SOUTH WEST AFRICA
SUIDWES-AFRIKA

MEMOIR 3

South West Africa Series

The Geology of the Area Around the Khan and Swakop Rivers in South West Africa

by

D. A. M. Smith

Met 'n opsomming in Afrikaans onder die opskrif:
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REPUBLIC OF SOUTH AFRICA, DEPARTMENT OF MINES
GEOLOGICAL SURVEY
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PREFACE

Although the area between the Khan and Swakop Rivers is situated on the fringe of the Namib Desert and forms an insignificant and sparsely populated part of South West Africa, it is of great geological interest. Metamorphism, granitisation and tectonism are intimately related as it lies approximately at the centre of the Damara Eugeosyncline.

After the deposition of the Damara System about 500 million years ago this area was subjected to intense metamorphism which gave rise to various types of granitic rocks. The ultimate product of metamorphism was the formation of pegmatites, some of which are mineralised and of great economic importance, especially in the northeastern portion of the area. At present they yield mainly lithium minerals, beryl and bismuth, and although the production is small, the reserves are considerable.

This memoir and accompanying geological sheet-map supplement the two adjoining maps, Karibib and Omaruru, which were published together with their explanations in 1942 and 1939 respectively, and it is hoped that with the larger map coverage, a better insight into the complex geology of the western Damaraland will be obtained.

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December 1964.

This memoir is published by kind arrangement with, and grateful acknowledgement to the University of Witwatersrand and is based on a thesis submitted for the degree of Doctor of Philosophy in the Faculty of Science of that University.

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THE GEOLOGY OF THE AREA AROUND THE KHAN AND SWAKOP RIVERS IN SOUTH WEST AFRICA

ABSTRACT

A sparsely populated and arid area of some 3000 square miles located in the region of the Khan and Swakop Rivers in South West Africa, was mapped on aerial photographs during 1959 and 1960. It is underlain largely by highly folded and metamorphosed and partially granitised Damara rocks.

Two major morphological units developed under arid conditions are present: an inselberg region and the Namib Plain region. Both of these are deeply dissected by the gorges and tributaries of the Khan and Swakop Rivers which drain the area into the South Atlantic Ocean at Swakopmund.

Rocks of the Precambrian Abbabis Formation outcrop in two anticlinal cores in the area mapped. They consist largely of a quartzofelspathic gneissose group (Abbabis gneiss), a dolomitic marble and calc-silicate group, and a biotite schist group. There are also a few amygdaloidal flows included in the succession. All these rocks are invaded by a number of pegmatites and some basic igneous dykes of uralitised gabbro.

The evidence presented shows that these older rocks were already- highly metamorphosed, invaded by granite and pegmatite as well as folded prior to the deposition of the Nosib Formation and the Damara System.

A description of the stratigraphy and lithology of the Nosib and Damara metasediments consisting of the mainly quartzitic Nosib Formation, the marbles of the Lower Hakos Stage, the Upper Hakos Stage also composed mostly of marbles with a tillite at the base, and the mica schists of the Khomas Series, is followed by a description and discussion of the generation, by ultrametamorphism of igneous rock-types, and the structure and its relation to metamorphism and granitisation.

The interpretation of these features, together with the mineralogical, chemical and detailed structural data derived from their investigation, is as follows:

The Nosib and Damara sediments were deposited in relatively shallow water probably between 500 and 600 million years ago. The lower arenaceous member (Etusis quartzites) was deposited in broad basins on an uneven floor in shallow turbulent waters. The sediments were immature and highly felspathic. Quieter and slightly deeper water conditions developed after the basins had been partially filled. Arenaceous sediments (Khan quartzites) were followed by argillaceous and calcareous deposition (Lower Hakos marbles) after which cold conditions, accompanied by tillite deposition, set in. After retreat of the ice, carbonate alternating with argillaceous sediments was deposited (Upper Hakos Stage) on a flat surface at moderate depths. The final and prolonged phase of argillaceous sedimentation (Khomas schists) was completed prior to the onset of tectonic deformation.

Probably a short time after sedimentation and deep burial of the sediments at present exposed, metamorphism began. It reached amphibolite grades concurrently with the onset of the first phase of fold movements which were directed by compression from the northeast and southwest. These folds eventually developed into large northwest-trending structures which were locally isoclinal and overturned to the southwest. Metamorphism and pegmatite formation continued throughout this phase as well as throughout the following intense compressional fold phase directed from the northwest and southeast, forming local strong interference patterns where early isoclinal folds existed. Metamorphism reached a peak towards the close of the second and major tectonic phase, resulting in the granitisation and local melting and mobilisation of the rocks. The felspathic quartzites of the Nosib Formation were transformed into red granite-gneisses, and the biotite schists and biotitequartz schists of the Khomas Series overlying the marbles of the Hakos Series were transformed into quartzofelspathic biotite gneisses and granites (Salem granites and

gneisses) and quartz diorite rocks. This transformation was largely isochemical. The gneissic rocks were locally mobilised and differentiated (mainly in the east) forming several intrusive dioritic, granitic and pegmatitic bodies. The Hakos marbles were only locally melted and not granitised. Temperature conditions of 600 to 650°C at a depth of about 18 km in the hottest spots at the height of metamorphism are postulated.

After the cessation of metamorphism brittle conditions, accompanied by minor fracturing and wrench faulting, set in. Pegmatitic liquid associated with volatile differentiate concentrations from metamorphic and magmatic rocks was introduced into tensionzones. Lithium-beryllium-bearing pegmatites are associated with these. This phase, followed probably shortly afterwards by uplift and erosion, completed the Damara geosynclinal cycle which is 510 ± 40 million years old.

The character of the rocks in the region mapped, indicates that they were deposited, folded and metamorphosed in the deeper portions of the Damara Eugeosyncline.

A very brief description of the Karroo sediments, extrusives and intrusives is given. The intrusive dykes trending largely north-northeast and east-northeast are mainly typical olivine dolerites emplaced in deep tensional fissures, The Karroo rocks were subsequently all but completely eroded and thin terrestrial superficial deposits were laid down over wide areas.

The economic mineral deposits which are mainly of little economic interest, are described and discussed in the light of their origin. Stratigraphic control on their localisation is marked, and thought to be due both to original sedimentary concentration of elements as well as to subsequent physical and chemical (structural, metasomatic and magmatic) controlling factors.

1. INTRODUCTION

A. GENERAL STATEMENT

The area under review occupies a portion of western Damaraland in the region of the Lower Khan and Swakop Rivers in South West Africa. It comprises some 3000 square miles* of territory bounded roughly by latitudes 22° 00' south in the north and 22° 30' south in the south, and longitudes 15° east in the west and 16° east in the east. This delineation is broken by an extension in the southwest covering the region around the confluence of the Khan and Swakop Rivers, and an extension in the northeast to include the locality in which the more important mineralised pegmatites in the Karibib District occur.

Prior to the present geological survey the areas noted as extensions above had not been covered by published geological maps. The region bounded by latitudes 22° 00' to 22° 30' south and longitudes 15° to 16° east had been mapped in a preliminary reconnaissance fashion only. This work together with the geological surveys of the two published sheets (Omaruru and Karibib) had, however, deciphered the stratigraphy of all but the oldest sequence of rocks.

The present investigation follows on previous field-work by the author as an employee of the Anglo American Prospecting Company, largely because so many extremely interesting problems of metamorphism and petrogenesis became apparent.

B. HUMAN ACTIVITIES AND MEANS OF COMMUNICATION

Apart from the town of Usakos (A. 4) the region is sparsely populated. In the west, in the Namib Desert, there are virtually no inhabitants and only a few small farms located within the gorge of the Lower Swakop River. In the central and eastern areas there are sheep

* 1 square mile=2·59 square kilometres.

and cattle farms of large dimensions, up to ± 100 square miles (64,000 acres) in extent, though generally much less, averaging about 32 square miles. These are inhabited by Europeans with attendant Bantu and Coloured servants. Karakul sheep only are raised in the central areas bordering on the desert. In the extreme east a portion of the more densely populated Otjimbingwe Reserve 104 (C. 5) falls within the area considered. The reserve is populated by Damaras.

Usakos has a total population of 3800 (1957) of which 1500 are Europeans; it is situated on the main railway line from Walvis Bay to Windhoek and serves as a junction for the northern line to Outjo, Tsumeb and Grootfontein.

Communications are generally good. The main rail and road links between the coast at Walvis Bay and Swakopmund and the interior run through the area. In the east there are several good roads leading south from Karibib and Usakos to serve the Otjimbingwe Reserve 104 and areas lying to the south. All the farms have serviceable roads and tracks. In the arid west tracks are few and far between, but most areas are readily accessible with a four-wheel drive vehicle. Flat sand-floored tributaries of the Khan and Swakop Rivers as well as these rivers themselves, serve as ideal roadways for the type of vehicle mentioned. There are many tracks of lesser importance not shown on the map. Some of these may have already become disused.

C. WATER

The area as a whole is poorly watered, as the rainfall is generally extremely low, and the" rivers" are only run-off courses and normally dry. Perennial surface-water occurs at a few points in the Swakop River and at one locality in the middle reaches of the Khan River. Owing to the salinity underground water in the latter is unpotable below a point some 11 miles* downstream from Usakos. Subsurface water in the Swakop River, however, can be relied upon as a sure source of supply at most places. In areas away from the main rivers and east of the desert where most bore-hole water is undrinkable, underground water tapped by means of bore-holes and windmills (generally) forms the chief source of supply. This may be supplemented by short-lived supplies of rain-water from episodic showers. Borehole water here is generally saline though potable. In the western regions, in the Namib, drinking-water can be obtained from railway sidings, the Swakop River, Walvis Bay or Swakopmund.

D. PREVIOUS WORK

That this area is of great geological interest has been known since the last century, but very little intensive geological work was done until 1929. Granite-gneisses in the Lower Khan Gorge were briefly investigated by Pechuël-Loesche in 1886 (Wagner, 1916, p. 34) and by Wulff (1887). Wulff also referred to the petrography of the quartz diorites south of Karibib. The chief interest, however, lay in the mineral occurrences, chiefly of copper, discovered late in the last century.

Voit and Stollreither first described the Khan copper-mine in 1904, and Voit (1904) the Pot and Ubib Mines, giving lateral secretion from the surrounding rocks in which the elements had been precipitated during sedimentation, as the theory of origin. A large number

* 1 mile=1·609 kilometres.

of investigators made reference to the geology and mineral occurrences of this area between 1904 and 1929. Stutzer (1914) again described the Khan Mine, later to be studied in greater detail by Söhnge (1939). Range produced in 1912 a coloured map which does not include the area under discussion, but proved useful to early workers such as Wagner who published his extensive work on "The Geology and Mineral Industry of South-West Africa" in 1916. In this he made many references to mineral occurrences and rock-types in this area. At this time the Pre-Nama rocks were still classified as belonging to the Fundamental Complex comprising gneiss, a schist formation and "intrusive older granites" (Wagner, 1916, p. 33). Further reference to mineral deposits were made by Wagner in 1921 and Reuning in 1923; the latter also made the most notable contribution towards the knowledge of the distribution of the main rock-types of the Basement Complex which he showed on a geological map of the central portion of South West Africa to a scale of 1:2,000,000. Investigations by Cloos in the Erongo added to the knowledge of the younger formations in 1919; and by 1929, following on an attempt by Beetz (1929) to set up a stratigraphic sequence within the Fundamental Complex, the stage was set for more detailed investigations on a regional scale in this portion of western Damaraland.

Detailed mapping in the region commenced in 1927 when the Erongo tin-fields were first investigated by Haughton, Frommurze and Gevers. This work, supplemented by that of Schwellnus and Rossouw, was published in several units of papers and finally as Geological Survey Sheets 71 (Omaruru) and 79 (Karibib). This joint work, together with that by De Kock (1934) in the Rehoboth area, laid the foundation for a more detailed knowledge of the geology of western Damaraland, particularly the stratigraphic succession within the Damara System as well as its structural pattern and intrusives.

In 1929 to 1930, Gevers (1931, 1934 and 1936) extended his work across the Khan and Swakop Rivers to latitude 23° south, establishing the occurrence of a tillite horizon within the Damara System (1931a) and showing the presence of an underlying unconformably group of rocks (Abbabis Formation). Nine sheets covering latitudes 22° to 23° south and longitudes 15° to 16° east were published in 1934 (Gevers, 1934). These maps, together with the accompanying descriptions of stratigraphy, tectonics and intrusives, proved a useful basis for further more detailed work.

Following this period of regional study the area received little attention apart from mineralogical and economic investigations. In 1935 Ramdohr published his mineralogical studies of the Arandis tin-mine (Stiepelmann's Claims). In 1944 and 1946 Nel followed with investigations of pollucite, petalite and amblygonite from pegmatites in the Karibib District, and finally in 1955 Cameron, after a brief visit, wrote on the internal structure of some pegmatites in the Karibib District.

Investigations made by various mining concerns have not been published. These include the prospecting of mineral occurrences (Khan Mine, Henderson Mine, etc.) as well as of large areas. During 1956 to 1957 the Anglo American Prospecting Company mapped some 600 square miles in the Lower Khan Gorge area during a successful search for uranium deposits. The resulting map (Hyman et al., 1957) to a scale of 1 :125,000 in the surveying of which the author took an active part, was used extensively in the compilation of the most southwesterly corner of the present map.

E. PRESENT INVESTIGATION

As previously mentioned, the present investigation follows on earlier field-work carried out by the author as an employee of the Anglo American Prospecting Company.

The area, bounded by latitudes 22° and 22° 30' south and longitudes 15° and 16° east, and its extensions were chosen because of its interesting geology and high percentage of rock outcrop. It was also thought that a more detailed and accurate map of this area would be suitable for publication by the Geological Survey, thereby extending the coverage of the regional maps to a scale of 1:125,000 to the south of the Omaruru and Karibib Sheets.

Mapping of the area was completed on aerial photographs in 1960. The Lower Khan Gorge was mapped on an uncontrolled mosaic to a scale of 1:24,600 compiled by the Anglo American Corp., Ltd. and the remainder on 12 uncontrolled mosaics to a scale of 1:36,000 compiled by the author. For detailed structural mapping in the Khan Mine area photo enlargements to a scale of 1:12,300 were used.

After completion of the field-work, the field-sheets covering the mosaics were reduced photographically on to a farm-boundary map to a scale of 1:100,000 of the Trigonometrical Survey, which did not cover the extreme' west of the area. Here ground control was obtained by plane-table survey by the author. The resulting map is therefore not completely accurate trigonometrically, especially in sectors D. 1 and D. 2.

No large-scale topographical maps of the area exist. The best obtainable are plane-table maps to a scale of 1 :100,000 compiled by the Topographical Section, General Staff Intelligence of the Union Defence Force in 1914, from older German maps. These are of insufficient accuracy for base-map use, but place-names and spot heights were taken from them. These maps do not cover the western portion of the area.

The author is indebted primarily to Professor T.W. Gevers and the Economic Geology Research Unit of the University of the Witwatersrand who supplied the facilities and encouragement for the present undertaking. Appreciation is expressed to the Administration of South West Africa who made a substantial contribution towards the costs; also to the Anglo American Corp., Ltd. and Tsumeb Corp., Ltd. for information and materials placed at the writer's disposal; and to the Geological Survey of the Republic of South Africa and South West Africa for their kind co-operation. Finally the author is indebted to several friends and colleagues for their considerable help and advice.

II. PHYSIOGRAPHY

Climate, drainage, vegetation and morphology are only briefly dealt with here. For a more detailed account readers are referred to the relevant publications by Gevers (1936) and Logan (1960).

A. CLIMAGE, DRAINAGE AND VEGETATION

The climate of the area is generally arid, more so in the west (Namib Desert) than in the east. The average annual rainfall varies from 16. 51 mm* p.a. (over 20 years) at Swakopmund to 51 to 102 mm

* 1 millimetre=0·0394 inch.

in the central areas and to about 102 to 152 mm in the east (Logan, 1960, p. 10-13). Apart from precipitation from the frequent fog in the immediate coastal belt, rainfall, if any, is generally confined to the summer months November to March when it is usually restricted to short-lived downpours. Drought years are common.

At Swakopmund the average temperature for the months December to March, for a 20-year period, was 16.67° C (62° F) and for the remaining months 13, 89° C (57° F). As a result of the cold off-shore Benguella Current the climate is generally cold and damp. Fog generated by the ocean current is occasionally driven as far as 80 miles inland by westerly breezes. "Trade winds" from the south are predominant during October to April. High temperatures on the coast in winter are associated with easterly "föhn" winds originating on the cold interior plateau. Temperatures rise away from the coast, especially in the river canyons where the heat is often excessive at midday. At night temperatures are generally moderate but may, in winter, fall below freezing point.

The whole of the area, with one exception, is drained by the Khan and Swakop Rivers and their tributaries. The area west of the watershed extending from Rössing Mountain (D. 1) to Ebony (B. 3) is drained directly towards the coast. The main rivers merely represent run-off courses from precipitation in the interior. Seldom does water flow in the Khan and Swakop Rivers for more than a few days, but subsurface water is always present at shallow depths.

Vegetation changes from the coast to the interior. Apart from dry river-beds with shallow ground-water, the western areas are almost devoid of vegetation. The only shrubby plants found on the desert flats are *Zygophyllum stapfi* and *Arthraeura leubnitziae*. Besides these the commonest plants here are mesembryanthemum, lithops, aerva and Bushman's candle (*Sarcocaulon burmanni*). *Welwitschia bainesii* abounds on the sandy flats around Welwitsch (D. 2). In the eastern transition-zone where the Namib merges gradually with the bush-clad country of the interior, xerophytic plants such as *Euphorbia gregaria* and *E. virosa*, are found in great abundance. The large aloe (*Aloe dichotoma*) is also quite common. In the east and in the beds of the major rivers larger trees and green shrubs are found. These include the ana (*Acacia albida*), seldom found in the west, camel-thorn (*Acacia giraffae*), bastard camel-thorn (*Acacia maras*), shepherd's-tree (*Boscia pechuela*), hook-thorn (*Acacia detinens*), leadwood, etc. The tamarisk (*Tamarisk austroafricana*) and the bright-green pungent bush locally known as the" waterbos" (*Salvadora persica*) as well as the tsawis bush (*Euclea pseudebenus*) commonly occur in the river-beds.

