in the outer zone of tension around phacolithic bodies of granite. It is also a noticeable fact, that pegmatite dykes are usually very much more abundant at localities, where the dip of the schists is steep, than at places where this is low. They generally conform closely to the strike and dip of the schists.

The thickness of the pegmatite dykes varies from a few inches to 50 feet and more and "blows" of considerable width are not uncommon. Their length naturally also varies. Some of the dykes of medium width are remarkably consistent.

There exist numerous different varieties of pegmatite according to the nature of subsequent pneumatolytic alterations. The basis of all of them is a coarse-grained rock consisting almost entirely of Quartz and felspar (orthoclase, microcline, albite and microperthite), a large proportion of the latter usually in graphic intergrowth with the former. The felspar is either pure white in colour or pink and salmon-red. In the northern area white pegmatites predominate by far, red pegmatites being mainly distributed in the southern area. It is a noteworthy fact, that the tin bearing pegmatites in the Erongo Area are all white in colour. Not a single tin-bearing red-felspar pegmatite is known to the author in the entire area. At a few localities the preponderance of lepidolite over ordinary muscovite imparts also to the ordinary tin-bearing white-felspar pegmatite a pinkish colouration.

Tourmaline / ......

Tourmaline pegmatites with black Schorl and muscovite pegmatites are by far the most common. Occasionally, as for instance on Neu Schwaben, near Usakos and Aukas and on ~~the~~ Irles' tin claims on Otjimboyo Ost and Otjakatjongo, beautifully coloured tourmalines occur, often banded in alternate zones of green and wine-red. These coloured, lithia-bearing tourmalines are very rarely associated with the ordinary black Schorl, but generally accompany muscovite, lepidolite and cassiterite. Where the two types do occur together, the Schorl can generally be shown to be deposited at an earlier stage of pneumatolysis.

Garnetiferous pegmatites also have a fair distribution. Very commonly the garnet (almandine-spessartite) is associated with Schorl and the available evidence indicates that it is pneumatolytic in nature and similar to black-iron-tourmaline, in general deposited at higher temperatures than most of the other pneumatolytic minerals. On Elliot's claims below the Hohensteine, these iron and manganese-garnets are associated with the iron-manganese phosphate triplite. § Economically the most important are tin-bearing and copper-bearing pegmatites.

The tin-bearing pegmatites have a very wide distribution in the northern portion of the area between the Khan and Ugab rivers. Wherever examined the cassiterite proved to be a secondary mineral metasomatically replacing felspar and quartz. There are several types of tin-bearing pegmatites. Frommurze and Gevers in their paper distinguish the following:-

A. Tin-bearing / ....

Plate 19

Microphoto by Veterinary Research Institute, Onderste Poort, Pretoria

Microphoto of Cassiterite replacing felspar and quartz in tin-bearing pegmatite from Otjimbojo, Erongo Tinfields

Microphoto by Veterinary Research Institute, Onderste Poort, Pretoria

Microphoto of Cassiterite replacing felspar & quartz in tin-bearing pegmatite from Tsomtsaub. Erongo Tinfields

A. <u>Tin-bearing pegmatites situated in the parent granite.</u> In them the cassiterite occurs directly associated and even intergrown with black tourmaline. The cassiterite is very dark in colour. Occurrences of this type are not frequent.

B. <u>Tin-bearing pegmatites situated in the adjoining schists</u>: These represent the bulk of all occurrences. They may be further sub-divided into -

(a) Pegmatites containing cassiterite associated with a large amount of albitisation of the potash-felspars and unaccompanied by greisenisation and tourmalinisation on any extensive scale.

(b) The ordinary common type of tin-bearing pegmatite, containing cassiterite accompanied by generally abundant muscovite and less abundant coloured tourmalines.

(c) Intensely greisenised pegmatites associated with intrusive bodies of pegmatitic quartz. At Mubeb, south of the Otjipatera Mt., there is an occurrence of this description. Occasionally cassiterite in these deposits is accompanied by triplite, <u>as at Sandamab and Kudubis.</u>

In general there exist well-marked metallogenetic zones. The pegmatites situated in the marginal portion of the parent granite and in schists of the immediate neighbourhood of the contact are generally full of black tourmaline with only sparingly distributed muscovite and devoid of cassiterite. At varying distances from the contact the black tourmaline disappears or becomes inconspicuous and muscovite becomes predominant. Associated with it occur cassiterite, wolframite and tantalite.

The / .....

The effects of the temperature gradient are thus well-marked.

Pegmatites with large books of muscovite are not rare. At Karub, on the railway line from Usakos to Swakopmund, a red-felspar pegmatite along a marble-contact contains considerable amounts of large plates of biotite. Associated with it occur garnet (grossular), epidote and diopside.

It has already been stated that at several localities the muscovite-greisen, tin-bearing or otherwise, passes into lepidolite-greisen, generally with abundant topaz. In the area immediately south and east of Karibib there occur large lenses consisting almost entirely of lepidolite.

Copper-bearing pegmatites are also fairly abundant, but have all proved disappointing. One of the largest occurrences of this type was worked at the Kahn Mine. The pegmatite here possesses a red felspar (orthoclase) and contains rather abundant hornblende, some mica and occasionally large crystals of apatite. The ore is copper-glance (upper levels), copper pyrites and bornite. Other pegmatitic and contact-pneumatolytic copper occurrences in the southern region are the Henderson and Ehlers' "Mine" near Usakos; several small occurrences on Ubib-Tsawisis; the Idamine near Husab (limestone-contact and adjoining pegmatite with scheelite, molybdenite and small amounts of uranium ore); Pforte (scheelite and wolframite); the Pot Mine near Palmtal (scheelite, molybdenite and a little gold) and Gamikaubmund north of the Potberg. The latter occurrence is of contact-pneumatolytic type and shows a heavy development of garnet and epidote. The ore is: Malachite, Azurite, Cuprite (zone of oxidation) and Copper pyrites, Bornite and Chalcocite. Large flakes of molybdenite also occur.

Pegmatites containing minerals of Tantalum, Niobium, Uranium and rare earths: It has already been mentioned that the cassiterite in the ordinary greisenised pegmatites is not infrequently accompanied by small amounts of tantalite and wolframite. Occasionally, as on Ploeger's claims south of the Brandberg, tantalite alone is present.

A very interesting, unusual type of pegmatite occurs on Donkerhoek. A pegmatitic blow of considerable size has been intensely altered pneumatolytically with the deposition of muscovite, lepodolite, Beryl, Tantalite, Niobite, Blomstrandite, black and blue tourmaline, apatite and garnet. A considerable portion of the rock consists of a dense aggregate of Rabenglimmer enclosing crystals of black tourmaline, green Beryl and red garnet. Albitisation of the original pegmatite is particularly marked at this occurrence. A large portion of the original pegmatite has been altered to a cellular aggregate of intersecting plates and lamellae of albite. Mainly with the latter are associated blue tourmalines.

Pegmatites with Beryl and Rose-quartz:

Bodies of pegmatitic quartz of varying dimensions are common throughout the Erongo tinfields and the southern and western portions of the area under discussion. Rose-quartz is particularly abundant in the surroundings of Rössing and Arandis. A few miles north of the latter locality there is a veritable hill of beautifully coloured rose-quartz. The mineral is associated with white pegmatites, which near Rössing contain large amounts of greenish Beryl, partly also in the form of greenish-blue aquamarine and more rarely of honey-yellow heliodore. The latter contains a small admixture of Uranium and is hence slightly radioactive. Associated with the Beryls occur small amounts of topaz, Wolframite, Tantalite, Niobite and Fluorite.

In the same region, particularly abundant in the surroundings of the Rössingberg, numerous irregular bodies of pegmatitic quartz, associated with the same pegmatites as the rose-quartz already mentioned, contain fair amounts of Ilmenite. Specimens of this mineral from south of Arandis are markedly radioactive.

Also in the area north and south of Arandis occur several small bodies of pegmatite containing abundant large crystals of apatite.

VII. Composite gneisses and hybrid rocks.

It has already been stated elsewhere that the degree of metamorphism of all rocks constituting the Fundamental Complex is very much greater in the coastal area than further inland. In addition the sedimentary components have been intruded by various gneisses and granites, mostly belonging to the main period of granitic intrusion and post-Damara in age, to such an extent that hybrid and mixed rocks are very common and often preponderate over the pure sediments. These features necessarily complicated the mapping along the western margin of the map considerably. While the very resistive marble-bands also in this region are well-developed and easily discernable, the schistose rocks have mostly been altered beyond recognition and transformed into mixed and hybrid rocks and composite gneisses. On the accompanying map these are grouped together irrespective of horizon and age. It is altogether impossible in this region to distinguish the schistose rocks of the Damara System from those of the Abbabis System, which may be present among the rocks underlying the marble horizon of the former.