The contrast in vegetational cover between the run-off slopes or "veld" and the watercourses is always great. The larger types of trees mentioned above are confined exclusively to the shallow ground-water areas of the major river-beds. After good rains the grass cover is quite substantial and sufficient to support sheep and a fair-sized cattle population in the eastern areas.

B. MORPHOLOGY

The area under review includes two well-defined morphological units (see pl. I, II and III). A third unit comprising the Great Escarpment is not prominent here, but is manifest to the south as the west-facing scarp of the Khomas Hochland.

1. THE INSELBERG REGION

This is the major morphological unit here and consists of extensive flats covered with variable thicknesses of superficial deposits through which the underlying rocks project to form prominent hills and mountains. The best examples of inselbergs within the area are Rössing Mountain (D. 1), the Otjipatera (B. 4) and Chuos (C. 3-4) Ranges, though these are not as spectacular as the single well-marked mountain "islands" such as the Gross Spitzkoppe and Erongo Mountains to the north of the area.

The inselberg region as well as the Namib Plain are modified by the drainage of the Khan and Swakop Rivers which are generally deeply incised and bordered by highly eroded and rugged "bad land" areas. Here the younger drainage-pattern and other morphological features are greatly influenced by the rock structure. The maximum depth of incision of these sand-filled canyon floors is about 600 feet* in the Khan River near the Khan Mine (D. 1).

2. THE NAMIB PLAIN

Reaching from the coast some 70 miles inland, this plain rises rapidly with a convex slope to an elevation of some 3600 feet northeast of Ebony (B. 3).

The Namib Plain as such is not very well developed in this area owing largely to the incision of the major rivers. It is best exemplified in the northwest around the Arandis tin-mine (B. 2) and to the south of the lower reaches of the Khan (C-D. 2) and Swakop Rivers (C. 1). This plain, largely covered by superficial deposits, is not an absolute one in that it is transgressed by long, low dolerite and marble ridges. This feature, together with the evidence of terrestrial fluviatile gravel deposits over wide areas, supports the view that the plain is not of marine origin (Wagner, 1916, p. 72; Gevers, 1936, p. 17).

The age and history of these morphological features will be dealt with in a later chapter on stratigraphy and lithology. The geomorphology is typically that developed by arid-cycle erosion and has been adequately described by Gevers (1936, p. 61-79), King (1951, p. 88-97 and 318-322) and Logan (1960).

III. GENERAL GEOLOGY

The area is underlain by rocks and deposits varying in age from Precambrian to Recent. Amongst these the Precambrian formations are by far the most important. Karroo strata are represented by only two small outliers, and the Tertiary and Recent deposits form only terraces and thin superficial covers on the ubiquitous, highly metamorphosed Precambrian rocks.

Amongst the Precambrian formations three major successions have been distinguished. They are from the oldest to the youngest: Abbabis Formation, Nosib Formation and Damara System. The Abbabis Formation is separated from the younger rocks by a phase of metamorphism, granitisation and pegmatite intrusion. The quartzitic Nosib Formation is, in the area under discussion, conformably overlain by the Damara sediments, but is in other areas separated from them by a discordance passing locally into an angular unconformity.

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* 1 foot=0·3048 metre.

The definition and the nomenclature of the Damara System and its subdivisions have been changed considerably. It is therefore necessary to discuss these changes briefly.

The name "Damara System" was given by Krenkel (1928) to the oldest group of sedimentary rocks in South West Africa, whereas a supposedly younger group of metasediments was called "Khomas System". Gevers (1931), recognising the intrusive relationship of the wide-spread granites and gneisses to the rocks of Krenkel's Khomas System, included the latter in the Damara System, but separated from this system a small occurrence of older gneisses under the name "Abbabis System". The Damara System was subdivided into the Khomas Series at the top, the Marble Series in the middle and the Quartzite Series at the base. This whole succession was thought to be considerably older than the preponderantly dolomitic Otavi System of the northern parts of the country.

Towards the end of the 1940's proof was found indicating a correlation between the Damara and the Otavi Systems (Martin, 1961; Truter, 1949). This correlation is now well supported by mapping in the Kaokoveld (Rabie, 1954), in the Fransfontein-Outjo area by Clifford (1959; Clifford, Nicolaysen and Burger, 1962) and in the southern Otavi Mountain-land (Söhnge, 1958; Smit, 1959). The different lithologies of the two sequences can best be understood if they are regarded as miogeosynclinal (the former Otavi System) and eugeosynclinal (Damara System in the sense of Gevers) facies developments in a big geosyncline (Martin, 1961).

The fact that the two systems had to be combined caused uncertainties concerning the naming of the system and its subdivisions. Clifford (Clifford, Nicolaysen and Burger, 1962) suggested the name "Outjo System" and the names "Otavi Facies" and "Damara Facies" for the former Otavi and Damara Systems, respectively. The Geological Survey experimented with the terms "Northern Facies" and "Southern Facies" (Martin, 1961) which were, however, found unsatisfactory. It has now been decided to keep the name "Damara" for the system as a whole and to use the terms "Swakop Facies" for the eugeosynclinal succession (former restricted Damara System) and "Outjo Facies" for the miogeosync1inal deposits (formerly Otavi System).

Regarding the subdivisions a further complication arose. Mapping in the Otavi Mountains (Söhnge, 1964; Smit, 1959), the Kaokoveld (Rabie, 1954) and the Windhoek District (Schalk, 1961) has shown that in most areas a discordance, locally passing into an angular unconformity, separates the predominantly quartzitic, basal formation from the higher portion of the Damara System. The quartzitic formation had been called "Quartzite Series" (Gevers, 1931 and 1934) in the central part of the country, "Nosib Series" (Hermann, 1908) in the Otavi Mountains and "Hundskopf Formation" in the Kaokoveld (Stahl, 1926). Subsequently Stahl (1940, p. 38) recognised the equivalence of this formation with the Nosib "Series" and used the latter name. In 1954 the Geological Survey (Union of South Africa, Department of Mines, 1954, p. 137-138), unaware of Stahl's paper of 1940, substituted the name "Hundskopf Formation" for the quartzitic sequences which had been called "Nosib Series" and "Quartzite Series", respectively, and separated this formation because of the unconformity from the overlying Damara System. The name "Nosib" having priority over "Hundskopf" it has now been decided to use the former name for this formation. In the area under consideration no unconformity between the Nosib Formation and the Damara System has been found despite the fact that the contact between the two is excellently exposed over great distances. This separation of the Nosib Formation from the Damara System is therefore entirely based on evidence gained outside the area under discussion.

With regard to the subdivisions of the Damara System (as defined now) the petrographical name "Marble Series" was found unsatisfactory. It has been substituted for by the name "Hakos Series" the name being taken from the Hakos Mountain in the Rehoboth District.

The following table gives the old and the new names:

Former name		New name	
Khomas Series	Damara System	Khomas Series	Swakop Facies of the Damara System
Marble Series		Hakos Series	
Quartzite Series		Nosib Formation	

The Hakos Series has been further subdivided into an upper stage, a middle or Chuos Stage and a lower stage. In most of the areas which have been mapped, the tillite of the Chuos Stage rests with a discordance on the underlying formations. In the area under discussion no discordance is recognisable, but the tillite shows a transgressive overlap from the Lower Hakos Stage over the Nosib Formation on to the Abbabis gneisses.

The following main subdivisions have been recognised in the area:

Quaternary and Tertiary			Aeolian sand; Scree deposits, eluvial and alluvial unconsolidated and calcrete-cemented sand and gravel; High-level calcrete terrace deposits
		Unconformity	
Post-Karroo			Dolerite dykes
Karroo System	Stormberg Series		Basalt overlying shale
		Unconformity	
Late to Post-kinematic			Granite and pegmatite
Swakop Facies of Damara System	Khomas Series		Quartzofelspathic biotite schist, gneiss and granite
	Hakos Series	Upper Stage	Dolomitic marble with intercalations of biotite schist and amphibole schist
		Middle or Chuos Stage	Tillite
			Transgressive overlap
		Lower Stage	Dolomitic marble, quartzite, intercalations of biotite schist
Nosib Formation		Upper Stage	Quartzite, amphibole granulite, biotite-quartz schist
		Lower Stage	Felspathic and pure quartzite, intercalated biotite schist
		Unconformity	
Abbabis Formation			Gneiss, biotite schist, local calc-silicate rock

IV. AN OUTLINE OF THE GEOLOGY OF THE AREA

The area under discussion is underlain almost entirely by highly folded and regionally metamorphosed rocks of the Swakop Facies of the Damara System and the Nosib Formation. The basement on which they were deposited, is composed of quartzofelspathic biotite gneisses and schists with subordinate para- and ortho-amphibolites, marbles and calc-silicate rocks of the Precambrian Abbabis Formation which outcrops in anticlinal cores in sectors B. 1 and B. 4 of the accompanying regional map. Pebbles of these rocks in overlying strata, i.e. the basal conglomerate and Chuos tillite, indicate that they had undergone metamorphism and had been intruded by granite and pegmatites prior to the deposition of the Nosib Formation and the Damara System. The degree of folding to which they were previously subjected, is difficult to determine.

An outline of the stratigraphy, lithology, metamorphism and granitisation and their relation to the mineralisation of this region is given in table 1.

V. THE ABBABIS FORMATION

A. INTRODUCTION

The rocks underlying the Nosib Formation and the Damara System in the area under discussion form less than 5 per cent of the total rock outcrop. They comprise highly metamorphosed heterogeneous types and have received less attention from the author than the overlying formations. The following description contains some repetition of a previous study by Gevers (1931, p. 21-36). The unravelling of the geological history of these rocks would entail a detailed study with accompanying mapping to a scale of at least 1 :25,000; a project which on account of the relatively poor outcrops would be less rewarding than a similar study of Damara rocks.

These rocks were recognised and named by Gevers (1931, p. 16-17) who mapped the unconformity with the basal conglomerate of the Nosib quartzites in the type locality on Abbabis 70 (B. 5). This discovery, together with the work of De Kock (1934) in the Rehoboth District, established the distinction of an older group or rocks within Rimman's "Primarformation" (Gevers, 1931, p. 16).

B. DISTRIBUTION

Owing to the high degree of tectonism and metamorphism with resultant generation of gneiss and granite over wide areas in Damara times, the recognition of the Pre-Damara formations is rendered extremely difficult. Within the area under review there is only one locality, that of B. 4 (see regional map), where the outcrop of Abbabis rocks is not doubted. Here the Damara beds are generally metamorphosed to a lower grade than elsewhere and the underlying rocks are exposed in the core of a large brachydome. A second exposure of this formation was mapped in the crest of a plunging anticline (Nose Structure) located to the west of the Khan Mine (D. 1). Remetamorphosed Abbabis rocks are very probably included in the cores of numerous other domes, but they cannot be readily distinguished from the overlying metasediments.

C. GENERAL FIELD RELATIONS

In the major outcrop on Bergrus 94, Tsawisis 16, Noab 69, Narubis 67, Ubib 76, Navachab A 58, Mon Repos, Etusis 75 and Abbabis 70 (B. 4-5) the Abbabis Formation is generally well exposed despite being morphologically subordinate to Nosib quartzite and rocks of the Hakos Series which flank the exposure. The contact with these last-named rocks is revealed at many places, but in spite of this, recognition of the unconformity is not easy owing largely to the general conformity of foliation and similarity of some rock-types found in the two formations.

At the foot of the northwest slope of the Otjipatera Mountains, southwest of the Abbabis farm-house (B. 4), is a thick layer (<200 feet) of basal conglomerate of the Nosib Formation containing an assortment of pebbles and boulders of the underlying gneiss and pegmatite. This conglomerate has been taken by Gevers (1931, p. 25) as the base-marker of the Damara System. This concept has been altered only in so far as the Nosib Formation has been separated from the Damara System, though there may be a case for including some argillaceous metasediments underlying the conglomerate to the south of Rooikop (B. 3) on Tsawisis 16 in the Nosib Formation.

The only area where an angular unconformity was recognised by the author, is where the Lower Nosib quartzite is absent and the tillite and marble of the upper stage of the Hakos Series rest directly on Abbabis rocks. This is on Navachab 58 and Mon Repos. Elsewhere the foliation and cleavage of the two systems are apparently concordant.

D. STRATIGRAPHY AND LITHOLOGY

Owing to tectonic complexity and intensity of gneissification of the Abbabis rocks it is difficult to unravel the stratigraphic succession. The following broad grouping merely differentiates the main rock-types:

Top:	Biotite schist
	Dolomitic marble and calc-silicate rocks
Bottom:	Abbabis gneiss

These formations are all intruded by basic dykes subsequently altered to orthogneisses.

1. ABBABIS GNEISS

This is the most widely distributed group of rocks in the Abbabis Formation exposed here and occurs both in the vicinity of Abbabis 70 and in the Lower Khan Gorge near the Khan Mine.

Although morphologically subordinate to the Nosib quartzite and the Damara marble it gives rise to characteristic reddish undulating hills in the region of the main outcrop.

It consists of a complex group of rocks ranging from the typical pink and grey quartzofelspathic biotite augen-gneiss to reddish muscovite-rich phyllitic quartzite and plagioclase-rich biotite gneiss. The distinction between individual units within this group on the map has not been attempted.

A type specimen (SM 191) of the augen-gneiss examined in thin section exhibits a medium to coarse-grained porphyroblastic gneissose texture in which quartz is the most abundant constituent occurring in large granular aggregates as well as in individual equant to elongate grains. Microcline forms large (<5 mm) porphyroblasts (augen) surrounded by curved biotiterich selvedges, and is commonly crowded with rounded inclusions of quartz as well as with biotite and sericite; the latter is an alteration product. Accessory magnetite and zircon occur as subangular to sub round grains. In the thin sections examined there is no evidence of intense post-metamorphic deformation, but significant shear-planes were observed in some outcrops in the eastern areas of the main outcrop.

The generally highly sheared reddish to buff-coloured muscovite-rich, phyllitic quartzite is particularly prominent on Navachab 58 and Mon Repos where it is directly overlain by the Chuos tillite and the upper stage of the Hakos Series. It is, however, frequently to be found intercalated with quartzofelspathic gneissose rocks. throughout the major outcrop area. Under the microscope a specimen (SM 192) was observed to have a mediumgrained granular gneissose texture. The predominant minerals are granular to elongate, angular quartz, wel1-oriented muscovite laths and partly sericitised microcline. Plagioclase, subhedral apatite, zircon and euhedral pink garnet are present in accessory amount. More argillaceous members of this rock-type contain abundant garnet, and biotite may supersede muscovite as the dominant mica. Black tourmaline is also locally present.

Another rock-type which occurs in the Nose Structure near the Khan Mine (D. 2) may be included under the general name of Abbabis gneiss. This is a spectacular porphyroblastic sillimanite gneiss situated structurally below the augen-gneiss and associated with a narrow deformed conglomerate band. This gneiss (SM 13) shows considerable deformation and is composed of ± 75 per cent quartz, 18 per cent sillimanite, 5 per cent biotite, chlorite, muscovite and sericite, and 2 per cent accessory pyrite, ilmenomagnetite, sphene and microcline-perthite. Nearly all the quartz grains which occur in both coarse and fine-grained granulated zones, are elongate and together with oriented aggregates of fine sillimanite fibres and accessory mica laths lend a marked lepidoblastic texture to the rock. The post-metamorphic character of the. deformation indicated in this rock tends to support the view that it belongs to a Pre-Damara succession. It will be shown in a later chapter that the metamorphism of the Damara rocks generally outlasted the tectonism.

2. DOLOMITIC MARBLE AND CALC-SILICATE ROCKS

This group is poorly developed and its presence was noted only in the western portion of the main Abbabis outcrop. The exact stratigraphic position has not been ascertained, though the marble units do occur above the Abbabis gneiss and below the biotite schist. The calc-silicate rocks well exposed on Tsawisis 16 north of the Klein-Chuos Mountains may, on the other hand, occupy several stratigraphic horizons in addition to that of the marble.

The white to yellowish-brown dolomitic marble disposed on the limbs of the Klein-Chuos Syncline is composed almost entirely of medium-sized grains of dolomite with secondary amounts of calcite and accessory graphite, tremolite, forsterite and epidote. Narrow bands of fine-grained calc-silicate rock, consisting chiefly of quartz, plagioclase and diopside, are occasionally found intercalated with the marble. The thickness of these beds cannot be readily assessed on account of the intense folding to which they have been subjected, particularly on Ubib-West 76 south of the Klein-Chuos Mountains. The marble is in any event less than 150 feet thick.

The major calc-silicate unit on Tsawisis 16 is intercalated in the Abbabis gneiss. It (SM 188) is essentially composed of quartz, poikiloblastic diopside and plagioclase in a fine-grained granular mosaic with accessory garnet, sphene and epidote. Pebbles of an identical rock-type were found in the Chuos tillite on Mon Repos (B. 5). One such pebble (SM 187) was cut by a coarse-grained epidote vein of Pre-Damara age.

3. BIOTITE SCHIST

This unit underlies the basal conglomerate of the Nosib Formation on Tsawisis 16 and is also disposed in a subsidiary (K1ein-Chuos) syncline extending from the southernmost point of the Gamgamchab Mountains on Naob 69 to the K1ein-Chuos Mountains where a more gneissose equivalent of this formation becomes morphologically prominent.