Apart from the Marble and Quartzite Series of the Damara System and some large intrusions of Post-Damara granite, the Fundamental Complex in the coastal area has therefore largely been reduced to a variety of gneissose hybrid-rocks and composite gneisses. It must be pointed out in this connection, that the bulk of the gneissose rocks so widely represented in the coastal area do not belong to older Systems than those described in this paper from further inland. The older literature describing these rocks contains several such suggestions. It is a wellknown fact that the degree of metamorphism

may greatly vary from place to place and is no absolute criterion in assessing the age of various rocks.
In this particular portion of South West Africa it can be demonstrated that the majority of gneissose rocks outcropping in the coastal area pass into the sediments and granites, exhibiting far less intense degrees of metamorphism, further inland. Such terms as "Gneiss-horizon", denoting an assumed older group of rocks, are therefore highly inappropriate and misleading.

Even in the normal area of the interior extensive lit-par-lit intrusion of schistose rocks by normal granites may occasionally lead to subgneissose and gneissoid rocks. There are quite extensive outcrops of such rocks immediately south of Karibib, underlying the Marble-ridge that encircles the north-eastern portion of the Okongava. The quartzite horizon is here locally absent and the crystalline limestones are underlain by dark biotite-schists, amphibole-schists and para-amphibolites. At the Okongava Pforte a reddish post-Damara granite can be seen to vein these rocks in lit-par-lit fashion with the production of a gneissoid hybrid-rock. Since the abundant lamellae of biotite in such rocks provide planes of easy gliding, it is not surprising that tectonic stresses have been more effective in deforming the enclosed felspar crystals and that kataclastic phenomena are more abundant in these rocks than in large masses of compact granite. The more mobile hybrid rocks may in this connection be likened to shock-absorbers. A similar feature is the frequently pronounced platy texture, foliation and even distinct gneissosity in the marginal portions of larger bodies of granite, which in the interior portions possesses the normal granoblastic texture.

VIII. Progressive differentiation of the Magma.

The order of succession and the mineralogical composition of the various rocks belonging to the main period of granitic intrusion form an excellent illustration of the progressive differentiation of a single parent magma.

The earliest fractions to arrive in that portion of the crust now exposed by denudation are intermediate and subbasic rocks: various types of diorites, including quartz-diorites, with subordinate hornblendites and quartz-hornblendites. Differentiation under special conditions also resulted in the production of small isolated bodies of anorthosite. In these rocks plagioclase is by far predominant and ranges down to acid labradorite.

Then follow, frequently by gradation, granodiorites and hornblende granites, in which acid plagioclase, ranging from albite-oligoclase to andesine, sometimes still slightly predominates or is present in more or less equal proportion with orthoclase, microcline and soda orthoclase. Invariably acid plagioclase is still very conspicuous.

Then vast volumes of biotite-granites (Salem) were intruded, generally markedly porphyritic. In most sections examined by the writer these rocks still contain appreciable amounts of very acid plagioclase (albite-oligoclase) and in the area mapped the Salem granite is a normal calc-alkaligranite. It has already been stated that the high biotite-content of some varities of Salem granite is partly due to the assimilation of considerable amounts of biotite-schist. In the same connection it was described how its marked porphyritic texture in part at least also is due to assimilative processes, during which, with progressive assimilation and enlargement of the space occupied by the magma, the felspar crystals newly formed between the marginal biotite-lamellae drifted from the sides of the body of magma into its interior. Being the first fraction to be intruded on an extensive scale and in close conformability to the structural plan of the sediments, the Salem granite had a far better opportunity to effect assimilation than the later phases, which were emplaced after the sediments had already been consolidated to a much higher degree.

The post-Salem phases represent successive fractions of gradually increasing acidity. Femic minerals are on the whole rare in them and gradually disappear as the acidity increases. Calcium-bearing acid plagioclase (oligoclase) is now also rare and often entirely absent. The sections investigated by the author indicate that most of these rocks represent alkali-granites according to the classification in use. This is an instance of calc-alkali and alkali-granite being derived from the same parent magma and not belonging to different provinces.

As the biotite-content in these rocks recedes and finally becomes inconspicuous, muscovite gradually increases in importance and in the final fractions (pegmatites and to a lesser extent aplites) often is a main constituent. Even in the precursory acid granites it is almost invariably seen to have resulted from the replacement of potash-felspars. The admixed gaseous constituents of the magma therefore gradually became more and more concentrated.

In this connection it is interesting to note that together with the decrease of calcium-bearing plagioclase and hornblende in the slides examined, other calcium-bearing minerals also gradually dwindle away. Thus in the diorites and associated hornblendites, as well as in the granodiorites and hornblende granites, sphene or titanite and also apatite are exceedingly abundant and form a characteristic feature of the rock, particularly the former. In the Goas granite both minerals are still very conspicuous. In the Salem granite sphene is quite inconspicuous and also the apatite very much reduced, zircon being the main accessory constituent. In the post-Salem phases also apatite dwindles away and frequently is almost entirely absent.

The Main Period of granitic intrusion therefore presents an exceptionally clear example of mineralogical changes in related igneous rocks and of progressive differentiation as a whole. The latter can be followed over a long successive series of mainly granitic rocks representing the liquid-magmatic stage and their pegmatitic derivatives, in which exceedingly varied pneumatolytic processes can be studied with a remarkably clarity of detail, right down to the hydrothermal stage with its innumerable quartz-stringers in the schistose rocks of the Khomas Highlands. There are probably few countries, in which there exist such unique exposures of a wealth of different types of pegmatites and where mineral-zoning is so pronounced. With the progress of investigation South West Africa should become a classic country for the study of mineral-paragenesis in pegmatites. The remarkable

wealth.....

wealth of exposures allow of the interconnection of certain phenomena, which in less arid climes with exposures more sparingly distributed appear more disconnected and incoherent. Detailed investigations in this field particularly stress the continuity of the process of magmatic intrusion and solidification and above all the importance of the temperature-gradient in the production of mineral-zones. Gradual gradations are the rule and abrupt changes the exception. Schematic systematisation is always untrue to nature.

E.....

E. TECTONICS AND MECHANISM OF MAGMATIC INTRUSION.

The ancient sediments of the Fundamental Complex everywhere have been intensely folded and there is evidence to show that they were affected by several periods of upheaval.

(a) Pre-Damara Folding Movements.

The first of these was responsible for the folding of the Abbabis beds. It has already been stated that it has been found almost impossible to unravel the stratigraphic succession of these most ancient sediments, partly on account of the intense interfolding, partly on account of the enormous amount of confusion caused by the intrusion of numerous ortho-gneisses and the production of large areas of composite gneisses.

Since the exposure of the Abbabis System is not very extensive, little detail can be gathered about these early folding movements. Already they appear to have had a predominantly northeast-southwesterly trend. As far as can be made out the tectonic upheaval was accompanied by the intrusion of the main bulk of pre-Damara orthogneisses and the production of the hybrid rocks, later altered to composite gneisses.

It has occasionally been stated, that the foundation rocks of the Damara System already must have been highly metamorphosed and rendered gneissose before the latter were deposited, because the conglomeratic horizon of the latter contain pebbles of highly altered and gneissose rocks. While it is certainly true that in the normal area, i.e. away from the more highly metamorphosed coastal area, the schistose rocks and limestones of the Abbabis System possess a higher crystallin-ity than those of the Damara System and that the pre-Damara igneous rocks are universally gneissose, while those of the Main Period of granitic intrusion are not or only in certain regions, nevertheless it is apparent that the pebbles of the conglomeratic layers of the Damara System were also metamorphosed together with the whole group.

A/...

A large part of their crystallinity and metamorphism is, therefore, probably a subsequent feature, impressed on them after their embedding. That this is so, is shown by the following facts : It has already been commented on, that in the case of those pebbles and boulders from the Chuos Tillite, of which the parent rock in the Abbabis System or among the pre-Damara gneisses is known, they invariably exhibit a lower degree of general metamorphism and gneissosity than that of the parent rock <u>en masse</u>. This peculiar feature can only be explained by assuming that, when the pre-Damara rocks were being eroded by ice and rock-fragments embedded to form moraines of younger age, they were not nearly as metamorphosed as they are to-day. In addition it stands to reason that small rock-fragments enclosed by a great thickness of plastic and yielding clay or silt will be better protected against subsequent tectonic and other stresses, such as load, and against heat-effects, than the massive and coherent body of the parent rock.

Another point worth mentioning in this connection is the fact, that at the foot of the Otjipatera Mountain and generally on Abbabis and its surroundings, the foliation of the hybrid rocks and composite gneisses of the Abbabis System as well as of the intrusive orthogneisses is mostly parallel and conformable to the post-Damara folding. This would suggest, that the rocks concerned had suffered comparatively little load-metamorphism, although, of course, a considerable amount of contact metamorphism must have been effected by the intrusion of the pre-Damara gneisses and at least some dynamic metamorphism by the pre-Damara folding movements, and that the greater part of the present degree of crystallinity and gneissosity was impressed on them by the vast post-Damara orogenic ~~period~~ upheaval.

(b) /...

The Main
(b) / Post-Damara Orogenic Period.

The latter represents by far the most colossal upheaval, which the African continent ever experienced, particular--ly since it was accompanied by magmatic intrusion on a scale, that not only was never equalled, but in comparison with which all later intrusive periods dwindle into insignificance. As a matter of fact, both processes of this period combined gave birth to the African continent. In magnitude and effect this upheaval can only be compared with the Laurentian revolution closing the Archean era in North America.

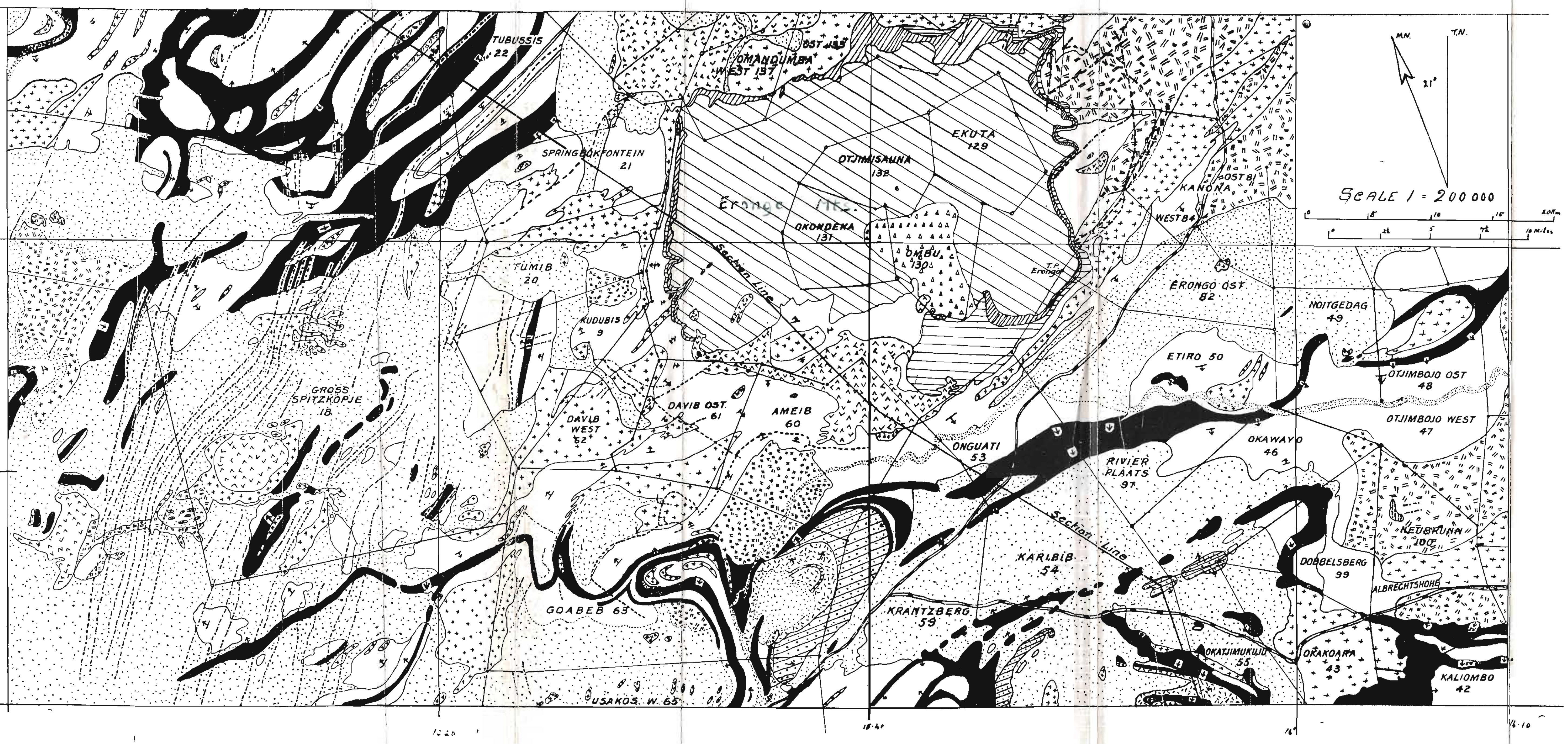
Since the main period of granitic intrusion no doubt was a long-continued process and since all its constituent igneous rocks from the first to the last phases, including the very last pegmatites, exhibit unquestionable evidence for intrusion and solidification under tectonic control, the folding movements must have been of very long duration.

The general strike of the sediments of the Fundamental Complex including those of the Abbabis beds throughout the central and northern portions of South West Africa is NE.-S.W. This strike is, however, by no means constant and the sediments deviate from it to an extent, that at once suggests the marked influence of multilateral stresses. Sudden changes into directions at right angles to the general strike are characteris--tic features of the structural plan of these ancient sediments. Excellent examples are afforded by the marble ridges of the Kampaneno Mountains north of Omaruru (Map, Fig.3) and the complicated marble "dome" on Goabeb between the Khan River and the Kudukuppe (Map, Fig. 2). Locally the sediments are powerfully ruptured and dislocated in such right-angle folds and also heavily intruded by igneous rocks. The irregularity of the folding movements is particularly well demonstrated by the outcrops of the bands of crystalline limestone constituting the Marble Series. The individual bands frequently meander

about /...

Plate 20

Fig. #1



- Surface Deposits (sand, surface-limestone, gravel, etc.).
- Erongo Granite.
- Diorite.
- Porphyrite and Porphyry Flows.
- Melaphyre and Diabase Flows.
- Erongo Sediments (probably Karroo)
- Schists.
- Marbles.
- Quartzites.

} Damara System

- Pegmatitic, Aplitic, Non-Porphyritic and Red Granite.
- Salem Granite.
- Gneissose Granite and Gneiss (composite)
- Diabase and Dolerite Dykes.
- Diabase and Dolerite Sills.
- Granite-, Diorite—and Quartz-Porphyry Dykes.

GEOLOGICAL MAP OF THE AREA AROUND THE ERONGO MOUNTAINS

Mapped by H.F. Frommurze and T.W. Gevers. 1928 about in a most bewildering manner, often producing an intricate network, a veritable maze of one and the same marble band(Map, Fig. 1).