The rock consists mainly of dark quartzofe1spathic biotite schist, biotite-quartz schist and hornblende-biotite schist. Sillimanite is commonly developed, especially in the Klein-Chuos Mountains (Schwarz Hügel) where these dark rocks have a more gneissose than a schistose texture. Pegmatite segregations, both concordant and discordant to foliation, are abundant.

Under the microscope a specimen of biotite-sillimanite gneiss (SM 190) exhibits a medium-grained lepidoblastic texture with suboriented laths of brown biotite and granular quartz making up the bulk of the rock. Poikiloblastic irregular grains of orthoclase crowded with inclusions of quartz, biotite and sillimanite are characteristic. Curved acicular needles of sillimanite are abundant and commonly closely associated with biotite, suggesting an instability field with regard to these two minerals. Accessory pink garnet is present as subhedra1 grains and shows little or no alteration. In the cores of one or two orthoclase grains minute remnants of a mineral of high relief and moderate birefringence resembling clinozoisite are present. This mineral assemblage, like that of other gneisses in the Abbabis Formation, is indicative of high-pressure and high-temperature metamorphism.

Around Ubib Mine (B. 4) and eastwards this formation becomes typically schistose and less fe1spathic. Intercalations oflepidob1astic biotite-hornblende schist are more noticeable, especially near the Henderson Mine and immediately south of Rooikop. The majority of these rocks show up as dense black areas on aerial photographs and were found to be absent in the core of the Nose Structure.

What seems to be a distinct unconformity between the sillimanite-bearing gneiss and the Abbabis gneiss occurs on Tsawisis 16 immediately north of the Klein-Chuos Mountains. Here the biotite-sillimanite gneiss forms a horizontal capping to a small flat-topped hill composed chiefly of augen-gneiss exhibiting a vertical foliation. This evidence leads to the conclusion that this contact is either a thrust-plane or represents an unconformity within the Abbabis Formation, or between the Nosib and Abbabis Formations. On the one hand, the fact that this biotite schist unit is transgressed by Pre-Nosib basic intrusives indicates that it is not a basal member of the Nosib Formation. On the other hand, it is, however, possible that the basic intrusives were emplaced in the lowermost members of the Nosib beds, as they were to the south of the Kuiseb River some 100 miles south of this area, and that the schist is of Nosib age. The solution to this problem lies in more detailed mapping.

E. INTRUSIVES IN THE ABBABIS FORMATION

1. BASIC INTRUSIVES

Melanocratic ortho-amphibolite dykes of variable thickness transgress all the above formations. The dominantly cross-cutting attitude of these rocks points to their dyke-like character, though in some instances they are apparently concordant and exhibit relict amygdaloidal textures. An example of such a rock outcrop occurs about three quarters of a mile north of the farm-house on Ubib-West 76. The general character of these basic intrusives and possibly also flows is that of uralitised diabase or basalt. Thin sections examined by Gevers (1931, p. 30) showed relict ophitic texture in which hornblende had replaced pyroxene and plagioclase had become saussuritised. Gevers also described elliptical spherules suggestive of amygda1es. These were composed of granular quartz aggregates cut by fissures filled with "fibrous, aggregate polarising matter" and calcite.

2. GRANITE, PEGMATITE AND QUARTZ VEINS

No intrusive granite of Abbabis age was recognised by the author in this area. All the granitic rock-types seen, apart from pegmatite, were of gneissose type and autochthonous character. Pebbles of a biotite-rich porphyritic granite were found in the Chuos tillite southwest of Gross Ubiberpforte (C. 4) and in Dome Gorge in the Lower Khan River area (C. 2). (See pl. IX.) These may possibly belong to intrusive granite bodies not observed to outcrop in this area.

Undeformed pebbles of pegmatite and of quartz in both the Nosib basal conglomerate and the Chuos tillite were frequently observed in the immediate vicinity of the main Abbabis outcrop. Unfortunately pegmatites of both Damara and Abbabis age have similar characteristics, i.e. salmon-pink microcline intergrown graphically with quartz, pale milky quartz and accessory biotite, muscovite and black tourmaline. They cannot therefore be readily distinguished from each other. The majority of large dyke-like pegmatites such as those transgressing quartzite of the lower stage of the Nosib Formation near the Henderson Mine on Naob 69, are of Damara age. There are numerous small folded pegmatites which are both concordant and discordant to the foliation of the Abbabis rocks and which could be of either age.

Quartz veins, developed to a lesser extent than pegmatites, are likewise difficult to date.

Many pegmatites and some quartz veins in the Abbabis rocks are mineralised and have been extensively prospected for tin, tantalite, beryl, gold and copper. Some of the more important prospects have been marked on the map.

F. THE PROBABLE CHARACTER OF THE ABBABIS FORMATION IN PRE-DAMARA TIMES

Examination of undeformed pebbles of Abbabis rocks in the basal conglomerate of the Nosib Formation and in the Chuos tillite indicates that the rocks suffered little mineralogical change in Damara times so that their general petrographic character, apart from subsequent shearing, was then nearly exactly the same as it is today.

The Damara rocks have been highly folded by both flexure and similar processes, and it cannot at present be ascertained to what extent the Abbabis rocks were previously folded. Today a greater part of the foliation of the Abbabis conforms with that of the Damara; but this effect could have been produced entirely by the later fold movements, especially by similar folding which tends to destroy the effects of an unconformity. Where the unconformity is visible, however, the maximum angle of intersection between the bedding-planes and the plane of unconformity is about 35°. Being on the normal northern limb of the major brachydome, this angle is likely to have been reduced by Damara fold movements. It can therefore be safely concluded that the Abbabis rocks had suffered a fair amount of tectonic deformation prior to the deposition of the Nosib and Damara sediments. Although the fold axes of the Abbabis appear to trend north-northeast at present, their original trend prior to at least two periods of folding in Damara times, may have been very different.

VI. THE NOSIB FORMATION

A. INTRODUCTION

This formation was formerly included in the Damara System under the name "Quartzite Series". The reason for its separation from the Damara System and its correlation with the Nosib beds of the Otavi Mountains and the Kaokoveld has already been discussed. In the area under consideration the unconformity between the Nosib Formation and the Damara System is not recognisable. Where the unconformity has been observed in other areas it is not the result of a major orogeny. It is therefore certain that the intense folding, metamorphism and granitisation of the Nosib rocks have been caused by the Damara Orogeny (Clifford, 1962) after the deposition of the Damara System.

The formation has been subdivided into an upper stage and a lower stage. A basal conglomerate is only locally developed. It should be stressed that the lower and upper stages represent in part a true vertical succession, e.g. in the western portions of the Lower Khan Gorge; but that in part they represent lateral variations or facies of each other.

B. THE LOWER STAGE

1. BASAL CONGLOMERATE

The relationship between this unit and the Abbabis Formation has already been discussed.

The conglomerate is locally developed around the periphery of the major Abbabis outcrop area and was found at oJ1ly two places: at Rooikop (B. 3) on Tsawisis 16 and on the northeast slopes of the Otjipatera Mountains on Abbabis 70 (B. 4).

The major and lenticular outcrop of conglomerate is well exposed where it overlies Abbabis gneiss in the entrance to the Abbabis Poort in the Otjipatera Mountains and westwards to the foot of the crags below Abbabis Peak. The maximum thickness is about 250 feet. It is composed of poorly sorted, generally well-rounded pebbles and boulders in a granular to schistose matrix. The pebbles are composed of underlying rock-types found in the immediate vicinity and include a wide variety of gneissose and schistose rock as well as tourmaline pegmatite, quartzite and quartz. The pebble layers are rarely separated by well-graded beds and only one or two imbricate zones were observed. The conglomerate has the appearance of a rapidly deposited, shallow-water terrestrial sediment. Subsequent deformation is apparently slight since the pebbles for the most part show little or no sings of tectonic flattening or shearing.

At Rooikop the conglomerateis poorly developed. Its maximum thickness is less than 20 feet and the strike length of the outcrop is ± 5000 feet. Here flattened and sheared pebbles of quartzite, quartz and granite are enclosedjn a quartzofelspathic matrix. The pebbles have undergone recrystallisation to the extent that much of their original character is unrecognisable.

2. QUARTZITE

This unit is well and widely exposed in the cores of antiforms in the area under consideration. Where they are well developed they tend to form characteristic reddish ranges of hills and mountains. The biggest ranges, the Chuos and Otjipatera Mountains, are composed of this rock-type which is overlain by the calcareous upper stage to which it becomes subordinate in the western areas.

The typical character of this formation is best seen in the Khan, Chuos and Otjipatera Mountains where they can, in some places, be observed in contact with the Abbabis rocks. Here they consist of felspathic quartzite generally massively bedded at the base and becoming thinly bedded towards the top. Narrow conglomeratic bands are intercalated in many horizons. The grain of the rock is variable throughout the succession though broadly finer in the higher strata. Cross-bedding is a common feature, especially in the fine outcrop in the Abbabis Poort where a continuous cross-section of these quartzites is exposed.

The thickness of the quartzite is exceedingly variable. The maximum in the Otjipatera Mountains where no minor folding was observed, is about 11,000 feet. A similar thickness is probably present in the Chuos Mountains, but here a high degree of folding complicates this calculation. The absence of the Nosib Formation overlying the Abbabis Formation on Navachab 58 and Mon Repos and its thin development on Tsawisis 16 and Naob 69 where it is locally less than 100 feet thick, are apparently a depositional feature. The reason for this deduction is that all the rocks overlying the quartzites, even on the crests of gentle folds, are conformable showing that no intervening erosion took place. It seems likely therefore that the quartzite was deposited on an eroded Basement surface in local basins of variable depth. The thickness of the majority of the quartzite outcrops cannot be determined since their base is not exposed and they have, in many places, been granitised, intruded by vast quantities of pegmatitic material and folded.

The petrography of the quartzite is variable due both to original composition and subsequent metamorphism. In the Otjipatera Mountains where the metamorphic grade is low, type specimens of reddish, medium and fine-grained quartzite (SM 107, SM 108 and SM 111) examined in thin section contained abundant rounded detrital quartz and felspar grains (pi. IV). These specimens are composed of ± 70 to 90 per cent quartz which occurs as coarse allogenic rounded particles as well as in a fine recrystallised matrix. Orthoclase and microcline are present as rounded, partly sericitised grains in subsidiary amount. Accessories present include iron oxides, zircon, sphene, apatite, calcite, hornblende, biotite and muscovite. The heavy minerals are generally round to subround having the characteristics of detrital particles and being particularly numerous in the darker bands in cross-beds. The general roundness and lack of consistent orientation of slightly elongate particles are indicative of little or no flattening or shear deformation despite their position on a limb dipping at an average of 60° to the southeast. The dip of the cross-beds, however, is in some cases unusually steep (i.e. more than 30°) and is probably caused by the effects of flexural folding or flexure plus compression (Ramsay, 1961, p. 96).

Greenish bands containing abundant epidote are commonly intercalated in the uppermost portions of these quartzites. The presence of epidote is ascribed by Gevers (1931, p. 42) to alteration of felspars.

Away from the type areas mentioned, the quartzite is less well developed; several argillaceous members may be present within the reddish quartzite strata. The granitisation of this assemblage so commonly observed, will be dealt with later.

The most prominent variation in the stratigraphy of the quartzite occurs to the southeast of the Swakop River (C. 5) where it becomes subordinate to thinly bedded quartz-biotite schist with intercalated amphibole schist and felspathic biotite quartzite. Here too, as in the Lower Khan Gorge area, the quartzite is pale pink to grey rather than red. The reddish quartzite is still, however, quite well developed in the domes on Horebis Nord 61, Dorstrivier 15 and Rooikuiseb 109 as well as in the dome containing Brockmann's beryl-bearing pegmatite on Tsaobismund (C. 4-5). At the latter locality an unusual tectonic brecciation in the quartzite immediately below the Hakos Series is apparent.

The petrography of the lower grade metamorphic facies of the quartzite in the Abbabis locality has already been described. In most other areas the grade is much higher and all vestiges of allogenic particles, apart from rounded heavy-mineral grains, have been obliterated. Typical specimens (SM 16, SM 98, SM 95 and KR 18) of quartzite in the Lower Khan Gorge area show medium-grained allotriomorphic equigranular textures in thin section. Variable amounts of micro cline in these sections indicate that the intensity of red coloration in the rock is dependent upon the abundance of microcline. The deepest coloration was observed in a rock (KR 18A) containing 25 ± 2 per cent microcline. Quartz and subsidiary microcline or plagioclase are always essential constituents and iron oxides (magnetite or ilmenomagnetite), muscovite, biotite, garnet, hornblende, zircon, sphene, apatite, calcite, staurolite and epidote may be present as allogenic or authigenic accessories.

Cross-bedding is preserved even in highly recrystallised quartzite in the dome near SJ Claims (C. 2). Here and at many other places the distinction between felspathic quartzite and paragneiss is arbitrary. A typical composition of this type of rock (KR 18A) is quartz 64·4 per cent, microclineperthite 25·6 per cent, plagioclase 2·3 per cent, muscovite 3·0 per cent and accessory ore, zircon and apatite 5·2 per cent by volume.

The argillaceous quartzite is generally more susceptible to metamorphism than the pure quartzite. At the northeast end of the Otjipatera Range the quartzite thins rapidly into a biotite-chlorite-muscovite schist facies which becomes completely granitised eastwards on Habis 71 (B. 5). Sillimanite is developed in argillaceous bands at many localities and is commonly closely associated with biotite. The finest exposure of this rock-type was seen underlying the Hakos marble in the bed of the Omasema River on Otjozondu 36 (inset).

C. THE UPPER STAGE

This succession represents a development of calcareous quartzite overlying the quartzite of the lower stage in the western portions of the mapped area. It is absent in the southeastern areas and best developed in the region of the Lower Khan Gorge. The stage may be broadly divided into two distinct types, viz. an amphibolite facies and a calc granulite facies.

1. AMPHIBOLITE FACIES

This facies occupies a stratigraphic position between the red quartzites of the lower stage and the Lower Hakos Stage. It is most extensively developed in the hills southeast of Usakos where it 5tands out darkly against the white marble bands which surround the outcr6p in the core of an elongate brachydome. It is also well exposed on the hill in the southeast of the residential area of Karibib (not on map). On Sukses 90 and Eureka 99 (B. 2) I the outcrop is poor though this facies is apparently extensively developed there as well as on Lukasbank 63 (B. 3) where its presence is suggested by the abundance of float.

The rock is characteristically dark grey to black, well bedded and frequently porphyroblastic. It is excessively tough and hard giving out a metallic ring similar to that of dolerite when struck. It is generally so finegrained that only the porphyroblastic minerals can be recognised in handspecimen. Though largely granulitic, amphibole-biotite schist may be intercalated locally.

The thickness is exceedingly variable. On Mon Repos (B. 5) the hornfels occurs as a rapidly thickening wedge overlying the quartzite of the lower stage and closely associated with a limited development of tillite. Here it attains a thickness of 600 ± 50 feet. Where best developed in the Usakos Hills the base of this facies is not exposed, the rocks are highly folded and adjudged to be at least 1000 feet thick.

In thin section (SM 195, SM 202 and SM 207) these rocks are shown to be very fine-grained with granular to lepidoblastic texture. Quartz and hornblende are the major constituents together with subordinate plagioclase and accessory biotite, chlorite, sphene, zircon, scapolite and apatite. Porphyroblasts of hornblende crowded with inclusions are generally well orientated showing early syntectonic crystallisation. In some cases the hornblende is seen to be an alteration product of original pyroxene as a post-deformational effect of retrograde metamorphism, as indicated by the random orientation of these undeformed amphiboles.

These rocks were probably originally calcareous semi-pelites to argillites, i.e. marls, and must represent deeper water conditions in the north of this area at the time of deposition of the upper stage.

2. CALC GRANULITE FACIES

Calc granulite is by far the most predominant rock-type of the upper stage. It is widely and thickly developed in the western areas, in the region of the Lower Khan and Swakop Rivers as well as at Rössing Mountain. In the Chuos and Otjipatera Mountains there is merely a thin band thickening westwards and overlying the lower stage.

Typically greyish-green, pyroxene or amphibole-bearing felspathic quartzites, these rocks give rise to many prominences of a greenish-grey tint, or at a distance, bluish. Hence the names Blauer Heinrich and

Blauerberg. Predominantly the rocks are massive and poorly bedded, but are generally characterised by thinly bedded biotite-rich horizons present at the base and top of the succession. Conglomeratic bands are present in many horizons at Rössing Mountain, but elsewhere they are rare. In the Dome and Roddy's Gorges locality (C. 2) a well-defined "striped" horizon consisting of alternating, thinly laminated, light quartzofelspathic and dark biotite-hornblenderich bands is present near the middle of the facies (see pl. V).

These calc granulites have been particularly favoured as a site for pegmatite emplacement so that nearly all exposures are riddled with pegmatite dykes and veinlets. The well-bedded basal zone of the upper stage surrounding the quartzites of the lower stage in the dome in Dome Gorge is a fine example of such pegmatite invasion.

The contact between the quartzites of the lower and upper stages is clearly visible and sharply demarcated in the western portions of the Lower Khan Gorge (see pl. VI and fold. 1), but it becomes increasingly ill-defined eastwards towards Blauerberg (C. 2-3) where several red quartzite bands are intercalated in the basal portion of the upper stage. The boundary shown on the map is therefore arbitrary in this region. The top of the succession is generally marked by black biotite-amphibole schist with a rapidly increasing carbonate content and appears to grade into marble of the Lower Hakos Stage. Narrow bands of quartz-pebble conglomerate are widely developed in the upper stage of the Nosib Formation. In the Khan Mountains as well as in the Chuos and Otjipatera Ranges, the quartzite is directly overlain by tillite. In the latter localities, calc granulite is not so well evolved and tends to be of lower metamorphic grade. Epidote is more abundant. In some places, e.g. Abbabis Poort, they resemble the amphibole hornfels facies.

Like all the formations beneath the Khomas Series the calc granulites are of extremely variable thickness. The variation takes place over very short distances as seen in the vicinity of Blauer Heinrich (D. 1). The maximum thickness measured was 3500 ± 100 feet in the cross-section in Cul de Sac Gorge (C. 2).

The petrography of these rocks varies from that of pure quartzite to that of quartz-biotite-amphibole schist. The present study was largely confined to the green-grey calc granulite which comprises the bulk of the facies. Of the 13 representative thin sections examined (see table 2) all contained quartz and felspar as major constituents, 10 had both potash felspar and plagioclase (4 with plagioclase dominant) and 10 contained either amphibole or pyroxene or both, The textures are generally similar throughout, ranging from fine to medium-grained granular, occasionally lepidoblastic. In addition to the accessories ncted in the table, garnet, scapolite and more abundant epidote and biotite are commonly found and can often be recognised in hand-specimen.

Specimen SM 211 taken from the Panner's Gorge locality (D. 2) may be described as a type example of these rocks. In hand-specimen it is a medium-grained, pale green-grey, granular quartzofelspathic rock studded with darkgreen pyroxene crystals and very subordinate amounts of biotite. Several green epidote grains were also present. In thin section an allotriomorphic granular texture was observed. The major constituents, quartz, plagioclase and microcline-perthite, occur as granular interlocking grains in which pyroxene of hedenbergite composition ($2V\gamma = 62 \pm 2°$, γ^c $= 46 \pm 3°$) is moderately porphyroblastic. Anhedral quartz shows wavy extinction.

TABLE 2.—MINERALS PRESENT IN GREEN-GREY QUARTZITE OF THE UPPER STAGE, NOSIB FORMATION

Specimen No.	Quartz	K felspar	Plagioclase (An_{5-15})	Biotite	Amphibole	Pyroxene	Zircon	Sphene	Calcite	Ore	Apatite
SM 211..........	+	×	+	*		+	*	*		*	*
SM 142..........	+	×	×		+		*	*		*	*
SM 104..........	+	+	×		[×]	×	*	*	*	*	*
SM 102..........	+	+			+		*	*	*	×	*
SM 96...........	+	+	*		[+]	*		*		*	*
SM 93...........	+	×	+		[+]	*	*	*		*	*
SM 89...........	+	+	*		+	×	*	*	Tourma-line*	*	*
SM 76...........	+		+			+	*	*	*	*	
SM 53...........	+	*	+		[×]	*	*	*	Epidote*	*	*
SM 21...........	+	+	+	+			*	*	*	*	*
SM 8............	+	+	×	×	[×]	×	*	*	*	*	*
SM 4............	+	+	×	×			*	*	Fluorite*	*	*
SM 23...........	+	+	×	×						*	*

+ = Major constituent.
× = Minor constituent.
* = Accessory constituent.
[] = Derived by retrograde metamorphism from pyroxene.

Oligoclase [maximum extinction-angle on (010) normal = 6 ± 2°] is subhedral and unaltered. Microcline-perthite and some orthoclase are subordinate in amount to quartz, plagioclase and pyroxene and are commonly seen to be partly sericitised. Subround grains of ore of variable size represent a minor authigenic constituent. Anhedral to euhedral biotite, hornblende and apatite as well as rounded allogenic zircon and sphene are accessory.

A feature of these rocks not observed in the above specimen is that of the retrograde metamorphism of pyroxene (of diopside-hedenbergite series) altering to hornblende. As far as can be judged this is a post or latetectonic feature.

The commonly observed random mineral orientation and deformation in the calc granulite as well as in most of the other rock formations are indicative of the fact that metamorphism outlasted the major fold movements. The relation of metamorphism to tectonism will be discussed in a later chapter.

The present distribution and mineral assemblage of the calc granulite indicate that it was originally a calcareous, felspathic sandstone deposited in fairly shallow-water basins deeper and more wide-spread in the west than in the east. The general lack of current-bedding, common in quartzite of the lower stage, is suggestive of a depositional environment in relatively quiet water, but above the depths at which turbidity currents operated to produce graded beds. The currents might have been just strong enough to remove the finer argillaceous material throughout most of the time of deposition of these rocks. Towards the close of the sedimentation of the upper stage, low Eh (oxygen deficient) and slightly alkaline conditions must have prevailed (Pettijohn, 1957, p. 599) to produce an environment suitable for the development of carbonaceous limestones.

VII. THE DAMARA SYSTEM

In the area under discussion the sediments of the Damara System follow conformably on those of the Nosib Formation. No conglomerate has been observed at the base of the Damara succession. There is therefore no reason why Gevers (1931, p. 39), on the evidence available in this area only, should not have included the Nosib Formation (his Quartzite Series) in the Damara System. Only observations made outside western Damaraland have now lead to a revision of the systematic boundary (p. 8 and 9).

The Damara rocks in the area under review represent the central and deeper portions of the Damara Eugeosyncline (Martin, 1961). It follows, therefore, that the metamorphism, granitisation and tectonism are intimately related. For the purposes of descrjption these features are discussed under the three main headings following hereafter.

A. THE STRATIGRAPHY AND LITHOLOGY OF THE METASEDIMENTS

The following subdivisions of the Damara System are represented in the area under discussion:

Damara System…….	Khomas Series	
	Hakos Series……………	Upper Stage
		Middle or Chuos Stage
		Lower Stage

1. THE HAKOS SERIES

(a) *The Lower Stage*

(i) *Distribution*.- This formation which underlies the Chuos tillite, is completely absent in the eastern parts of the area under discussion. It is, however, well developed in the Lower Khan Gorge. Observations in the southern Windhoek District as well as in the areas of the Outjo Facies probably indicate that the absence of the Lower Hakos Stage is due to a discordance at the base of the tillite.

(ii) *Stratigraphy*.-The stage is characterised by extremely variable stratigraphy, the broader elements of which are illustrated in the cross-sections in figure 1. (The localities of the cr6ss-sections are indicated on folder 1.) It may be noted that rapid facies changes from granular " sugary" quartzites to pure dolomitic marble are a common feature. The thin-bedded quartz schist is generally pyritic and weathers to a reddish-brown colour which is characteristic of the stage.

The quartzite and grit are white to pale pink and usually deeply stained by manganese hydroxide on fracture surfaces. Pebble bands or washes have been found at several localities at different stratigraphic levels. These pebbles composed ubiquitously of quartz, are distinctly flattened both at SJ Claims (C. 2) and in the zone of parasitic folding southeast of Blauer Heinrich (see fold. 2), whereas they are generally round to sub-round elsewhere.

The marble units are of variable character though white to buff coloured and regularly, evenly and thickly bedded for the most part. The marbles usually make up the bulk of the stage and there are fewer siliceous bands than in the marbles of the upper stage.

Dark-grey to black, massive quartz-biotite schist is prominent in the synclinorium surrounding the dome as well as in other localities (see fold. 1). In addition there are several biotite-amphibole schist bands occurring both in and below the marble. These are medium to thinly bedded or even laminated, the lighter bands being richer in quartz and felspar. Where pegmatites cut these biotite-rich members they are commonly uraniferous.

(iii) *Thickness*.- The thickness, like the lithology of the stage, is exceedingly variable. The maximum thickness measured in least-deformed strata, is ± 600 feet. Some of the variation is possibly due to tectonic compression during which the strata on the steep limbs of folds were stretched or even boudinaged while those in the crests and troughs were thickened (De Sitter, 1956). This is supported by the fact that the stage is better developed in synclinal troughs and poorer on steeply dipping limbs (see fold. 1). Its position between two more competent units (tillite and quartzite) may have accentuate this tectonic effect. As mentioned above, however, it has been determined elsewhere in the country that at least part of the variation in thickness may be due to erosion immediately prior to the deposition of the tillite.

(iv) *Petrography*.-The petrography of the stage is complex owing to the variety of rock-types present. The mineral assemblages reflect the original composition of the rock perhaps more than the metamorphic facies. This is well illustrated in single cross-sections of the strata in which potash felspar, cordierite, garnet, plagioclase, biotite, sphene, pyroxene, amphibole, calcite, epidote, scapolite, olivine, etc. are all stable within several beds.

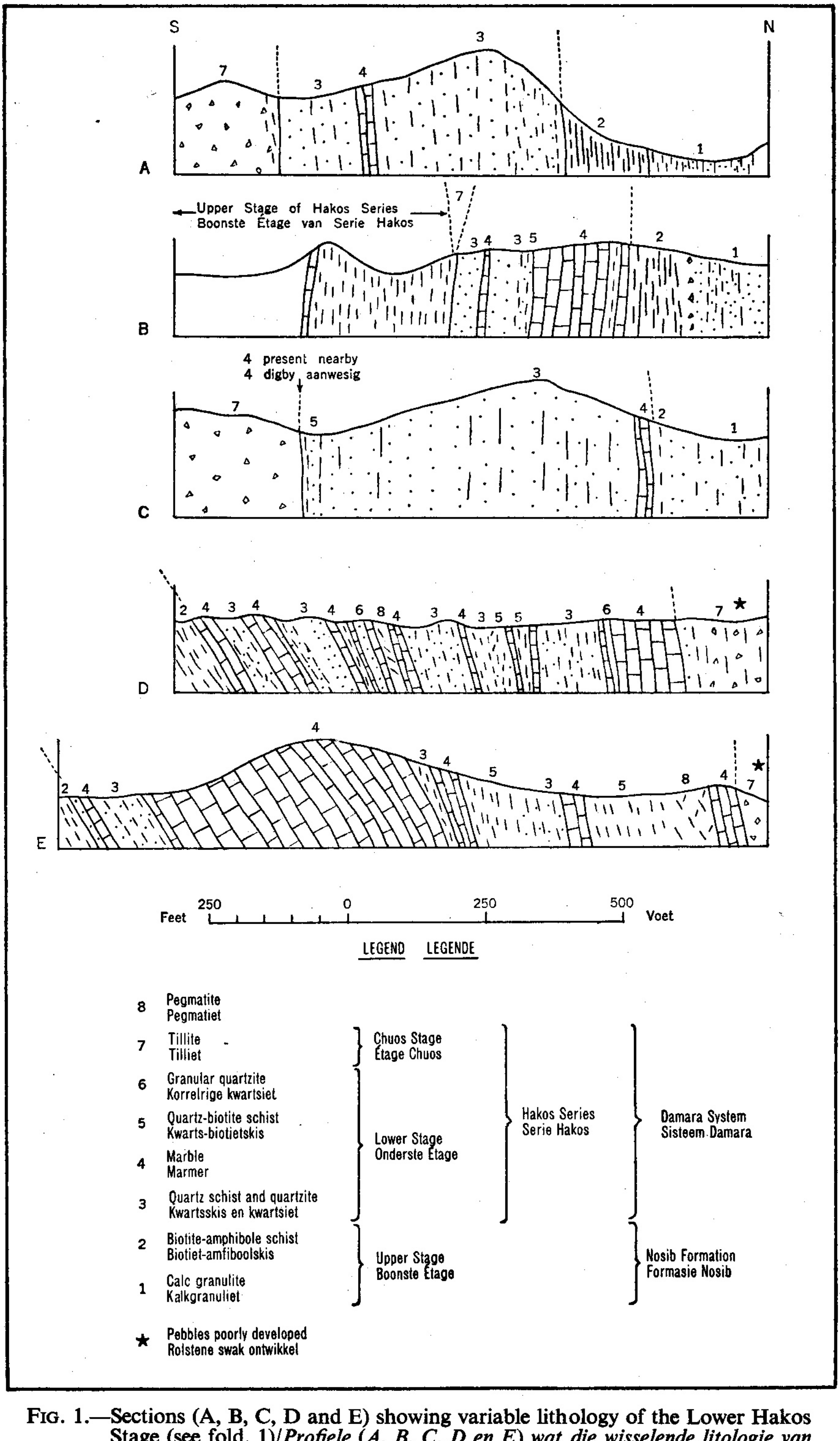


FIG. 1.—Sections (A, B, C, D and E) showing variable lithology of the Lower Hakos Stage (see fold. 1)/*Profiele (A, B, C, D en E) wat die wisselende litologie van die Étage Onder-Hakos aantoon (kyk voubl.* 1).

Typical specimens of the marble (SM 22 and SM 67) show medium to coarse crystalline textures in thin section. Stains with Lemberg's solution reveal that the dolomite generally composes about 80 per cent of the carbonate and that calcite occurs either as isolated crystalline grains or as veinlets. Accessories include serpentine (altered from forsterite), garnet, graphite and possible chondrodite. Calc-silicate bands were observed to contain very fine-grained quartz, scapolite, calcite, diopside (?) and accessory epidote, pyrite, pyrrhotite, bornite and chalcopyrite. These sulphides were found as major constituents in some places.

The biotite schist (SM 48, SM 47, SM 49, SM 70 and SM 83) varies from medium to fine-grained quartzofelspathic schist containing biotite, cordierite and garnet to porphyroblastic biotite-hornblende-scapolite-hedenbergite schist which characterises argillaceous units both within and below the lower stage. In these rocks plagioclase, potash felspar, hornblende, biotite and pyroxene may occur as porphyroblasts which are generally randomly oriented. In rare cases biotite was seen to be oriented in the axial planes of minor folds. These features show that while metamorphism was in part contemporaneous with fold movements, it did for the most part outlast them. Biotite or phlogopite is quite commonly developed in large "books" (< 18 inches* across) in these horizons. Such occurrences have been worked at times. Sphene, tremolite, apatite, zircon and epidote constitute accessory minerals. Sphene, though usually found occurring as distinct irregular grains, also occurs within biotite laths (see pl. VII). With slightly highel grade metamorphism sphene is apparently absent, suggesting that the TiO_2 has been absorbed by the biotite (Ramberg, 1952, p. 161) and that these rocks crystallised in the upper grade of the amphibolite facies. This indicates a crystallisation temperature of between 400 and 650° C (Ramberg, 1952, p. 137) which is indeed a wide range. Sillimanite is present in quartz-biotite schists elsewhere in this stage and is indicative of high temperature relative to pressure conditions during metamorphism. Kyanite is generally absent. The maximum pressures prevailing could not have been higher than about 12 kilobars (equivalent to a depth of ± 40 km†) (Clark, 1959, p. 53) and are more likely to have been in the neighbourhood of 6 kilo bars, assuming a geothermal gradient of 30° C/km and a melting temperature of about 650° C (Wyllie and Tuttle, 1960, p. 230).

The granular quartzite which occurs both as distinct units in the lower stage and as facies equivalents of marble members, is generally felspathic containing microcline and/or plagioclase as subsidiary constituents together with zircon, apatite, biotite, muscovite and iron oxides. One specimen (SM 46) from a quartzite zone was composed entirely of equigranular (average grain size ± 0·40 mm) oligoclase with accessory phlogopite, epidote-clinozoisite, zircon, rutile and quartz. The normal composition is, however, that of quartzite.

The higher grade skarn assemblages found in the marble of this stage in granitised environments are essentially similar to those in the upper stage with which they will be described.

(v) *Deposition*.-The environment of disposition of the lower stage is difficult to visualise. It must certainly have been in shallowish water subject to variation of current velocities depositing grit, sandstone and conglomerate in rough-water periods, and argillaceous and calcareous

* 1 inch=2·54 centimetres.

† 1 kilometre=0·6214 mile.

sediments in quiet waters. The actual facies changes indicating deposition of sandstone at the same time as limestone cannot be accounted for from the available evidence. Fairly similar rocks are evidently common in the orthoquartzite-carbonate suites, e.g. in the Early Palaeozoic of the Mississippi Valley, but these are generally Post-Cambrian and the carbonates probably originated largely from shelly material (Pettijohn, 1957, p. 612-614).

(b) *The Middle or Chuos Stage*

The Chuos tillite in the area under consideration has been established as such and described in some detail by Gevers (1931 and 1931a) who first discovered its occurrence in the Navachab Hills west of Karibib. R. B. Young had previously noted tillitic rocks on the southern slopes of the Chuos Mountains (Gevers, 1931a, p. 3).

The present study has little further to contribute to the original work of Gevers, apart from noting that the tillite in this area extends eastwards as far as Ombujomenge 39 (inset) and that it outcrops extensively in the Lower Khan Gorge.

(i) *Distribution*.-The tillite is widely distributed in South West Africa, occurring extensively from the Kaokoveld in the north possibly as far as the Richtersveld in the south where it has been suggested to be of the same age as the Numees tillite. In the area considered it crops out sporadically and is locally present in fold limbs and some domes and basins in a broad belt, some 20 miles wide, extending from the northeast on Mon Repos (B. 5) to the southwest of the area. It is far better developed in the latter portion of this belt. It overlies Basement Abbabis rocks, both stages of the Nosib Formation and the lower stage of the Hakos Series with a locally concordant contact with the exception of the first-named. It is ubiquitously overlain by the upper stage of the series except at Abbabis Poort where its identification is in some doubt, and in the Navachab Hills where it is locally followed by amphibole schist.

(ii) *General Appearance*.-Typically it is a greenish-grey to dark-grey granular, unbedded rock containing various sizes (½ inch to 5 feet) of ill-sorted pebbles and boulders (see pi. VIII and IX) which are commonly deformed. The matrix is generally granular, but also schistose at many localities or in parts of a single sequence. A few horizons are medium to thickly bedded while thinly bedded schistose metasediments, akin to varves, may be present locally, especially at the top of the succession. Where deformation has been intensive and the included fragments reshaped into long lenticular stringers, the rock does not resemble a tillite at all and can be readily mistaken for the calc granulites of the upper stage of the Nosib Formation. Even where the pebbles and boulders have not been structurally flattened, facets are rare and striations absent. Angular pebbles do, however, predominate over round and subround ones in most places.