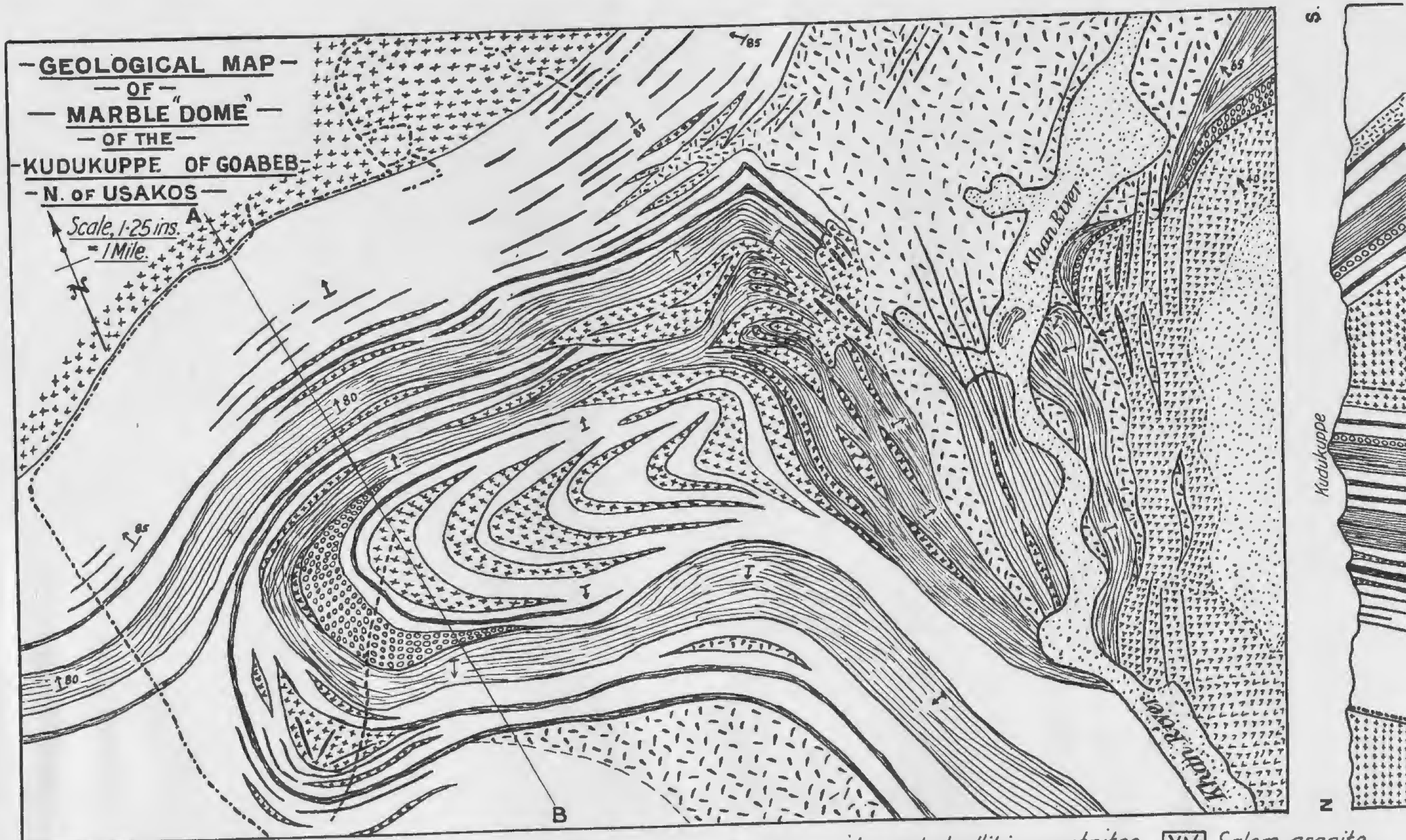
Apart from these very marked deviations, the folding is on the whole very irregular. Long continuous folds in the form of regular synclines and anticlines are rare. Where they do occur, they are usually complicated by minor additional folds, which render even the more regular and consistent folds complex. A characteristic feature are numerous domes separated by irregular basins, and meandering anticlinal ridges, generally of marble, separated by irregular synclinal basins frequently filled by granites. The area north of the Khan river around Arandis, Trekkopje and Ebony on the large accompanying map illustrates these features in a very clear way.

The north-western and northern limbs of syn- and anti--clines generally possess a very much steeper dip than the south--eastern and southern. Actual overfolding is very common and mostly directed from the S. E. and S. to the N.W. and N. The dominant stress during the folding movements, therefore, come from the S.E. and S.

The complex nature of the folding, however, and the features already described immediately suggest, that the stresses were not entirely unilateral. On the contrary, it is apparent, that the sediments when folded were not free to yield laterally, but experienced a considerable amount of resistance also in a direction at right angles to the dominant stress, or, in other words that they were subjected to multilateral stresses. Hence the bewildering irregularity of the folds.

If sediments are compressed in one direction only and are entirely free to yield sideways in a direction at right angles to the stress, long continuous folds of great regularity result. The tendency of a single stress in one direction only is to reduce the width of outcrop in the direction parallel to the stress and extend it in the direction at right angles to

Plate 21



Mica Schists, Marble, Quartzite, Gneissose Arkoses, grits and phyllitic quartzites, Salem granite, Non-porphyritic granite, —— Pegmatites, -·-·- Quartz porphyry, ... Diabase, Sand, gravels & surface limestone

FIG. 2

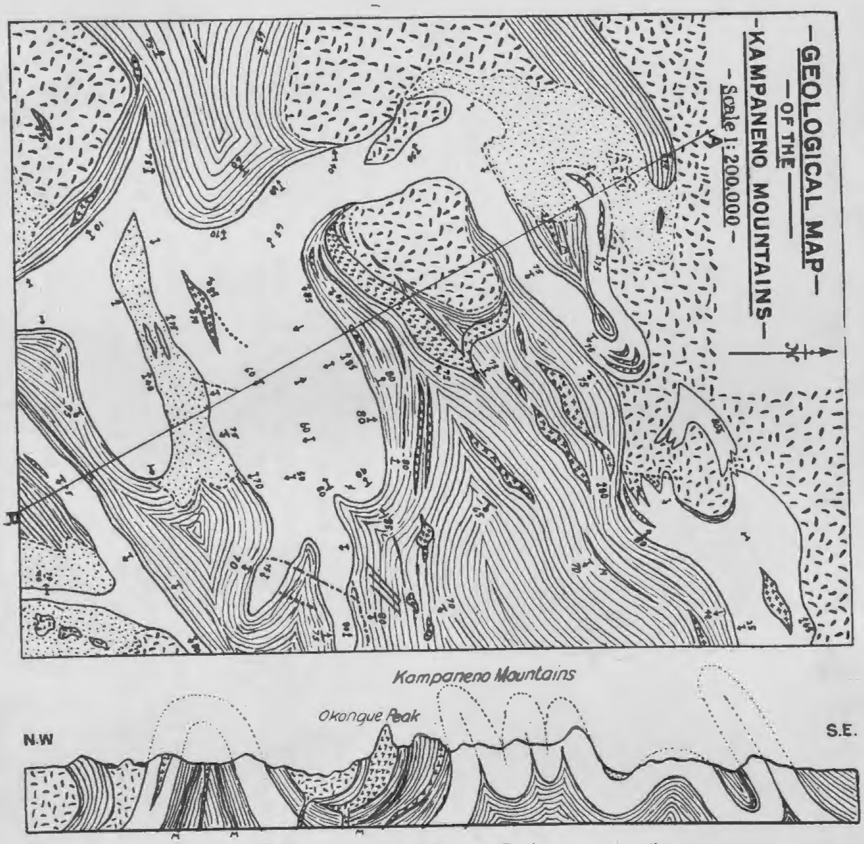
the latter, in which direction an active strain is operating. In the case of multilateral stresses, however, particularly if the sediments are also compressed by stresses operating at right angles to the dominant stress, the rocks are not free to yield sideways and the resultants of these lateral stresses produce movements, that are mainly directed upwards. The whole block of sediments is as a result buckled up in an irregular way and hence the large number of dome-like structures, which characterise the tectonic plan of these ancient sediments. Their convexity, outline and direction of elongation naturally depend on the relative strength of the operating stresses at any one point. The tendency of multilateral stresses, therefore is not to reduce the width of outcrop in one direction only and extend it in a direction at right angles to the former, but generally to reduce the circumference and surface extent of the whole area of outcrop, and to increase the vertical thickness of the folded rocks. This same circumferential compression and the resultant of multilateral stresses, the effect of which is to produce movements mainly directed upwards, would naturally also concentrate any highly mobile magmatic material at their disposal into such dome-like structures and it is not surprising, therefore, frequently to find the latter particularly heavily intruded by granite (Map, fig.2).

One of the largest and most complex dome-like structures of this description are the Kampaneno or Tjirundu Mountains North of Omaruru, in which the Marble Series has been strongly arched upwards and bent about in an extraordinary fashion (Map, Fig.3). The whole structure could, perhaps, be referred to as an irregular compound dome.

Very complex folding is also evidenced by the area between the Chuosberg range and the Swakop River around Dorstrivier and Sphinx (Large accompanying Map). Here there are

two /...

FIG. 8



Section A–B (Vertical Scale exaggerated)

Schists, Marble. Salem granite, Non-porphyritic granite, Aplitic granite, Pegmatite, Narrow Marble band, Diabase dykes. Quartz-Porphyry dykes Sand and surface limestone.

Mapped by T. W. Gevers, 1928

Plate 22

two small perfect domes of marble. At the site of a sudden right angle bend, a few miles south of the road from Dorstrivier to Sphinx, the marble horizon has been thickened into a block several kilometres in width. This is partly the result of folding (compressed basins and domes), partly no doubt, however, also due to rock-flowage into the areas of minimum stress, particularly since the marble-bands only a few miles to the east and west are quite narrow. It is a well-known fact, that plastic rocks are often attenuated and even completely drawn out in the limbs of anticlines and synclines and thickened in the crests of the former and the floors of the latter.

In this connection another interesting feature may be pointed out. It is the extreme paucity of lines of disloca--tion or faults of any appreciable throw in these highly folded sediments. Their almost complete absence on the large accompany--ing map is not due to obvious difficulties,that might be experienced in locating them in great thicknesses of very uniform rocks. This might hold for the extreme south-eastern corner of the map in the Khomas Highlands and other extensive areas uniformly underlain by schistose rocks without marker beds or by large bodies of granite. Throughout the greater portion of the map, however, the marble horizon forms an excellent marker-bed, which at once would indicate the presence of faults of any considerable throw. The writer at quite a number of localities was struck with the facility with which these now coarse-grained rocks respond to sudden and abrupt changes in the direction of stress without any fracturing worth speaking of.