(iii) *Thickness*.- The thickness of the horizon is exceedingly variable and may develop from nothing to 1000 feet over a strike distance of 1500 feet, e.g. in Panner's Gorge (see fold. 1). The greatest thickness measured was just over 2000 feet southeast of Blauer Heinrich, but here a certain amount of minor folding, difficult to detect in the unbedded strata, may have exaggerated the result. Overall the thickness is very much less than 1000 feet, even where the tillite is better developed in the southwestern areas.

(iv) *Petrography*.- The petrography of the tillite shows little uniformity. Although only seven specimens of the matrix and four of the inclusions were studied in detail, a reasonable amount of information was obtained macroscopically from these largely medium to coarse-grained rocks.

The petrography of the included fragments was discussed when dealing with the Abbabis Formation from which all these inclusions were apparently derived. In areas surrounding this Basement outcrop (B. 4-5) the boulders and pebbles have suffered little deformation or recrystallisation and are mostly readily recognisable. As previously mentioned they are composed mainly of gneiss, calc-silicates, phyllitic and ordinary quartzites, quartz, pegmatite and subordinate biotite or amphibole schist. In many places in the Khan Gorge area, metamorphism and tectonism have altered most of the pebbles into gneissose material.

The matrix is composed of quartz, felspar, biotite and amphibole for the most part. Iron oxides (magnetite and/or ilmenite), tourmaline and epidote are locally abundant. Typical specimens (SM 59, SM 50, SM 75, SM 88, SM 100 and SM 101) all contain angular quartz with largely sericitised felspar (dominantly plagioclase) and biotite and/or amphibole as major constituents, except for SM 59 which contains no felspar and is representative of basic segregations in the matrix. Green hornblende, usually porphyroblastic and euhedral, is the major amphibole. Common accessories are calcite, iron oxides, zircon and apatite while sphene, garnet, staurolite and monazite were more rarely found. Textures vary from equigranular allotriomorphic to porphyroblastic and lepidoblastic. Hornblende is the dominant porphyroblastic mineral and is often seen to be randomly oriented, sometimes radially disposed, in the matrix.

Thinly bedded units at the top of the succession, notably in the Panner's Gorge vicinity (D. 2), are composed of alternating bands of biotite schist and quartzofelspathic layers. Individual bands are generally thicker than 1 inch and are seldom less than two fifths of an inch (the lower limit of very thin bedding). (See Dunbar and Rodgers, 1957, p. 97.) The banding is apparently in part due to metamorphic processes though some is initially sedimentary in character. Many light bands are composed of coarse quartz and felspar with biotite-rich selvedges, indicating a basification of the darker units. The sedimentary character is evident in that there are a large number of uniformly alternating bands of which some are apparently graded.

Gevers (1931, p. 63) has described similar beds as varves, but those inspected by the writer were found in several horizons, only one of which was associated with the tillite. The bedding, moreover, was not in the nature of fine lamination ($^{1}/_{10}$-$^{2}/_{5}$ inch) in the manner of most true varves.

(v) *Deposition*.-Owing to the very wide distribution and local thick accumulations of bedded tillite (Gevers, 1931a, p. 9), it must be concluded that the duration and extent of the ice-sheet were considerable. The floor on which the tills were deposited and from which material was removed, was composed of hard rocks of the Abbabis and Nosib Formations and of the lower unconsolidated member of the Damara System. The evidence of tillite directly overlying the Basement on Navachab 58 and Mon Repos (B. 4) indicates that hard rock pavements were likely to have been present locally in the basin of deposition. The overlying marble of the upper stage was deposited on a fairly flat surface indicative of a levelling of the topography by the ice-sheet which modified elevations and filled the depressions responsible for the local thick accumulations of till. The ice did not disrupt the stratification of the unconsolidated sediments immediately underlying the tillite to any great extent. This is in accordance with the view that the glaciers were unburdened in shallow water in which conditions were occasionally sufficiently disturbed to produce thick bedding in the tills. After deposition of the coarse material and upon retreat of the ice-sheet, argillaceous material was deposited in lower lying areas prior to the onset of a further carbonate cycle.

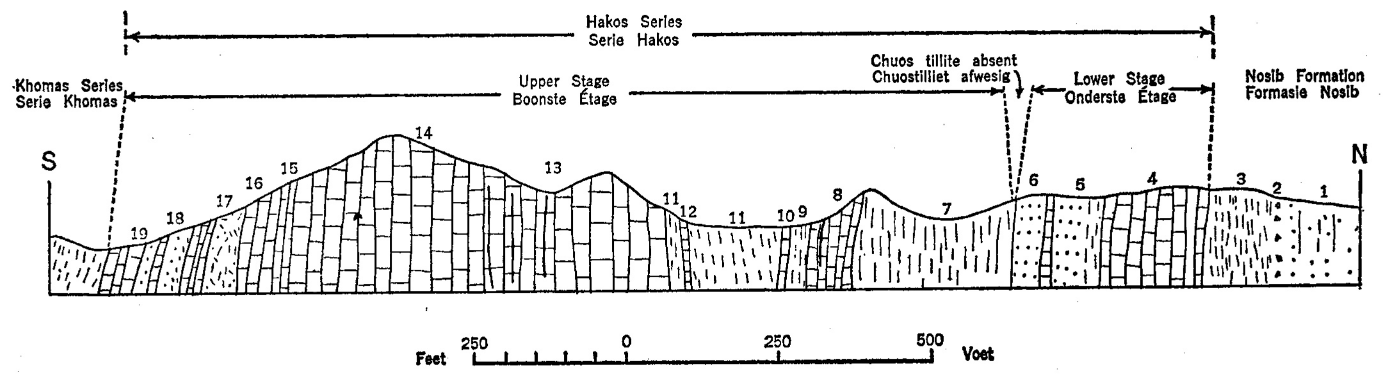
(c) *The Upper Stage*

Together with the Khomas Series this is the most widely distributed unit in the Damara System. In the area considered it forms a prominent marker horizon by virtue of its resistance to erosion as well as to ultrametamotphism. It is found throughout the area on limbs of folds and, rarely, in domes and basins. It is entirely absent in only very few localities.

(i) *General Characteristics*.-The stage consists of a number of marble bands with intercalated biotite schist and some quartz schist. In general the marble units are concentrated into a single broad sequence of massive to thick beds, but in some areas, notably on Namibplaas 93 (C. 3), Otjozondu 36 (inset) and in and around the Otjimbingwe Reserve 104 (C. 5), several marble bands are separated by thick biotite schist units of Khomas type.

On the whole the marble is white in colour with prominent blue-grey bands at various levels in the succession, apart from in the western regions where bluish rock occurs near the top only. Dark-brown to green calcsilicate bands are commonly very abundant. There is, however, a great variation of colour in the marble in some places, especially in the Karibib, Usakos and Marmor III (C. 4) environs where mainly blues and greys are to be found. The bulk of these are composed of thickly bedded, finely banded and laminated rock which, when highly folded (see pl. X and XI), makes exceptionally spectacular outcrops. Marble quarries are located at several places near Karibib.

(ii) *Thickness*.- The incompetency of these rocks makes them especially susceptible to similar folding processes with the result that considerable thickening takes place in the crests and troughs of many tight folds. Good examples of this phenomenon can be seen on Gross Aukas 66 (B. 4) and Marmor III (C. 4). The variation in thickness is not entirely due to tectonic activity since relatively gently folded strata are also inconsistent in thickness. Thus the variability in width of the upper stage is much like that of the formations beneath it, though less abrupt. The maximum thickness measured in strata showing a minimum of minor folding, was 2000 ± 100 feet in the Dimetrodon Hill (D. 2) area. A similar amount is also present to the southeast of the Otjipatera Mountains on Etusis 75 (B. 4). Thick units of marble are commonly found developed throughout the area, but many of these are highly folded and not readily measurable. In the southeastern portion of the area, the proportion of marble to schist in the upper stage is less than at most other places. Here the strata lying between the bottom and topmost marble bands have been included in the Hakos Series resulting in considerable thicknesses of it being shown on the map. Where large uniform masses of biotite schist occur between marble bands, however, they have been mapped individually. Single homogeneous units of marble are generally less than 500 feet thick.



LEGEND LEGENDE

- 19 White marble / Wit marmer
- 18 Biotite-quartz schist / Biotiet-kwartsskis
- 17 Quartz-biotite schist with pegmatite / Kwarts-biotietskis met pegmatiet
- 16 White marble / Wit marmer
- 15 Blue marble (stinkkalk) / Blou marmer (stinkkalk)
- 14 Massive white marble / Massiewe wit marmer
- 13 Massive white marble with siliceous bands / Massiewe wit marmer met silikahoudende bande
- 12 Serpentine-calcite band / Serpentyn-kalsietband
- 11 Porphyroblastic quartzofelspathic biotite schist / Porfiroblastiese kwartsveldspatiese biotietskis
- 10 Marble band / Marmerband
- 9 Quartz-biotite schist / Kwarts-biotietskis
- 8 White marble with siliceous bands / Wit marmer met silikahoudende bande
- 7 Porphyroblastic quartzofelspathic biotite and schist / Porfiroblastiese kwartsveldspatiese biotiet en skis
- 6 Brown granular quartzite. / Bruin korrelrige kwartsiet
- 5 Granular quartzite and quartz schist / Korrelrige kwartsiet en kwartsskis
- 4 White-brown marble with schist / Witbruin marmer met skis
- 3 Biotite-amphibole schist / Biotiet-amfiboolskis
- 2 Pebble band / Rolsteenlaag
- 1 Banded calc granulite / Gestreepte kalkgranuliet

FIG. 2.—Section (B) across upper and lower stages of the Hakos Series, Panner's Gorge (see fold. 1)/*Profiel (B) oor die boonste en onderste étage van die Serie Hakos, Panner se Kloof (kyk voubl.* 1).

A cross-section of the upper stage, representative of the Lower Khan Gorge area, is shown in figure 2. (The locality of the section is indicated on folder 1.) In contrast to this section, a traverse across the upper stage north of the Potberg (C. 5) reveals some 20 marble bands, varying from 2 to 80 feet thick, unevenly distributed in 2500 to 3000 feet of biotite schist.

(iii) *Petrography*.-There are three major petrographic types within the upper stage, viz. dolomitic marble, calc-silicate rock and biotite schist.

Dolomitic Marble.-In general it forms the bulk of the stage and, as previously mentioned, consists mainly of blue-grey and white marble of variable grain size (1-60 mm). The coarser grained varieties are associated with ultrametamorphism and granite emplacement.

Table 3 shows the mineral assemblages of 14 specimens of the marbles. Calcite and dolomite stain tests with Lemberg's solution (Holmes, 1930, p. 264) were carried out on five of these and the remainder were tested with cold diluted hydrochloric acid. In most of the thin sections, however, the two minerals are readily identified by their twin orientations. The marble was found to be dominantly dolomitic with variable amounts of calcite. Tremolite identified by optical and X-ray methods was the most common accessory followed by graphite, forsterite, diopside and others listed in the table. The textures are nearly all granular with some porphyroblastic. One specimen (KR 42) shows a very distinct orientation of calcite grains in which twin lamellae are bent and the extinction is strained, while dolomite and tremolite grains are unaffected (see pl. XII). The blue-grey marble showed no significant mineralogical difference from the white marble, though the former was found, in the field, to give off the smell of hydrogen sulphide (hence stinkkalk) more commonly than the latter. The calcsilicate minerals do not on the whole, supply good indication of metamorphic grade since they are abundant in localities distant from granite bodies. Tremolite, forsterite and diopside are stable in a single specimen which may be found in proximity to wollastonite and scapolite bands, e.g. Louw's Claims (C-D. 1). Iceland spar of near-saleable quality occurs in cavities in the marble at several places. Serpentine, usually, is found as the common alteration product of forsterite.

Calc-silicates.-Calc-silicate rocks occur both as intercalated chert-like bands and as massive skarn-zones associated with granite or pegmatite emplacement. The former type is usually fine to very fine-grained and tends to form competent uniform dark bands in crystalline marble (see p. XI). The latter is often very coarsely crystalline. The mineral assemblages are generally similar in the two types (see table 4). The wollastonite skarn rocks are the most spectacular of this group, having crystals attaining individual lengths of over 12 inches. Such rocks are found at Louw's Claims (C-D. 1) in association with highly metamorphosed marble capping red gneissic granite and much pegmatite. Marble bands intercalated in Salem gneiss to the northeast of the dome (C. 2) contain large masses of crystalline wollastonite skarn. Scapolite is very common as euhedral crystals in these rocks and attains some 5 cm in length in some areas. The composition of those examined at Louw's Claims is that of mizzonite (± 55 percent $Ca_4Al_6\ Si_6O_{24}\ CO_3$) as determined by refractive index measurements of n ω = 1·572 and n ε = 1·550 ± 0.005 (Winchell and Winchell, 1957, p. 352).

TABLE 3.—MINERALS PRESENT IN MARBLE OF THE UPPER STAGE OF THE HAKOS SERIES

Specimen No.	Calcite	Dolomite	Olivine	Amphibole	Pyroxene	Graphite	Serpentine	Others
SM 20	10%	50%	×	Tremolite*	Diopside*	*		Sphene*, graphite*
SM 39	+	+			*	*		Sphene*, apatite*, phlogopite*
SM 40	5%	90%						Siderite*, leucoxene*
SM 81	20%	70%			Diopside*	*		Quartz*, apatite*, chlorite*, garnet*
SM 85	20%	70%		Tremolite*		*		Quartz+
SM 87	20%	75%	*				Antigorite*	Pyrite*, garnet*
SM 128	×	+	*				*	
SM 125	*	+		Tremolite*				
SM 128	*	+		Tremolite*				
SM 158	*	+		Fluor-tremolite*				
SM 165	*	+				*		
KR 40	+	+		Tremolite*				
KR 41		+						Phlogopite*
KR 42	+	×		Tremolite×		×	*	

Percentages approximate.
+ = Major constituent.
× = Subsidiary constituent.
* = Accessory.

TABLE 4.—MINERALS PRESENT IN CALC-SILICATE ROCKS OF THE UPPER STAGE OF THE HAKOS SERIES

Specimen No.	Calcite or dolomite	Felspar	Quartz	Biotite	Amphibole	Pyroxene	Scapolite	Others
SM 18			+	×	×	Diopside*		Ore*, zircon*, apatite*, serpentine*
SM 28					Tremolite	+	+	Wollastonite +, sphene ×
SM 29a	+		+			Diopside*	+	Sphene ×, wollastonite*, graphite*, etc.
SM 29b	+	*	+			Diopside +	+	Sphene, pyrite, chalcopyrite
SM 67	+	Labradorite ×	+			Diopside*		Sphene*, pyrrhotite*, pyrite*, etc.
LC_2 63′		Orthoclase + Oligoclase +	*	Phlogopite +		Hedenbergite +		Sphene*, pyrite*, apatite*, ore*
LC_2 65′	+		*		Tremolite	+	+	Pyrite*, graphite*, chalcopyrite*, etc.
SM 112	+				Hornblende × Tremolite ×	Diopside ×		Zircon, clinoenstatite, sphene
SM 151					Tremolite +			Graphite
SM 205	*						*	Wollastonite +

+ = Major constituent.
× = Subsidiary constituent.
* = Accessory constituent.

TABLE 5.—MINERALS PRESENT IN BIOTITE SCHIST INTERCALATED IN MARBL   THE UPPER STAGE OF THE HAKOS SERIES

Specimen No.	Quartz	K.felspar	Plagioclase	Biotite	Amphibole	Others
SM 44.............	+	+ Perthite+	*	+		Ore*, zircon*, apatite*, sphene*
SM 42.............	+	+		+		Phlogopite+, garnet*, rutile*, apatite*
SM 43.............				Phlogopite*		Calcite+, dolomite+, serpentine+, ore*
SM 45.............	+	+ (sericitised)	+			Phlogopite×, zircon*, apatite*, ore*
SM 56.............	+	+ Perthite×	+	+	Tremolite	Muscovite*, zircon*, apatite*, sphene*
SM 65.............	+	+ Perthite+	+	×		Magnetite*, zircon*, cordierite×, scapolite
SM 91.............	+		+	+	Hornblende§	Pyroxene, ore, sphene

+ = Major constituent.
× = Subsidiary constituent.
* = Accessory constituent.
§ = Altered from pyroxene.

Biotite schist.-These rocks are found intercalated in the marble in many localities and may constitute considerable thicknesses especially in the lower horizons of the upper stage. As previously stated, such units have been included in the Khomas Series where they predominate over widely spaced marble bands. In general these rocks are very similar to the Khomas schist, but tend to contain fewer semi-pelitic intercalations. They vary from fine-grained, thin-bedded banded (some graded) to coarsely crystalline, thickly bedded types. Porphyroblasts of cordierite or garnet are abundant, though glomeroporphyroblasts of quartz and felspar with biotite-rich margins are more typical of the knotted schists. Table 5 shows the mineral assemblages of seven thin sections from these rocks.

(iv) *Deposition*.-In contrast to the underlying strata the upper stage is widely and relatively consistently developed, and there is no indication that the Basement protruded through the sedimentary floor as hills or mountains. It is evident, therefore, that the dolomite and limestone were laid down on a regular submarine plain in which the previously existing basins had been filled. Conditions like those operative during the deposition of the lower stage, must have been of fairly shallow, still waters of low Eh and above normal pH. Though probably dominantly of chemical origin, the carbonate precipitation may also have been aided by algae which are present in the Otavi rocks in the form of stromatolites. The carbonate material is probably also partly allogenic. Breaks in limestone deposition were frequent in many areas as the abundant intercalations of argillaceous and lesser semi-pelitic rocks indicate. Sudden changes of pH may have been the cause of silica precipitation during the formation of chert bands.