The key to these phenomena is found in studying the banding of the limestones, or at localities where they enclose large numbers of narrow parallel bands of chert. Beautiful exposures of extensive surfaces of these crystalline limestones are very common under the arid climatic conditions (rainfall in coastal portion of the Namib less than ½ inch per annum). Numerous exposures of this kind show the banding and narrow

chert /...

chert bands to be folded and contorted in an almost incredible manner without the slightest sign of fracturing. The limestones at the time of folding must have been as plastic as dough and it is this extraordinary plasticity, that enabled them to respond in such an elastic way to abrupt changes in the direction of stress. It also no doubt greatly aided the rock-flowage just referred to.

(c) <u>The Mechanism of Magmatic Intrusion</u>.

Throughout the entire area there is abundant evidence to show that the intrusion of the old granites and their pegma--titic derivations was closely associated with the folding of the ancient sediments. There is no doubt, that even the last phase of intrusion, i.e. the swarms of innumerable pegmatites were injected while the folding movements were still in active progress. Not only is this the case, but the intrusion of the granites and pegmatites appear to have been mainly controlled by the tectonic forces operating.

A variety of facts point to this conclusion. To begin with, granites and associated rocks almost invariably closely follow the structural plan of the sediments, even down to the minutest detail. Map, Fig. 4 and the large accompanying map very clearly demonstrate this. The granite intrusions are found either to occur as laccolithic bodies forming the cores of anticlines and domes and conformably filling or forming part of synclines and basins, or as numerous lens-shaped and irregular phacolithic bodies, the outlines of which are determined by the strike and disposition of the sediments. With the exception of the schistose rocks, particularly of the Khomas Series, which are frequently displaced and in part have also been assimilated, the igneous rocks, although preponderating in bulk over the sediments over the greater portion of the mapped area, have left the sedimentary frame intact to an extraordinary degree.

As/...

It has already been pointed out, that they mainly fill separate compartments in a sedimentary skeletal frame.

Conformable and concordant contacts are the rule throughout the entire area. Discordant contacts naturally also occur locally, but are, on the whole, very restricted. So close indeed is the adherence of the igneous intrusions to the tectonic plan of this region, that the magma appears to have been made use of by the tectonic forces operating as a highly mobile and plastic material in filling potential cavities and compartments in the sedimentary skeleton. In accordance herewith granitic material is found with particular abundance in regions of minimum stress, such as in the cores of domes, the crests of anticlines and the floors of basins and synclines.

The very large granite-intrusion along the northern foot of the Khomas Highlands, as far as its contacts are con--cerned, also closely conforms to the strike and dip of the sediments. It seems to be in the nature of a very large and massive sheet wedged in between sediments. The latter are merely disrupted and pushed apart by the granite, the normal succession continuing on each side of the granite-body. The great number of large xenoliths of schists that are found to float in the granite, particularly in the area north of Donkerhoek and Onanis, do not materially affect the sedimentary succession.

That the magma at the time of its emplacement was subjected to tectonic stresses, is further revealed by a study of the ~~texture~~ structure of most granites and their parallel textures. It has already been mentioned, that the Salem granite, particular--ly in smaller bodies, exhibits a pronounced flow-structure. The parallelism of the felspar phenocrysts follows closely not only the tectonic structure in general, but also any sudden and abrupt variation in strike of the enveloping sediments. Micaceous and acid "Schlieren" and all other parallel textures of the granite bodies, as well as incipient foliation, where present, invariably closely conform to the strike and dip of the sediments and thus indicate, that at the time of intrusion the magma was subjected to active stresses.

The fact, that although all parallel textures in the igneous rocks of the main period of granitic intrusion strictly conform to the tectonic plan, but that on the other hand the granites and associated rocks, except sometimes in highly micaceous varieties or more often in hybrid rocks, generally show no trace of foliation, but possess a typical hypidiomorphic granular texture, indicates, that their intrusion was most likely contemporaneous with the later phases of tectonic upheaval.

That it was still controlled by tectonic forces, however, is shown conclusively by numerous very clearly exposed phenomena. Throughout the entire area there is abundant evidence to show that the position, outlines and distribution of granite--bodies and pegmatite dykes are very frequently the direct result of stresses operating on the sedimentary frame and of movements within them. Differential movements in areas of powerful torsion are the principal factor in this connection.

The whole phenomenon is best explained by comparison with a pack of loose, pliable cards bent downwards at their ends. Differential gliding movements take place along the surface of each card and lens-shaped open spaces are formed in the outer arc of tension, while the inner arc represents a zone of compression. If this bending movement is carried out to its full extent, the tension in the outer and the compression in the inner arc will progressively increase and, if the process is carried out in a rigid frame and the card-ends firmly gripped, there will come a point, when the outer cards will break and be pulled apart, while those in the inner arc will crumple up.

This is precisely what has happened in the case of chistose rocks at quite a number of places. An excellent example is afforded by a granite phacolith situated along the Khan river below the northern slopes of the Great Rooiberg,

northeast /...

Plate 23

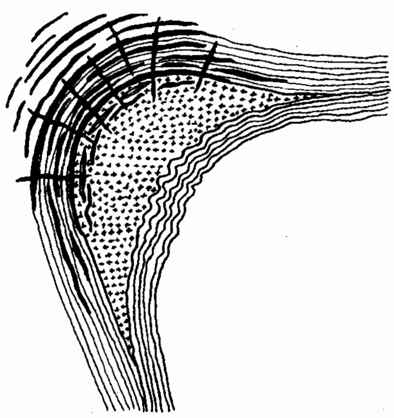


FIG. 4.

Schematic plan of granite phacolith filling space formed by differential movements in schists during bending; also showing abundance of pegmatite dykes in the outer arc of tension.

northeast of Usakos. At this locality all series of the Damara System have been bent into a sharp curve constituting the northern flank of a strongly arched-up dome (Map, Fig.4). The sediments within the inner arc have been powerfully crushed, crumpled up and folded, particularly the schist partings between the marble bands. In the outer arc of the curve, on the other hand, numerous slabs and xenoliths of schists floating in the granite, but still parallel to the strike of the sediments, show that a large amount of disruption took place in the outer region of tension. The granite merely fills the largest open space formed by differential gliding in the strongly bent schists in the form of a phacolithic body. (Fig. 4).

This feature: disrupting and igneous intrusion in the outer strained arc and crushing and crumpling up and an absence of igneous intrusion in the inner arc of compression is continually met with throughout the whole area (Map,Fig.2).

Particularly the numerous dome-like structures, more especially those the elongation of which is at right angles to the general strike, are regions of intense and intimate igneous intrusion. One of the best examples of this nature is the complex area between the Kudukuppe and the Khan river on Goabeb north of Usakos (Map,Fig.2). The sediments here form a sharply bent anticlinal structure with quartzites appearing from under--neath the marbles at theKudukuppe. It is clear that during the formation of such a sharply bent structure, differential movements in the alternating beds of Marble and biotite-schists should produce ideal conditions for magmatic intrusion on an intimate scale. The schistose rocks in consequence are actually riddled with innumerable wedges and lens-shaped phacoliths of granite. No other supposition, but that the granite was intruded contemporaneously with the folding movements, is possible to explain these phenomena.

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The same tectonic factors also have a most important bearing on the question of dyke-intrusion. It is found that pegmatite dykes occur with particular, usually overwhelming abundance in the vicinity of granite-schist contacts where the latter execute a marked bend in strike (Map, Fig.1, Map, Fig.2). Thus on Ameib in the case of the granite-phaco--lith at the foot of the northern slopes of the Great Rooiberg (Fig.4) hardly a single pegmatite dyke is to be found in the inner arc of compression, where the schists are crumpled up, but hundreds of them occur as a distinct swarm in the outer zone of tension. Where the schists straighten out again the pegma--tites become less abundant or even disappear.

While there are large numbers of pegmatites in the parent granite bodies themselves, particularly in their marginal portions, they attain their greatest development in the enve--loping schists. This feature is not surprising. The granite-magma itself being under a powerful pressure and the rock produced on solidification being massive and coherent except for joints, the pegmatitic residual magma, rendered extremely mobile and aided in its upward ascent by concentrated gaseous solutions, found the schists, weakened by innumerable planes of schistosity and bedding, along which differential movements during folding were producing potentially open spaces, far easier to penetrate. For the same reason they avoid the massive and compact bands of marble and quartzite.