2. THE KHOMAS SERIES

Being the topmost member of the Swakop Facies of the Damara System this series is widely distributed in synclines within the area under discussion, especially in the east where it is also extensively occupied by granite and gneiss. Southeast of the Swakop River and beyond the line of hills bordering its banks, the schist becomes increasingly prominent towards the Khomas Hochland to the southeast of the map.

(a) *General Character*

The Khomas Series is composed of a vast thickness of magnesium-rich biotite schist of generally monotonous character. In the area under review they consist of alternating thinly to thickly bedded units of fine to mediumgrained, biotite-rich quartzofelspathic schist. They are commonly coarsely crystalline and form massive units of considerable width. In many areas the schist is crowded with knots of quartz-felspar or with porphyroblasts of garnet, cordierite, hornblende and occasionally sillimanite. Though morphologically subordinate to most other formations, they are very well exposed in the Swakop and Khan Gorges. Here they show up on aerial photographs as black areas transgressed in some places by hundreds of largely concordant white stripes (pegmatites). (See p. XIII.)

Being a fairly uniform unit throughout the area it is by its mineral assemblage a good indicator of metamorphic grade. In detail there is little evidence of a variation in grade from east to west as similar mineral assemblages can be found in both areas, e.g. sillimanite-biotite schist or cordieritebiotite schist. There are, however, certain low-grade areas which are more prevalent in the eastern half of the map. Such areas occur between the Otjipatera and Kuduberg Ranges on Gamikaub West 115 and Etusis 15 (B-C. 4) where the schist is locally more phyllitic in character.

TABLE 6.—MINERALS PRESENT IN THIN SECTIONS OF KHOMAS SCHIST

Specimen No.	Quartz	K felspar	Plagioclase	Biotite	Cordierite	Others
SM 54	+	× (sericitised)	× (sericitised)	Chlorite-biotite +	×	Zircon*, apatite*
SM 84	+		An_{10} +	+	+	Sericite ×, apatite*, zircon*, ore*
SM 92	+		×	+	+	Zircon*, apatite*
SM 98	47·15%	12·29%	24·79%	15·2%		Apatite*, zircon*, garnet*
SM 149	+			+		Ore*
SM 163	+			+		Ore*
SM 214	+		+	+	+	Apatite*, zircon*, ore*

+ = Major constituent.
× = Subsidiary constituent.
* = Accessory constituent.

Percentages by volume determined on stained thin section (1376 counts over 2·75 sq. cm).

(b) *Thickness*

The top of the series has not been found anywhere in South West Africa so that the true thickness cannot be assessed. The series, like those below it, is also subjected to intense folding entailing much repetition of beds on micro-, meso- and macroscales. The maximum development of the schist in this area is probably present to the northwest of the Erekereberg in the Otjimbingwe Reserve 104 (C. 5) where it is upward of 10,000 feet thick. Here several marble bands are intercalated at widely spaced intervals.

TABLE 7.—CHEMICAL ANALYSES AND CATION PROPORTIONS OF SALEM GRANITE AND GNEISS, KHOMAS SCHIST AND QUARTZ DIORITE

Rock-type.................	Salem granite and gneiss					Khomas schist		Diorite
Sample No.................	A	B	SM 97	SM 153a	SM 153b	SM 98	SM 218	SM 181
				Chemical analyses				
SiO_2	73·86	67·10	68·05	68·32	65·96	73·36	63·10	59·40
Al_2O_3	13·63	14·30	15·90	16·97	17·58	12·61	17·60	19·65
Fe_2O_3	0·80	1·11	0·39	0·79	0·78	1·30	0·81	1·85
FeO	0·14	2·59	2·68	1·60	1·71	2·73	5·90	4·05
MgO	0·08	1·82	1·59	0·58	0·93	1·91	3·75	2·54
CaO	1·22	3·40	2·84	3·47	3·87	2·00	2·08	5·23
Na_2O	3·36	3·20	2·57	4·93	3·43	2·15	2·25	3·19
K_2O	5·25	3·70	3·70	1·74	2·31	2·20	2·40	1·87
H_2O+	0·40	0·67	0·50	—	—	0·41	—	—
H_2O-	0·12	0·13	0·20	—	—	0·21	—	—
CO_2	0·60	0·50	0·35	—	—	0·46	—	—
TiO_2	—	0·75	0·63	0·18	0·24	0·85	0·20	0·74
P_2O_5	0·03	0·26	0·28	0·11	0·12	0·20	0·12	0·18
MnO	0·02	0·07	0·06	—	—	0·05	—	—
TOTALS..........	99·51	99·60	99·74	98·69	96·93	100·44	98·21	98·70
				Cation proportions				
Si	69·75	64·30	63·11	63·90	63·52	70·06	60·50	56·10
Al	15·91	15·80	17·38	18·69	19·87	14·38	19·70	21·80
Fe^{+3}	0·56	0·78	2·67	0·55	0·57	0·94	0·62	1·31
Fe^{+2}	0·11	2·01	2·08	1·24	1·24	2·21	4·72	3·19
Mg	0·11	2·56	2·19	0·81	1·34	2·75	5·38	3·60
Ca	1·24	3·44	2·82	3·59	3·99	2·07	1·99	5·28
Na	6·17	5·84	4·62	8·93	6·38	4·03	4·17	5·82
K	6·32	4·45	4·38	2·08	2·84	2·72	2·94	2·26
Ti	—	0·53	0·44	0·12	0·17	0·62	0·16	0·59
P	0·02	0·20	0·22	0·08	0·10	0·16	0·10	0·14
Mn	0·03	0·05	0·05	—	—	0·04	—	—
TOTALS..........	100·22	99·96	99·96	99·99	100·02	99·98	100·28	100·09

A. Fine-grained granite. Zebra River south of the Ugab River (Jeppe, 1952).
B. Coarse-grained porphyritic granite. Brandberg West Airstrip (Jeppe, 1952).
SM 97. Coarse-grained porphyroblastic gneiss. Swakopmund–Usakos main road (see fold. 3).
SM 153a & b. Medium-grained granite. Etusis 75 (see fold. 3).
SM 98. Khomas schist. Same locality as SM 97.
SM 218. Khomas schist channel-sample over 950 feet. Lower Khan River Gorge (see fold. 3).
SM 181. Quartz diorite. Gamikaub 78 (see fold. 3).
(i) SM 153a & b and SM 218 are specimens selected as having a mean mineralogical composition from a number of volumetric analyses (see tables 11 and 12).
(ii) SM 153a & b are identical samples crushed and quartered prior to analysis. The probable reliability of these samples is ± 1·0 per cent for K, Si and Al; ± 0·5 per cent for Fe^{+3}, Fe^{+2}, Ca and Mg; 2·5 per cent for Na; and ± 0·08 per cent for Ti and P. The other analyses are expected to have similar reliabilities.

Analyses:
SM 97 and SM 98 by Soils Research Institute, Pretoria; and SM 153a & b, SM 218 and SM 181 by Heymann's Laboratories, Johannesburg.

(c) *Petrography*

Table 6 shows the mineral assemblages of seven thin-sectioned specimens taken from widely spaced localities in the Khomas schist. Quartz and biotite are always dominant constituents, while the amount of felspar and sericite varies considerably, plagioclase generally being the dominant felspar. Cordierite, both in thin section and in hand-specimen, is by far the most common accessory metamorphic mineral, though sillimanite, amphibole or garnet is frequently found to be locally abundant. The lower grade schists of the area around Gamikaub West 115, mentioned above, usually contain no felspar and a high proportion of chlorite and sericite as well as quartz and biotite. The knots in these rocks are composed largely of quartz aggregates with biotite-rich selvedges (see pl. XIV).

The texture of the argillaceous schist is distinctly lepidoblastic grading, where coarsely crystalline, into porphyroblastic and in some cases gneissose. The biotite quartzite has granoblastic to lepidoblastic textures. Biotite in nearly all cases is oriented parallelto the bedding and only rarely to the axial planes of folds. Porphyroblastic garnet, cordierite, hornblende, tremolite and sillimanite were seldom observed to be structurally deformed or rotated, though glomeroporphyroblasts were occasionally seen to be (see pl. XIV). Oriented elongate crystals of sillimanite and amphibole parallel to major and miner fold axes can sometimes be found. On Gamikaub 78 on the banks of the Gamikaub River (c. 4) there are abundant sillimanite-rich beds in the schist in which sillimanite exhibits a vector orientation.

(d) *Chemical Composition*

The chemical analyses and derived cation proportions of two Khomas schist samples are compared with igneous rocks occurring in the same stratigraphic horizon in table 7. SM 218 is a pseudochannel-sample taken across 950 feet of schist in the Lower Khan Gorge area and should be fairly representative of the bulk composition of these rocks. SM 153a and l53b are two analyses of one sample taken from a rock showing a mean mineralogical composition of the Salem granite (see table 11). SM 181 is of a specimen having a mean mineralogical composition of quartz diorite (see table 12).

Comparison of the cation proportions of SM 218 with the igneous types shows that with the exception of Mg and Fe+2 in which the schist is richer by 1·78 to 5·27 per cent and 1·53 to 4·61 per cent, respectively, and Na which is nearly double in the granite, the analysis falls within the range of those of the igneous rocks.

The significance of these comparisons will be discussed together with the origin of the igneous rocks.

(e) *Deposition*

The thick and uniform distribution of the Khomas schist overlying dolomite and limestone over a very wide area in South West Africa, suggests that after deposition of the carbonate rocks a distinct but not radical change of environment occurred. That the carbonate cycle must have been reinstated several times is evident in the presence of widely spaced marble intercalations in may places. The most distinctive features of the schist, as found in this area, are its thickness, rhythmic sequence of semi-pelitic and argillaceous beds, presence of intercalated carbonate beds and absence of graded beds, conglomerate and cross-beds.

In the light of the above features, the sediment cannot be regarded as resembling a flysch deposit or greywacke. The schist is in general of too mature a sedimentary type. It seems reasonable to assume that it accumulated at an intermediate depth-zone under. oscillatory transportation conditions many miles from its source.

B. THE GENERATION OF IGNEOUS ROCK-TYPES

1. INTRODUCTION

The investigation of the igneous rock-types present in the Nosib Formation and the Damara System in this area forms part of a special study which although incomplete, should serve as a basis for any future detailed research.

In addition to mapping the regional distribution and structural setting of the different granites and gneisses, representative specimens of the more homogeneous groups were taken and studied in detail. Emphasis has been placed on mineralogical composition as well as on texture in dividing the granitic rocks into different groups.

2. LABORATORY METHODS

Some 50 specimens were volumetrically analysed after the method of Chayes (1949) using a Swift automatic point-counter. For rocks of an average grain size of more than 2 to 3 mm the analyses were made on polished slices containing a surface area of at least 100 times that of the largest grain present. A dot-pattern Zip-A-tone grid was used for grain counting under a binocular microscope (Jackson and Ross, 1956). None of the rocks were sufficiently fine-grained (less than 0,3 mm) to become subject to the "superposition error" outlined by Elliott (1952).

In order to obtain rapid identification of the minerals present, especially quartz, potash felspar and plagioclase, staining techniques were used on both thin sections and polished slices. Potash felspars were stained yellow with sodium cobaltinitrite and plagioclase was stained red and biotite green (as distinct from hornblende) with potassium rhodizonate using the methods of Bailey and Stevens (1960).

Plagioclase compositions were determined by measuring the refractive index and albite twin extinction-angles of crushed grains lying on the (001) cleavage. The results given have a maximum error of ± 5 per cent An.

The accuracy of the volumetric determinations tested over five separate counts on the same specimen was shown to be fairly good. The minimum error was ± 1·8 per cent for any mineral on stained sections or slices (e.g. quartz 29·10 ± 1·8 per cent, plagioclase 29·00 ± 1·8 per cent, biotite 4·98 ± 1·8 per cent, etc.). It can therefore be assumed that the accuracy is fairly constant in all the analyses, though inhomogeneity in the rocks may provide a greater variation.

3. CHEMICAL ANALYSES

A study of this nature should in fact be supported by a large number of total rock as well as mineral analyses. Facilities for analyses were extremely limited. Only nine analyses were available resulting in only weak chemical support to the arguments on petrogenesis raised at the end of this section.

4. THE VARIOUS ROCK-TYPES

The following granitic types were distinguished in the field by virtue of their structural position, macroscopic appearance and mineralogical character: Red gneissic granite, grey biotite-rich gneiss and granite (Salem type), quartz diorite and diorite-gneiss, homogeneous intrusive granite, pegmatite and quartz veins, and aplite.

(a) *Red Gneissic Granite*

(i) *Distribution*.- These rocks underlie large areas in the region mapped, but occur only in domes, brachydomes and anticlines within strata underlying the upper stage of the Hakos Series.' They do not occur in all of these structures, but are broadly confined to two distinct belts running from southwest to northeast, one from the Khan-Swakop confluence to Usakos, and the other from Okakoara 43 and Kaliombo 119 (inset) to Dorstriviermund.

(ii) *Macroscopic Character*.- In the field these types of gneiss and granite-gneiss have a typically reddish colour and vary in texture from inhomogeneous concordantly banded gneisses with dark ferromagnesian-rich bands and large metasediment xenoliths to homogeneous coarsely crystalline granite which is not readily distinguished from those showing distinct intrusive relations. The former gneissic rocks are, however, by far predominant and are exceptionally well exposed in the lowest portion of the Khan Gorge (D. 1) as well as in the Kuduberg and on Otjua 37 (B. 5 and inset) where they are morphologically prominent. Less striking exposures occur at many other places.

The contacts between gneiss and metasediment are mostly ill-defined within the Nosib Formation, though granitic types may exhibit quite sharp contacts against sillimanite or biotite-rich gneiss or metasediment. The distinction between gneiss and metasediment is too subtle a one to draw a distinct boundary. On the map the boundaries are defined by dotted lines which usually divide areas of dominantly granitic gneiss from areas of bedded metasediment with subordinate amounts of gneiss. The transition from sediment to granitic rock is well exposed in a section from Welwitsch to Blauer Heinrich in the area on folder 1. Similar though less distinct transitions occur in most of the antiforms where the gneiss does not occupy the whole of the Nosib Formation up to the lowest marble band of the Damara System. In many cases, however, the marble is found in contact with and capping the gneissic granite and granite, e.g. in brachydomes south of Rössing and Arandis in the southwest and on Otjua 37 (inset). Here, as for example at Louw's Claims, the gneiss occupies the tillite horizon and the marble of the lower stage remains as skarn and marble xenoliths in the gneiss. The contacts with the marble and with xenoliths are sharp, though in the former case are frequently found to be separated by large developments of pegmatite.

The distinction between autochthonous and intrusive bodies is not readily made where the homogeneous red granite bodies occur within the same stratigraphic horizon as their apparently parent gneisses. In the Okatjeneberg on Meyersrust 118 (inset) the rock underlying as well as overlying the Upper Hakos marble which remains undisturbed (see pl. XV), is a homogeneous granite, weathering into large exfoliated blocks and containing no gneissic structure. Although possibly largely autochthonous, it is deemed to have moved and have been intruded into the overlying Khomas schist, and is classified as an intrusive granite of the Geisterberg type. other places too, smaller homogeneous bodies of apparently magma character have been classed as intrusive even though they may have onl moved very short distances. These bodies of red granite are, however, ver subordinate in volume to the moderately homogeneous granite-gneiss which is characteristic of a great many domes in the area.

(iii) *Petrography*.-The petrography of the gneiss is variable especially in the inhomogeneously banded varieties. Individual bands may vary from granular felspar-quartz-biotite rocks of granitic composition to quartzofelspathic biotite-sillimanite and biotite-amphibole schistose or gneissose types. An apparent metamorphic sequence of this nature was examined in detail at Louw's Claims (C. 1)

TABLE 8.—CHEMICAL ANALYSES, CATION PROPORTIONS, MODES AND KATANORMS OF SCHIST AND GNEISS

Sample No.	SM 34	SM 35	SM 36
Chemical analyses			
SiO_2	47·19	64·78	61·74
Al_2O_3	16·05	13·35	14·14
Fe_2O_3	10·34	6·46	6·37
FeO	5·81	3·58	4·31
MgO	3·61	1·33	1·05
CaO	3·60	0·60	0·13
Na_2O	1·30	1·77	2·08
K_2O	3·50	6·12	7·85
H_2O+	2·19	0·18	0·26
H_2O-	1·19	0·28	0·20
CO_2	1·06	0·29	nil
TiO_2	3·48	0·83	1·78
P_2O_5	0·43	0·11	0·12
MnO	0·34	0·05	0·05
TOTALS	100·09	99·73	100·08
Modes			
Quartz	12·91	25·31	13·13
K felspar	Sericite=	49·40	59·40
Plagioclase	45·15	11·20	14·48
Biotite	20·92	10·40	8·66
Iron ore	17·20	3·00	2·95
Accessories	3·78*	0·68†	1·47§
TOTALS	99·96	99·99	100·09

	SM 34	SM 35	SM 36
Cation proportions			
Si	48·53	62·90	59·45
Al	19·21	15·28	15·93
Fe^{+3}	7·95	4·72	4·62
Fe^{+2}	4·96	2·90	3·47
Mg	5·45	2·21	1·50
Ca	3·91	0·62	0·12
Na	2·57	3·41	3·87
K	4·53	7·58	9·59
Ti	2·69	0·76	1·27
P	0·37	0·09	0·12
Mn	0·31	0·04	0·06
TOTALS	100·48	100·51	100·00
Katanorms			
Quartz	22·59	29·27	19·07
K felspar	13·05	34·15	45·70
Plagioclase	20·20	18·15	19·35
Biotite	15·36	6·00	7·55
Iron ore	13·90	8·16	8·09
Sphene	5·10	0·66	—
Apatite	1·11	0·27	0·24
Corundum	9·17	3·85	—
TOTALS	100·48	100·51	100·00

SM 34. Biotite-sericite schist.

SM 35. Quartzofelspathic biotite gneiss.

SM 36. Red quartzofelspathic granitic gneiss.

Analyses:—By Soils Research Institute, Pretoria.

* Major accessories include apatite, epidote, zircon, pyrite, hornblende and sphene.
† Major accessories include apatite and clinozoisite.
§ Major accessories include zircon, sillimanite and apatite.

Three specimens comprising a biotite-sericite schist (SM 34), a quartzofelspathic thinly banded biotite gneiss (SM 35) and a comparatively homogeneous redquartzofelspathic granitic gneiss (SM 36) were taken from a single outcrop in which these rocks were intimately related. To the writer it was apparent in the field that the mica schist had been progressively metasomatised by potash-rich 'solutions which introduced microcline into the rock in the immediate vicinity. The mica schist is representative of abundant concordant metasediment xenoliths, the granitic gneiss of massive volumes of rock composing the bulk of the core of the brachyanticline and the banded gneiss of intermediate types. The results of the laboratory investigations of the specimens are shown in table 8.

From table 8 it can be seen that the modes which were carefully calculated from several thin sections from each specimen, compare extremely poorly with the calculated compositions (katanorms). This is extremely unfortunate since a comparison of the cation proportions in table 8 would indicate which ions would have to be added or subtracted to form one rock from another. The available evidence obtained from a study of thin sections and chemical composition is indicative of an addition of mainly potassium, and silicon on a small scale at least, to produce the granite-gneiss from mica schist of the type SM 34 and not of a simple isochemical reaction. This may not necessarily be true on a larger scale.

The texture and mineral assemblages of the three specimens are interesting in the light of progressive metamorphism. SM 34 consists of orientated laths of biotite, some of which contain sphene as inclusions, which form bands in a matrix of disorientated sericite, angular quartz and irregular iron oxide and pyrite grains. SM 35 has similar orientated biotite bands with no sphene, set in a matrix of quartz and microcline-perthite. SM 36 contains disseminated orientated biotite in an equigranular matrix of microcline, microcline-perthite and quartz. A feature of this rock is the intergranular disposition of the plagioclase which has evidently exsolved to the boundaries of the potash felspar (SM 36) to form a type ofrapakivi texture (see pl. XVI). This textural feature is commonly found in potash felspar-bearing metasediments of a higher grade, especially where the felspar is concentrated into glomeroporphyroblasts as in certain felspathic biotite quartzites in the lower stage of the Hakos Series in Pinnacle Gorge (C. 2). The texture of SM 34 (biotite-sericite schist) is not indicative of retrograde metamorphism as there is no sign of parent felspar or other mineral to which it could be attributed. It is regarded as being a low-grade remnant typical of the many metasediment xenoliths found in the granite-gneiss terrains.

For the purpose of making a comparative study of the red gneissic granite throughout the area, specimens of the most homogeneous varieties which are very widely developed and typical of this type, were collected and their mineralogical compositions determined volumetrically by the methods outlined above. The results are shown in table 9 and are plotted together with the Salem granite and quartz diorite types on the triangular diagrams in figures 3, 4 and 5. On these diagrams the red gneiss is shown to form a distinct mineralogical group of rocks rich in potash felspar, poor in ferromagnesian and deficient in calcic plagioclase. Furthermore, the specimens collected from the east of the area (SM 154, SM 157, SM 161 and SM 166; localities on fold. 2) exhibit a different subgrouping from those in the west as shown in figure 6. Within the major group all these gneissic granites show a fair range of composition which is probably present on micro-, meso- as well as macroscopic scales.

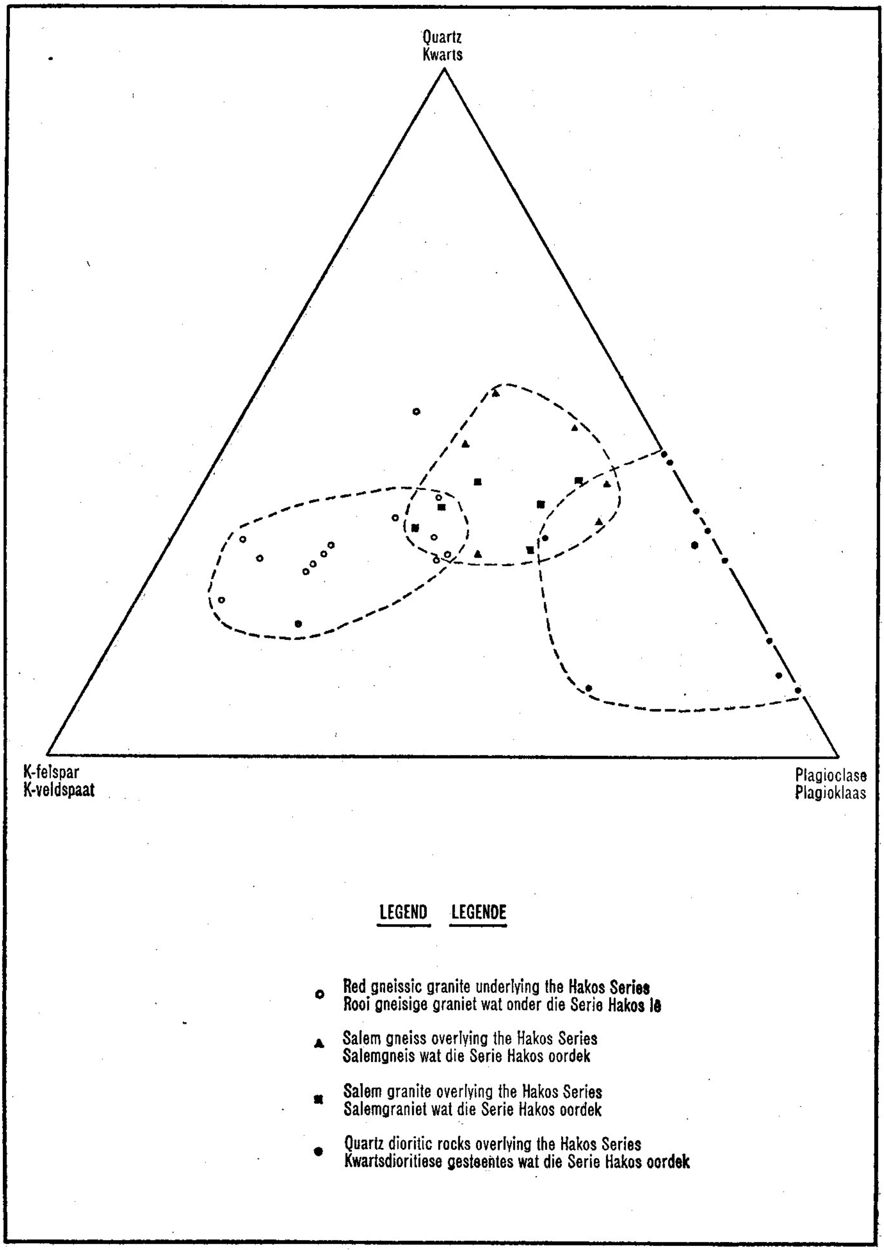


FIG. 3.—SiO_2–$KAlSi_3O_8$–$Na,CaAl_2Si_3O_8$ plot for igneous rocks of autochthonous character/*SiO_2–$KAlSi_3O_8$–$Na,CaAl_2Si_3O_8$-uittekening vir stollingsgesteentes met outochtone kenmerke.*

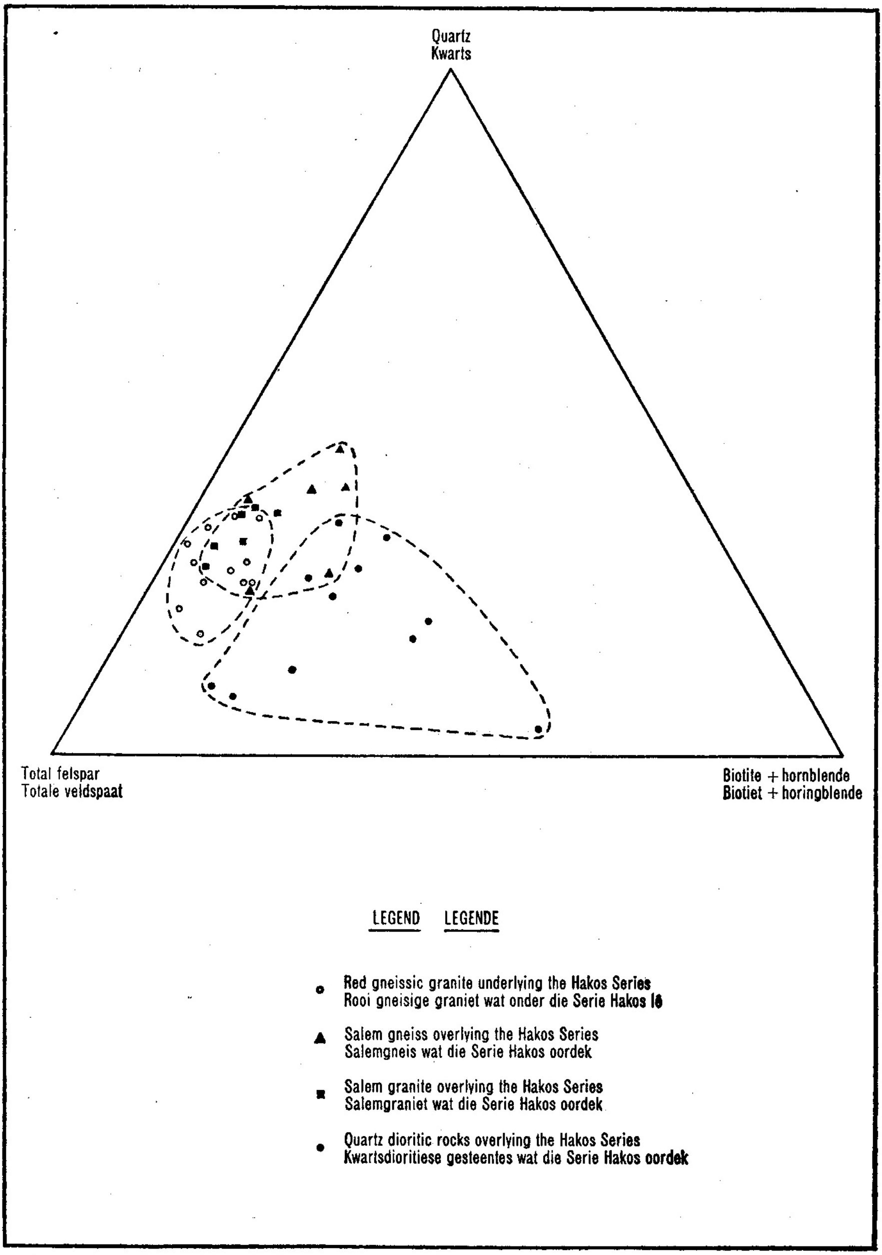


FIG. 4.—SiO_2–($KAlSi_3O_8$+Na,$CaAl_2Si_3O_8$)–(biotite+hornblende) plot for igneous rocks of autochthonous character/*SiO_2–($KAlSi_3O_8$+Na,$CaAl_2Si_3O_8$)–(biotiet+horingblende)-uittekening vir stollingsgesteentes met outochtone kenmerke.*

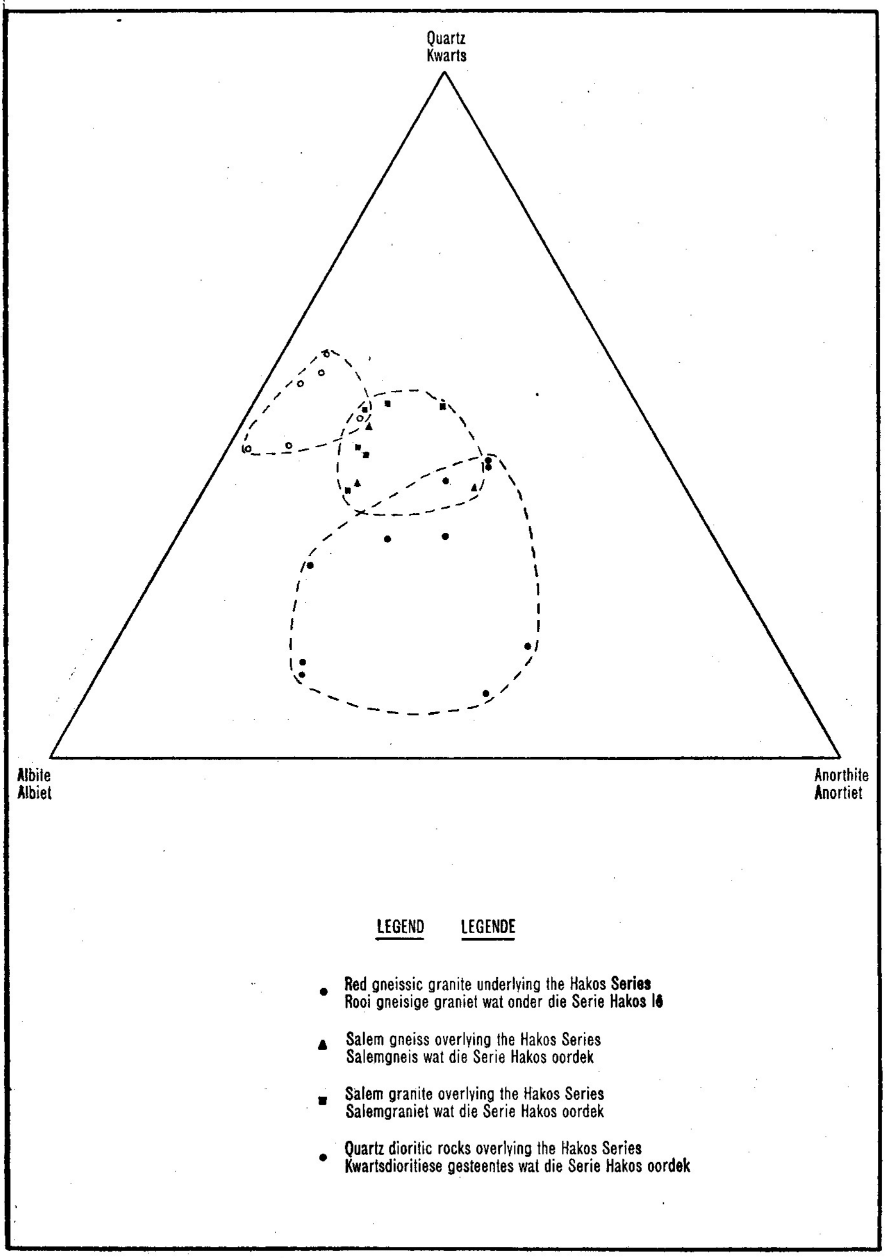


FIG. 5.—SiO_2–$NaAlSi_3O_8$–$CaAl_2Si_2O_8$ plot for igneous rocks of autochthonous character/*SiO_2–$NaAlSi_3O_8$–$CaAl_2Si_2O_8$-uittekening vir stollingsgesteentes met outochtone kenmerke.*

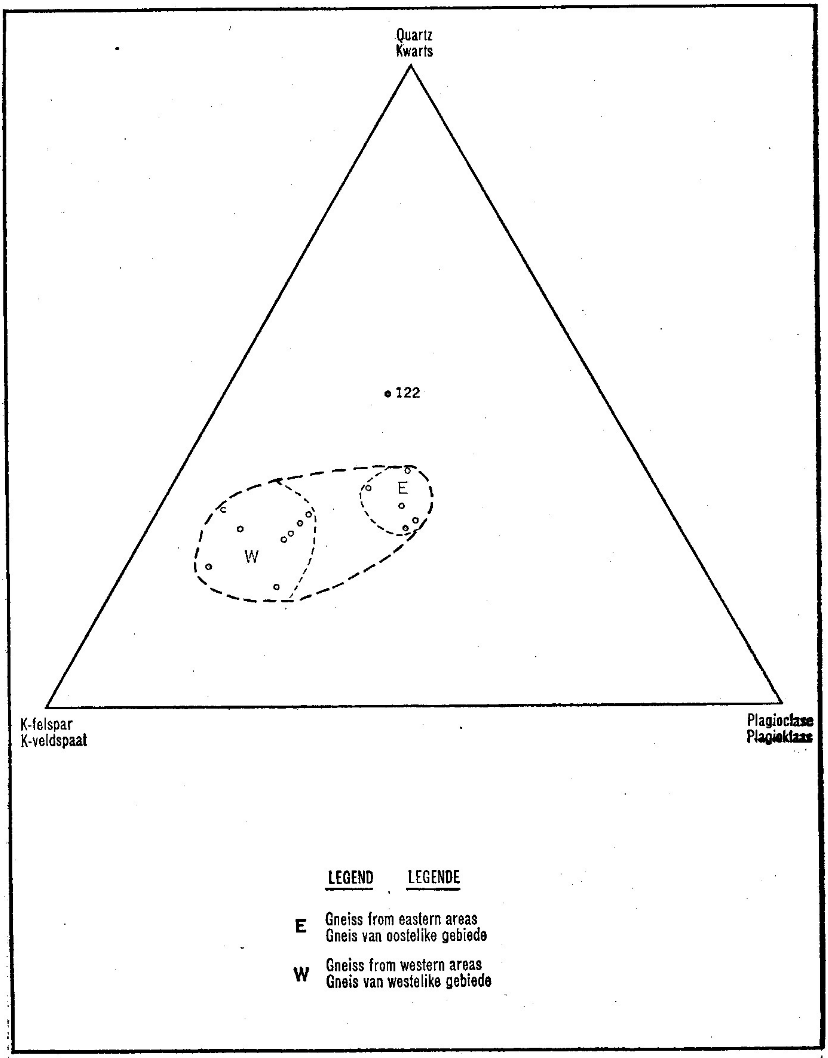


FIG. 6.—SiO_2–$KAlSi_3O_8$–$Na,CaAl_2Si_3O_8$ **plot for gneiss underlying the Hakos Series/** ***SiO_2–$KAlSi_3O_8$–$Na,CaAl_2Si_3O_8$-uittekening vir gneis wat onder die Serie Hakos lê.***