Other factors favouring the intrusion of dykes are connected with the close neighbourhood of two or more granite bodies separated by schist wedges of only narrow width. Such a strip of schists is then usually intensely invaded by dykes, but also here it is a noticeable fact, that distinct swarms usually occur in regions where the schist-wedge or strip is bent, even if it be only by a few degrees.

Also /...

parallel, 13 per cent. ar right angles and 8 per cent. at diagonal and oblique angles to the strike of the schists.

While the majority of dykes, whether strike-, cross- or oblique dykes, in any one area show no differentiation with regard to their respective ages, it is a noteworthy fact that dykes obviously somewhat later and cutting across strike-dykes, are usually cross- or oblique-dykes. This fact indicates that after the first injections the sedimentary frame had already become somewhat consolidated by the folding and presence of the at least partly congealed granites and pegmatites and that the lines of smallest resistance and easiest penetration had already been occupied. The later magma was, therefore, obliged to follow joints and fissures across the strike of the sediments. Summarising, there is, therefore, abundant evidence for the contemporaneity of folding and magmatic intrusion during this particular period of upheaval.

(d) The higher degree of metamorphism of the Fundamental Complex in the coastal area.

This feature, first pointed out by Reuning (7), has already been commented on on several occasions. Its manifes-tations have also already been described. There remains, however, its cause.

Wagner (6, p.72 & 83) has already pointed out, that generally the foliation of the schists of sedimentary origin and of the composite gneisses in the coastal area strictly co-incides with the original stratification. This indicates, that a large part of their schistosity "was induced by load-metamorphism before they were folded in a general north-easterly direction". When the enormous thickness of these ancient sediments is taken into account, this fact is not surprising. In the case of a sedimentary group several tens of thousands of metres thick, the lower portions of early sedimentation must be undergoing load and thermo-metamorphism, while the upper beds are still being deposited. In any case, metamorphism,

particularly /...

particularly the initial recrystallisation of the original shales to schists, must have already commenced before dynamic and contact-metamorphism set in with the folding of the sedi--ments and the contemporaneous intrusion by igneous rocks on a vast scale.

That dynamic metamorphism has also been active is shown by the already mentioned fact, that at the foot of the Otjipatera range and elsewhere the foliation of the sediments, composite and orthogneisses of the Abbabis System is in the main parallel to the folds produced by the great post-Damara tectonic upheaval.

What now is the cause of the higher degree of general metamorphism in the coastal area? It cannot be a dynamic one, since in the regions further inland, the sediments have been folded on just as intense a scale.

Features that are different in the two regions are the following : In the coastal area very extensive outcrops of granite are very much rarer than in the interior. It has already been stated that the most extensive outcrops occur between the northern limit of the Khomas Highlands, the Erongo Mountains, the upper Omaruru river and the western margin of the Sandveld. The western portion of the latter is underlain by extensive tracts of granite as proved by boring. In this area sediments entirely recede and occur to a considerable extent in the form of large xenoliths. This area mainly underlain by granites is interruptedly continued parallel to the coast into the southern portion of the Kaokoveld.

Further west, towards and in the coastal area, granites over a large portion of the total region still preponderate over sediments, but here they occur intimately interwoven with the sedimentary frame, mainly filling comparatively small separate compartments in the latter in the form of laccolithic and phaco--lithic bodies, as shown by the large accompanying map and map, fig. 4.

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The extensive granite-tracts of the upland plateau--region have so far not been mapped in detail and a large proport of the contacts are covered by sand. Reuning (7, p.235) inter--prets the phenomena here briefly outlined in the following way:

He considers the whole mass of the rocks belonging to the Main period of granitic intrusion to represent a huge batholith, which has penetrated the crust to the greatest height in the interior uplands. In the latter region the roof of the batholith is said to have been denuded away and the upper portion of the batholith thus to have been exposed. The upper limit of the batholith is then supposed to have a westerly dip, so that in the coastal area deeper portions of the crust are exposed which accordingly and in addition to the sediments being inter--mingled with large amounts of igneous material present a higher degree of metamorphism.

It has already been stated on several occasions, that no typically batholithic bodies of granite have yet been met with in the mapped area, but only laccolithic, phacolithic and sheet--like bodies. The possibility, of course, exists, that in accordance with Reuning's interpreation the latter merely re--present portions of magma squeezed into the sedimentary roof of the batholith by the folding movements, which the batholithic intrusion accompanied; and that these detached portions of magma are underlain in greater depth by a very large batholithic body. This, however, still has to be proved and before no detailed mapping has been done in the extensive granite tracts of the interior uplands, which no doubt will throw considerable light on this problem, the writer considers it to be futile to debate the problem further at the present state of investigation.

There is little doubt, however, that the greater degree of metamorphism of the Fundamental Complex in the coastal area is mainly the result of the greater intermingling of the sediment with magmatic material, which has been intimate enough to produce large areas of mixed and hybrid rocks. Injection- and ~~contact~~

contact-metamorphism have, therefore, probably played the chief rôle in bringing about this excess of metamorphism over the inland region. Load metamorphism may have supplemented the former to some extent, as suggested by Reuning.

(e) The Consistency of Tectonic Directions in South West Africa.

Mention has already been made of the fact, that already in pre-Damara times the sediments of the Abbabis System appear to have been folded in a general N.E.-S.W. direction. During the great post-Damara upheaval this direction was again the general and dominant one, the main stress having come from the S.E. as indicated by overfolding. Following the Damara System there is a vast stratigraphical gap in central South West Africa and the rocks next in age are isolated outcrops of sediments and lavas belonging to the Upper Karroo period. These comparatively youthful sediments have not been folded, but experienced a fair amount of warping and faulting.

One of the largest faults in South West Africa is the Waterberg fault, which has been proved to stretch from the vicinity of the Okavango past the north-western slopes of the Waterberg and Etjo as far as the neighbourhood of Omaruru (Omburo) a length of about 700 Km. At the Etjo it has a throw of several thousand feet, the downthrow being on the south-eastern side. The western continuation of this rupture is represented by hundreds of closely-spaced and parallel dykes of Karroo dolerite or diabase, which continue the direction of the Waterberg fault from Omburo, east of Omaruru, where it apparently terminates as an actual fault, past the northern edge of the Erongo Mountains, past Trekkopje and Arandis and past Haigamchab and Goanikontes as far as the coast near Walvis Bay. (North-western corner of large map).

Since both Stahl (17) and Krenkel(18) assume the fault to continue as such as far as the coast, the writer wishes to stress the point that the marble horizon as an excellent marker-

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marker-bed nowhere in the mapped area indicates any such fault, the dolerites merely filling normal ruptures without any displacement worth speaking of. The abundance and closely spaced nature of this multitude of dolerite-dykes (see north--western corner of large accompanying map and Map, Fig. 4), however, indicates this line to be a zone of weakness in the earth's crust, which subsequent to the intrusion of innumerable dykes of dolerite in the southwestern area developed into a fault of large throw along its continuation ~~in~~ to the north-east~~ern~~ ~~area~~.

It is further of interest to note that also the foci of eruption in late Karroo times and the centres of intrusion of the Erongo granite were evidently influenced by zones of weakness in the earth's crust, which in post-Karroo times partly developed into powerful faults. The former exhibit linear arrangements, which are certainly remarkable.

The universal tectonic direction through central and northern South West Africa, therefore, is N.E.-S.W. from the very earliest tectonic phases in the Archean era right down to post-Karroo times. Only in the extreme north-western corner of the country do the ancient sediments again bend into the N.N.W. direction, which roughly parallels the coast. In accordance therewith post-Karroo faulting and warping also follow that direction in this region.

The southern portion of South West Africa presents dif--ferent features. Here the main folds of the ancient sediments of the Fundamental Complex are oriented slightly west of North, which direction continues across the Orange River into Cape Province. The same axis of folding was then repeated at intervals and at later periods by the tectonic upheavals affecting all younger beds represented. In the Cape Province this direction was followed not only by the folding movements that crumpled up the Malmesbury beds and guided the intrusion of the

Cape /...

Cape granites, but also by the mesozoic upheaval, that built up the Cape Ranges.

But also in the southern portion of South West Africa the N.E.-S.W. direction is evidenced by post-Nama faulting in the Witputz "Graben" and in the "horst" of the Karas Mountains.

The subcontinent, therefore, was consolidated in Archean times along certain definite lines, which have been re--newed again and again during its subsequent history.

According to verbal communication by Dr. Beetz, the turn-in-strike of the ancient sediments of the Fundamental Comple along the coast of South West Africa takes place a little north of Spencer Bay, situated about a third of the distance from Luderitzbucht to Walvis Bay. Here the main tectonic direction, after being oriented a little west of north right up from the southern part of Cape Province, suddenly bends round into the N.E.-S.W. directi which dominates throughout central and northern South West Africa

It would be an interesting and, in the author's mind, a conclusive test of the Wegnerian hypothesis of continental drift to study these phenomena also in South America at the corresponding portion of its east-coast. Should such investiga--tions yield similar and comparable results, they would form a convincing argument in favour of Wegner's hypothesis.

THE AGE OF THE ABBABIS & DAMARA SYSTEMS.

South Africa as one of the old, long-established rigid portions of the earth's crust, in common with Canada and Fennoscandia, exhibits a particularly marked wealth of ancient, unfossiliferous groups of sediments. In spite of great differences of age these are very often of similar petrological facies. While it is generally possible to determine their relative age in any one area, where a number of them occur together or at least are not separated by great intervals, longrange correlation on the other hand invariably presents great difficulties. Correlations based purely on petrographical comparisons are always a very hazardous, if not a futile undertaking. Quite a number of such attempts have later on been shown to be grotesque.

It is therefore impossible to state with any degree of finality the age of any of these ancient sediments when compared with those of other countries. By far the most promising means of arriving at an at least approximate idea of their age is to utilise the principles of diastrophism as developed in North America.

For a fuller discussion of the probable ages of the various groups of ancient sediments in South West Africa, the reader is referred to the important paper of Beetz listed in the annexed bibliography (12).

The old pre-Cambrian Systems of Southern Africa can conveniently be separated into two main divisions: A group of very ancient, generally highly metamorphosed sediments and lavas, which everywhere are intruded by and are therefore older than the oldest wide-spread gneisses and granites; and a group of younger, less highly metamorphosed sediments, which rest upon the latter with

To the first group belong the various members of the Swaziland System in the Union and the Basement Schists of Rhodesia, while the Witwatersrand and Ventersdorp Systems are prominent members of the latter group.

In South West Africa the Abbabis and Damara Systems belong to the first group, while the systems investigated by Beetz in the southern coastal portion of South West Africa (12), namely the Chlorite-schist group, the Phyllite Formation and the Konkip System, belong to the latter. The Kunjas Series of the latter Beetz (12) correllates with the Witwatersrand System, while the mass-eruptions of the Sinclair Series, also part of the Konkip System, bear a strong resemblance to those of the Ventersdorp System of the Union.

If now the principles of diastrophism possess any validity at all, that is to say, if one does not suppose the widespread gneisses and old granites, which cover huge areas of Southern Africa, to have been intruded at widely separated intervals, the Abbabis and Damara Systems of South West Africa can only be correllated with members of the Swaziland System of the Union. The Damara System appears to bear most resemblance to the Kheis Series of the Northern Cape.

It is obvious, of course, that a correllation over greater distances, particularly over a whole ocean, can only be within very wide limits. The writer is fully aware of the limitations of the following attempt to compare the Fundamental Complex of South West Africa with the ancient, well-known Systems of North America. To his mind, however, such a comparison, although it is mainly of theoretical interest, helps to visualise the closely corresponding conditions of sedimentation in that the latter were not so very different from those of much more recent periods. Further it helps to make clear, at what an early epoch of the geological record, as we know it, the Canadian Shield and Southern Africa were consolidated into continental neuclei. The Primitive Systems of Southern and Central Africa record the history of the development of our portion of the earth's crust into the African continent.

North America and Fennoscandia have led the way in setting up a stratigraphy of the Precambrian and the North American classification has become standard throughout the world. It must be realised, however, that the division of pre-Cambrian rocks into Archean and Proterozoic is largely a matter of convenience and usage and only the Principles of Diastrophism lend to it a wider significance.

In Pirsson and Schuchert's Textbook of Geology (1924) the Proterozoic rocks are said to be "not much altered", while those of the Archaen era are stated to be highly altered. No really typical schists, highly altered marbles and gneisses are found in the Proterozoic of North America. On this subdivision the Damara System would without the slightest doubt fall into the Archaean, for all its constituent sediments are highly metamorphosed, typical schists, gneissoid mixed rocks and highly altered tremolitic marbles being characteristic components. But it is a well-known fact that the degree of metamorphism can vary to a surprising degree even in closely neighbouring areas and depends to a large extent on the tectonic history of any particular locality. A classical example is the Lower Cambrian clay of the former Russian Baltic provinces. § ~~It has already been stated that according to Coleman also the Laurentian schield in Proterozoic times has been largely exempt from fold-~~

~~ing and faulting (ibid. p.226). The sediments of the Fundamental Complex of South West Africa on the other hand have been subjected to a maximum of Tectonic stresses.~~

The oldest known North American rocks belong to the Coutchiching Formation consisting mainly of mica-schists and metamorphosed dolomite. The next in age are the schistose rocks interbedded with the highly altered basic lava-flows of the Keewatin. According to Coleman (ibid. p.236) the Doré Conglomerate, the glacial origin of which is considered probable by the same author, also belongs to the Keewatin. Then follow the very widespread rocks of the Grenville Series, generally stated to be also Archaeozoic in age. The most striking part of this series are crystalline limestones or marble, abounding in graphite, mica, hornblende and serpentine. Associated with it are schists and metamorphic quartzites.

These rocks are then followed by the only slightly altered sediments of the Proterozoic. Of the lowest of this group, the Sudburian Series, it is stated, "that their apparently modern nature is the most surprising impression made on the observer." (Pirsson and Schuchert: Textbook of Geology p.162) According to Coleman (ibid. p.229) sediments belonging to this group (the Timiskannian) include a boulder-conglomerate of probably glacial origin. These younger sediments are said to be almost entirely continental and shallow-water deposits. The main characteristic of their upper division, the Keweenawan, are lava flows, mainly basic, of great thickness.

These mass-eruptions Beetz (12) compares with those of the Ventersdorp and middle Konkip (Sinclair Series) Systems of the Union and South West Africa.

commented on by Beetz, further exists between the Proterzoic deposits of N. America and the sedimentary beds of the several South West Africa systems overlying the highly altered rocks of the Abbabis and Damara Systems and underlying the Nama (Chlorite-schist-, Phyllite- and Konkipformations). The bulk of these rocks, in so far as they are not igneous, are shallow-water deposits. Limestones occur, but do not form a dominant feature (Beetz, ibid. p.52, 53, 55).

Comparing the older sedimentary Systems, Abbabis and Damara, with those of North America (Archean: Coutchiching, Keewatin and Grenville Series) lithologically, common features are not hard to look for. In both areas, their constituent rocks are highly metamorphosed, schists, gneissose mixed-rocks and altered limestones predominating. The latter (marbles) are a characteristic of the Grenville series and in the Marble Series of the Damara System identical rocks attain a thickness of several thousand feet. Graphite, which is almost universally disseminated in the sediments of the Grenville Series, is in numerous places also a marked feature of the Marble Series of S.W.A.

The tremendous thickness of the schistose rocks of the Khomas Series of the Damara System (±30000 Metres) suggests marine conditions over a great length of time. Also in the Abbabis beds schistose rocks attain a great thickness. The predominent shallow-water nature of all the succeeding, later sediments shows how far back in geological time and at what early stage in the formation of the earth's crust the nucleus of S. Africa as a continent came into existence.

A comparison based on diastrophic principles yields further interesting results. In N. America the Laurentian revolution closes the Archaen era, all invaded by granite (Laurentian) on a vast scale. In S.W. Africa both Abbabis and Damara Systems have undergone a maximum of tectonic stresses and have been intruded by granites on just as vast a scale. Although All subsequent Precambrian formations are also folded to a considerable extent, nevertheless compared with the former systems the tectonic stresses were far less intense. The folding movements that set in subsequent to the deposition of the sediments of the Damara System and were accompanied by the main granitic intrusion of S.W.Africa without a doubt represent a first-rate revolution, that in magnitude and effect is on a par with the Laurentian upheaval.

Comparing the periods of main granitic intrusion in the two countries, in N. America the Laurentian granite is by far the most widespread and important. No older granites are known, but a second period of granite intrusions accompanied the Algomian Revolution. These later granites are very much more subordinate in extent and effect, but according to Pirsson and Schuchert (Ibid. p.162) "are so much like the Laurentian granites, that it is often very difficult to distinguish the two sets of deepseated instrusives." The Laurentian granites have been rendered gneissose to a considerable extent, but not universally. In S.W.Africa the Salem granite and its later phases (Main period of granitic intrusion, cf. The Geology of N.W. Damaraland, Frommurze & Gevers, 13) by far predominate over all other granites, but on the whole have been rendered gneissose only to a subordinate degree, though fairly extensive areas composed of gneissose types of these granites also occur. In addition, while in N. America the Laurentian granites are the oldest acid intrusives, in S.W.Africa the main period of granite intrusion is preceded by at least one generation of markedly gneissose pre-Damara granite

Granites younger than the Salem also occur, but are very subordinate.

It is somewhat difficult, therefore, to decide, whether the Main Granites of S.W.Africa and the folding, which they accompanied, should be correlated with the Laurentian granites and the Laurentian revolution respectively or the Algoman granites and the Algoman Revolution. Beetz (ibid. p.44) has decided in favour of the latter, but there are several strong arguments in favour of the former correllation. As regards magnitude and effect the two main periods of intrusion of the two countries stand on a par. Very similar is also their mode of intrusion, i.e. both have broken into folded sediments or sediments in the process of being folded, leaving the structure of the latter to a large extent intact. In the central and northern portions of S.W.A. these granites form the filling material to a sedimentary skeleton. In both areas, therefore, where heavily invaded, the sediments, though intruded, mechanically rest or float upon the granites.

Further in N. America the Ep-Archeozoic Interval, following on the Laurentian revolution, forms the long-continued period of active peneplenation of the newly-formed nucleus of the continent and the succeeding Proterozoic sediments are in the main either shallow-water or continental deposits. In S.W.A. the same occurs after the folding of the Damara System and its invasion by the Main Granites (Salem etc.). Although also the Abbabis beds and the granites intruded into them appear to have been folded before the deposition of the sediments of the Damara System and the lowest of these represent continental deposits, nevertheless the middle and tremendously thick upper beds suggest long-continued marine conditions. The nucleus of the continent therefore appears to have been formed with the folding of the Damara beds and their contemporaneous intrusion by the main granites.

For these reasons, therefore, it seems preferable to the writer to correllate the period of intense folding after the deposition of the Damara System and accompanied by the main granitic intrusion with the Laurentian revolution, and the subsequent period of peneplanation with the Ep-Archeozoic interval. The appended table presents the suggested and probable correlations - naturally within very wide limits - in clearer form. It is based to a large extent on that of Beetz (ibid. p.44), the evidence being gathered mainly from the central and northern portions of South West Africa.

TENTATIVE COMPARATIVE STRATIGRAPHIC TABLE.

	S. W. Africa.	North America
Cambrian	Nama System (Cambrian ?)	Cambrian.
	Great Epiproterozoic Interval.	
Killarney Revolution	Konkip System (Auborus series / Sinclair Series / Kumjas Series)	Keweenawan
Late Proterozoic	Pegmatitic and graphic granites, etc.	Post Huronian granite and norite.
	Phyllite Formation	Animikian.
Middle Proterozoic	Chlorite-schist Formation	Huronian (Cobalt Series with Tillite / Bruce Series.
	Ep-Algoman Interval.	
Algoman Revolution.		Algoman Granites
Lower Proterozoic		Sudburian.
	Ep-Archeozoic Interval.	
Laurentian Revolution	Main Granitic Intrusion (Diorite, Salem Granite etc.)	Laurentian granite
Archaen	Damara System (Khomas Series / Marble Series / Chuos Tillite / Quartzite Series)	Keewatin
	Pre-Damara Gneisses	Coutchiching
	Abbabis System.	

Accepting......

Accepting then the N.American division of Pre-Cambrian sediments into Archean and Proterozoic, there seems very little doubt after considering the above evidence, that the Chuos Tillite is Archean in age and considerably older than the Huronian Cobalt or Gowganda Tillite of Canada. It is interesting to note that Coleman, the discoverer of this tillite, records also from N.American deposits of similar age (Keewatin) a boulder-conglomerate (Doré conglomerate) of highly probable glacial origin. Already in these ancient epochs therefore there appear to have been glacial periods of world-wide extent.

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G. THE BIRTH OF THE AFRICAN CONTINENT.

With the gradual extension of geological investigation into the more remote parts of our earth's surface, it is becoming more and more apparent that most of our presentday continents have been built up or have accrued around neuclei, which already existed as rigid blocks at very early periods in the earth's history. Some of them appear to have been formed together with the original crust of the earth, if the theory of Kant-Laplace be accepted.

The writer does not propose to discuss the inner causes of the consolidation of certain portions of the earth's upper crust into particularly rigid blocks. There are several well-known hypotheses, which have attempted this. He merely wishes to stress the point that some of these continental neuclei appear already to have been present as such in the very earliest periods of the geological record. The history of the Fundamental Complex and the succeeding pre-Cambrian sedimentary systems of South West Africa prove this conclusively for the African land-block, the largest of all continental neuclei known, particularly if Wegners hypothesis of continental drift be accepted as true. Very similar evidence is also provided by other ~~portions~~ parts of our sub-continent, in which the thin surface-veneer of younger rocks has been denuded away and where there are extensive exposures of pre-Cambrian rocks. § The sedimentary succession of pre-Cambrian times seems to be particularly varied and complete in South West Africa and....

and this country therefore seems to be destined to throw considerable light on the early history of our continent.

It has already been mentioned that in Central South West Africa the oldest known gneises are intrusive into the oldest known sediments (Abbabis System) and that no trace of the original crust of the ~~original crust of the~~ earth has been found. It is of course obvious that the Abbabis beds must have possessed a rock-foundation on which they were deposited. This obvious fact is in addition clearly demonstrated by the coarse gneissose arkoses, which represent a granitic detritus, and the conglomeratic layers in the latter and the overlying quartzites. Characteristically enough no pebbles derived from sedimentary rocks were found in any of the sedimentary components of the Abbabis System. Supposing no earlier sedimentary group completely denuded away before the deposition of the Abbabis beds to have existed in this region, the latter would represent the earliest sediments formed on this portion of the earth's crust.

The nature of the component rocks indicates that also in those far off times weathering and sedimentation went on under conditions very similar to those of later periods. The coarse pebbly gneissose arkoses no doubt represent a detritus derived from ~~igneous~~ granitic rocks and are obviously of terrestial origin. Already before the deposition of the beds of the Abbabis System and the intrusion of the old gneisses there must have existed a land-surface and the great volume of these rocks suggest it to have been of continental extent. The

great.....

great thickness of the apparently succeeding schistose rocks of the Abbabis System indicate long-continued subsequent marine conditions and a deep submergence of the primaeval land surface. The land as then existing was still in a labile condition and also the subsequent tectonic (pre-Damara) and magmatic (old gneisses) consolidation does not appear to have been sufficient to form a well-consolidated continental neucleus.

For, although in Damara times there must have been a long continued continental period, during which the mountain chains formed by the pre-Damara orogenic period were gradually worn down and great thicknesses of continental and shallow water-deposits were accumulated (Quartzite Series), and even a glacial period with great ice-sheets on a low-lying land-surface led to the accumulation of extensive morainic material and varved clays, the whole land was again submerged and there again followed long-continued marine conditions. The enormous thickness of the Khomas Series (several tens of thousands of metres) indicates how long this marine period must have lasted.

This peaceful period of sedimentation was than terminated by the gigantic post-Damara revolution, during which the sediments, formed no doubt over an enormous interval of time, were crumpled up and folded into high mountain chains and in addition interwoven with vast volumes of magmatic material injected contemporaneously with the later tectonic phases during the main period of granitic intrusion.

This gigantic revolution gave birth to the African continent. The upper crust of this portion of the earth's surface had now been consolidated to su

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an extent, that it remained rigid and comparatively immobile for the rest of geological history. The nucleus of the African continent had now been formed and finally established and during all succeeding periods its rigidity was never seriously shaken.

The era of continental peneplanation now began and most probably this period is contemporaneous with the Ep-Archeozoic Interval of North America. While both Abbabis and Damara Systems contain enormous thicknesses of marine beds, the latter are conspicuously absent in the sedimentary systems that follow the great post-Damara upheaval. All later systems such as the Chlorite-schist group, the Phyllite and Konkip systems are mainly built of terrestial and shallow water deposits so far as their sedimentary components are concerned. Also the comparatively narrow lime-stone horizons in the Konkip do not materially affect this aspect.

Also in the Union the Witwatersrand and the sedimentary components of the Ventersdorp System represent terrestial or shallow-water deposits.

Only once in post-Damara times does our portion of the continent appear to have considerably sunk in level. In Nama-Transvaal times practically the whole subcontinent appears to have been submerged below a shallow sea. The inundation, however, can only have been a shallow one, except perhaps in the southern portion of the Cape Province. The bulk of the Nama beds in South West Africa are of terrestial and shallow-water origin. Except for a marginal portion in lower Dwyka times and minor oscillations of the coast in Cretaceous and later times, the surface of our portion of the continent has been land ever since.

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