In hand-specimen these rocks are coarse medium to fine-grained granular, containing abundant pink to red potash fe1spar, pale plagioclase and clear quartz with subsidiary amounts of black biotite ,arranged in bands. Some specimens have well-oriented fe1spars. In thin section textures vary from allotriomorphic granular to lepidoblastic and porphyroblastic (or porphyritic). Microcline and microcline-perthite and plagioclase (An5-30) are the dominant felspars; plagioclase is more commonly altered than is microcline. Quartz is present

Table 9.—VOLUMETRIC ANALYSES OF GNEISS IN THE NOSIB FORMATION

Specimen No.	SM 122†	SM 154†	SM 157	SM 161	SM 166†	SM 216	SM 214A †	SM 154†	SM 15	SM 35	SM 36	SM 6*	KR 4	KR 4(i)	KR 43	KR 28
Quartz	41·90	33·25	25·12	27·10	28·82	33·56	28·52	34·18	30·84	25·38	13·17	21·16	30·18	35·22	28·08	25·23
K felspar	24·25	28·11	31·89	32·18	31·78	37·35	46·10	28·91	58·84	51·81	61·91	62·56	46·15	49·35	48·26	50·50
Plagioclase	18·39	28·25	31·14	32·72	29·91	26·23	19·91	27·61	8·47	11·38	14·31	10·61	22·50	9·84	19·50	17·92
Biotite	14·56	10·30	10·85	8·40	7·98	2·82	4·34	8·70	1·68	9·39	7·72	5·29	1·07	5·16	4·08	5·33
Accessories	0·30	0·09	0·88	0·08	0·91	0·04	1·15	tr.	0·20	1·99	2·95	0·33	tr.	0·49	tr.	0·52
Totals	99·40	100·00	99·88	100·48	99·40	100·00	100·02	99·40	100·03	99·95	100·06	99·95	99·90	100·06	99·92	99·50
Heavy minerals	Zircon Apatite Sphene	Zircon Apatite	Zircon	Zircon Apatite	Zircon Apatite	Zircon Apatite Ore	Zircon Apatite Ore	Zircon Apatite	Zircon Apatite Ore	Zircon Apatite Ore Clino-zoisite	Zircon Ore Silli-manite	Zircon Apatite Ore	Zircon Ore	Zircon Ore	Leucox-ene	Zircon
Composition of plagioclase	—	$An_{10\pm3}$	$An_{5\pm2}$	$An_{15\pm3}$	$An_{30\pm5}$	$An_{14\pm5}$	$An_{15\pm5}$	—	—	—	—	—	—	—	—	—

* = Unstained thin section.

† = Polished slice.

All others were stained thin sections.

as irregular grains and biotite, or rarely muscovite, in disorientated or orientated laths. Zircon, apatite and ore are common accessories, the first two being present as round, subround and subangular grains. Sillimanite is locally abundant and intimately associated with biotite. Its presence is indicative of a metamorphic rather than a magmatic origin. Sphene is conspicuously absent and is thought to be unstable in this group of rocks.

The textures, especially those of porphyroblastic type, are generally indicative of late-syntectonic to post-tectonic crystallisation. In some of the coarse-grained porphyroblastic types the felspars are euhedral and randomly orientated showing no signs of flattening or crushing. In others the tabular crystals, though euhedral to subhedral, are well oriented thus indicating either flow-structure or gentle compressjon conditions during crystallisation. Neither cleavage nor mylonitisation associated with fold movements was observed. As far as can be judged therefore, metamorphism and granite emplacement took place simultaneously.

The mode of emplacement of the granitic rocks will be discussed at the end of this section.

(iv) *Chemical Composition*.- The analyses of a banded gneiss (SM 35) and a more homogeneous granitic gneiss (SM 36) are shown in table 8. SM 214A was chosen as a sample showing the mean mineralogical composition of all red granitic gneisses examined and had the chemical composition and cation proportions shown in table 10.

TABLE 10.—CHEMICAL ANALYSIS AND CATION PROPORTIONS OF RED GRANITIC GNEISS

Chemical analysis		Cation proportions	
SiO_2	66·16	Si	63·49
Al_2O_3	18·38	Al	20·75
Fe_2O_3	2·01	Fe^{+3}	1·44
FeO	1·48	Fe^{+2}	1·18
MgO	0·99	Mg	1·61
CaO	1·92	Ca	1·98
Na_2O	1·66	Na	3·08
K_2O	5·13	K	6·26
TiO_2	0·42	Ti	0·29
P_2O_5	0·12	P	0·11
TOTAL	98·27	TOTAL	100·19

Analysis by Heymann's Laboratories, Johannesburg.

This analysis is, unfortunately, accurate only up to ± 2·5 per cent for sodium and ± 1·0 per cent for potassium, but as compared with the composition of the Salem granite and quartz diorite (table 7) is on the whole considerably higher in potassium and lower in sodium.

(b) *Grey Biotite-rich Gneiss and Granite (Salem Gneiss and Granite)*

This group includes the typical porphyritic biotite granite originally described by Gürich (Gevers, 1931, p. 101) from Salem on the Lower Swakop River; hence the name Salem granite. In addition to the above porphyritic granite which generally exhibits a distinct foliation, the writer has included biotite-rich non-porphyritic gneiss and granite. With the exception of those occurring on Ubib 76 and Kubas 77 (B-C. 4), which are non-gneissose intrusive types, they are the same as those mapped as Salem granite by Gevers (1934).

(i) *Distribution*.- The Salem gneiss and granite, as seen on the maps of the area, are confined entirely to synclines occupied by the Khomas Series. Two major northeast-trending zones are present; one extending from southwest of Arandis to near Usakos and the other from the south of Horebis Nord 61 (D. 4) to Neu Schwab en 73 (B. 5).

(ii) *Macroscopic Character and Field Relations*.-In the field these rocks are generally morphologically subordinate and tend in flat areas to form low whale-back outcrops with rounded exfoliated surfaces. They are particularly well exposed in the Swakop River gorge between Horebis Nord 61 and the Tsaobis-Swakop confluence. The bulk of the rock is light-grey porphyritic (or porphyroblastic) biotite-rich gneissose granite, but large portions are purely granitic, e.g. on Neu Schwaben 73. The porphyroblasts are almost exclusively potash felspar and only rarely plagioclase. They are generally euhedral to subhedral and are found to be strongly orientated, poorly orientated and unorientated. In the more gneissose varieties, the rocks are very inhomogeneous and contain variable amounts of biotite and potash felspar. In some localities they could be described as porphyroblastic schist. Plates XVII and XVIII illustrate the typical character of the porphyroblastic type. Plate XVIII shows its relation to schist xenoliths close to the main contact with Khomas Series.

Contacts between the Khomas schist and marble and the Salem granite and gneiss are often very sharp. The xenoliths in these places are usually orientated parallel to the contact and are composed of both dense biotite schist and lighter coloured quartzofelspathic schist. In some cases [e.g. north of Roddy's Gorge (C. 2)] the granite looks as though it is intrusive owing to the sharp contact with the Upper Hakos Stage, but even here there are isolated narrow marble bands concordantly situated in the granite. Also to the northeast of the dome on folder 1 there are several intercalations of marble in the granite which, when followed along strike northeastwards, is found to grade into biotite schist bands. A similar condition is present within the Upper Hakos Stage at Dorstriviermund (C. 4).

The Salem granite types are not found in contact with the red gneiss described above, but on Goas 79 (B. 5) a distinct relationship between a coarse-grained variety of porphyritic Salem granite and quartz diorite-gneiss is present. This granite body cross-cuts the foliation of the gneiss along a sharp curvilinear contact. Here it seems clear that this particular granite is both later than and intrusive into the quartz diorite-gneiss. Similar relationships are found between the gneissose and granitic types of Salem granite in many places. On Stinkbank 62 (B. 3) a non-porphyritic granite type distinctly post-dates the gneissic variety. The granitic rock becomes indistinguishable in many places from the truly intrusive bodies founo on Ubib 76 and Kubas 77 (B-C. 4) so that although clearly separated on the maps, parts of the areas designated Salem granite and red homogeneous granite are mineralogically and texturally indistinguishable. Likewise, the distinction between Salem granite and quartz diorite of granitic texture becomes difficult where an intermediate type occurs and contains quartz, potash felspar, plagioclase, hornblende and biotite. Such rocks outcrop over wide areas on Gamikaub West 115 (C. 4) and Etusis 75 (B. 5). It is apparent that the gneissic varieties are late syntectonic and autochthonous while the granitic varieties crystallised under non-compressive conditions and were locally mobilised and intruded.

TABLE 11.—VOLUMETRIC ANALYSES OF SALEM GRANITIC ROCK-TYPES

Specimen No.	SM 38†	SM 80*	SM 94†	SM 97‡	SM 217†	SM 215†	SM 153	SM 135	SM 121†	SM 150†	SM 180	SM 119†
Rock-type	Gneissose granite						Granite					
Quartz	38·95	39·20	37·00	31·57	26·05	24·36	34·99	36·08	27·82	30·78	31·85	35·41
K felspar	21·80	7·90	6·90	17·29	10·80	27·21	16·00	22·99	22·53	35·50	29·41	11·25
Plagioclase	25·80	35·20	41·50	33·90	40·80	35·72	42·30	32·08	43·40	29·00	30·20	42·65
Biotite	13·50	17·40	12·60	11·44	22·25	12·79	6·66	8·92	6·32	4·98	8·57	10·59
Accessories	tr.	0·30	2·00	5·38	tr.	tr.	tr.	tr.	tr.	tr.	0·14	tr.
TOTALS	100·05	100·00	100·00	99·58	99·90	100·08	99·95	100·07	100·07	100·26	100·17	99·90
Heavy minerals	Zircon Apatite Ore	Zircon Apatite	Zircon Apatite Sphene Ore	Zircon	Zircon Apatite Ore	Zircon Apatite	—	—	Zircon Allanite Sphene	Zircon Apatite	Zircon Apatite	Zircon Apatite Sphene
Composition of plagioclase	—	—	—	$An_{32}\pm_3$	$An_{56}\pm_3$	$An_{30}\pm_5$	$An_{30}\pm_5$	$An_{30}\pm_5$	$An_{30}\pm_5$	$An_{25}\pm_5$	$An_{50}\pm_5$	$An_{30}\pm_5$

* Unstained specimen.

† Polished specimen.

‡ Norm.

All other analyses made on stained thin sections.

Another curious phenomenon is the relation of the porphyroblastic Salem gneiss to the quartz diorite-gneiss. The latter always contains hornblende and seldom potash felspar, whereas the former always contains potash felspar and seldom hornblende. In the vicinities east of Neu Schwaben 73 (B. 5) and Gamikaubmund (C. 4-5) the two rock-types are in close association and at the former locality apparently in contact, though only suboutcropping. In the latter area they are separated by minor anticlines only. As far as can be judged these two gneisses are contemporaneous and the reason for the differences in mineral assemblage in adjoining subsidiary synclines is difficult to explain.

(iii) *Petrography*.-The mineral assemblages of 12 specimens of Salem granitic types were determined volumetrically, and the results are shown in table 11 and plotted on triangular diagrams in figures 3, 4 and 5. The localities of the samples are indicated on folder 3.

In general the granites show higher potash felspar than do the gneisses, and low biotite contents. When plotted as a group they fall within a distinct zone on the diagrams (fig. 3, 4 and 5), but are of variable composition and overlap the red granite-gneiss as well as the quartz diorite group.

In thin section these rocks are generally coarse to medium-grained allotriomorphic granular or sublepidoblastic. Quartz occurs as irregular grains showing occasional undulose extinction. Microcline is rarely perthitic and usually found in subordinate amount to plagioclase. It is also commonly altered to sericite. Plagioclase (An25-56) is always abundant as subhedral to euhedral grains and is rarely myrmekitic. Bent twin lamellae were noticed in several specimens which, together with undulose extinction of quartz, indicate post-formational deformation. Preferential alteration along one set of lamellae is a common feature. Biotite occurs as subhedral laths of variable abundance. One specimen contained a light-brown and a darkbrown variety of biotite. Zircon, apatite and ore were found in nearly all specimens and sphene in only two. Sillimanite and garnet are also locally present. Zircons from samples taken at the site of SM 217 and SM 97 were studied by Mathias (1962) who found the granite to contain a high proportion of colourless grains (78 per cent) and the total to be made up of 3 per cent angular, 85 per cent subround and 12 per cent rounded grains. Her general conclusion drawn from the zircon study was that the Salem granite had an autochthonous character.

(iv) *Chemical Composition*.- The chemical analyses and cation proportions of four Salem types are compared with two samples of Khomas schist and one of quartz diorite in table 7. Of the Salem group SM 153 is probably the most representative as it was chosen from those listed in table 11 as having the closest to the mean mineralogical composition. The most significant chemical differences, between Salem granite, quartz diorite, Khomas schist and red gneissic granite within this area (see table 10) are seen by comparing the cation proportions in table 14. These comparisons are discussed in the light of the petrogenesis of the igneous rocks at the end of this section.

(c) *Quartz Diorite and Diorite-gneiss*

(i) *Distribution*.- These rocks are found only in the east of the area in synclinal structures occupied in part by Khomas schist. They outcrop over wide areas on Mon Repos (B. 5), Gamikaub 78 (C. 5), Goas 79 (B. 5), Okongava Ost 72 (B. 5), Otjimbingwe Reserve 104 (C. 5 and inset), Ukuib

84 and Kamandibmund 83 (C. 5). They include those mapped by Gevers (1934 as diorite, granodiorite and Goas granite on his preliminary reconnaissance map.

(ii) *Macroscopic Appearance and Field Relations*.- These quartz-hornblende-biotite-plagioclase-rich rocks of a dark to bluish-grey colour and of wide areal homogeneity are morphologically subordinate to all but the Khomas schist and Salem granite group. On Okongava Ost 72 the prominent hills of the Sargdeckel and Jungfrau are largely composed of diorite, but their prominence is due to the capping of Karroo basalt. On Mon Repos (B. 5) the diorite gives rise to a fairly typical scenery of numbers of small inselbergs composed of conical piles of exfoliated boulders rising from a level plain.

At close quarters these medium to coarse-grained rocks resemble norite except for the fact that the hornblende is darker than the pyroxene. There is generally a very high proportion of mafic minerals present varying from about 15 to 50 per cent and consisting of biotite together with hornblende. In some places very dark portions of the rocks are made up almost entirely of hornblende and may be termed hornblendites.

In general the macroscopic textures are granular or gneissose, very rarely porphyritic, and have been marked on the maps as diorite or dioritegneiss. The latter frequently shows strong foliation marked by oriented biotite and hornblende and locally by tabular plagioclase grains.

Where hornblende becomes an accessory constituent the diorite is distinguished from Salem granite with difficulty and as previously mentioned, they have been grouped together where extensively developed.

The contact between diorite types and Khomas schist and marble is nearly always very sharply defined. Such contacts are readily observed on Gamikaub 78, Etusis 75 and Goas 79 (B-C. 5). While the boundary between the metasediments and the diorite is usually superbly conformable on a large scale, there are slight discordances in detail. The rock changes abruptly from diorite to schist with a very slight intervening ferromagnesian-rich selvedge and no increased metamorphic grade in the metasediment along the immediate contact. Xenoliths are often abundant along the margins and are rounded and not well oriented in all but the gneissose diorites. Such contacts are strongly suggestive of local intrusive relationships and the lack of any metamorphic aureole is indicative of either cold conditions or absence of large amounts of volatiles expelled from the molten diorite body. The textures of gneissic varieties vary from granitic to banded gneissose. At the Etusis windmill near the boundary of Neikhoes 74 (B. 5) all gradations from schist to diorite can be found. The gneissose intermediate types have a distinctly metamorphic appearance (pl. XIX), while the diorite has an igneous texture (pl. XX).

The relationships between Salem gneiss and granite on the one hand and quartz diorite on the other have already been discussed.

(iii) Petrography.-Table 12 shows the volumetric mineralogical composition of 11 typical specimens of quartz diorite ranging from hornblenderich, biotite-poor to biotite-rich, hornblende-poor types. Plotted on triangular diagrams (fig. 3, 4 and 5), they form a distinct group with a very wide variation in composition which, in part, overlaps that of the Salem granite and gneiss. The most distinctive feature of these rocks in thin section is the abundance of plagioclase (An30-60) and ferromagnesians as well as gene al total lack of or deficiency in potash feldspar.

TABLE 12.—VOLUMETRIC ANALYSES OF QUARTZ DIORITIC ROCKS

Specimen No.	SM 133	SM 147	SM 175	SM 148	SM 169	SM 170	SM 171	SM 124*	SM 181*	SM 129*	SM 115*
Quartz	31·80	25·9	26·2	34·00	17·7	12·2	3·72	19·65	23·20	8·03	9·95
K felspar	—	—	—	—	—	—	—	13·08	1·98	21·32	1·49
Plagioclase	41·80	54·1	47·3	46·50	45·2	63·3	36·20	29·00	50·40	51·45	73·40
Biotite	13·00	16·5	13·5	16·60	14·1	21·1	10·40	27·70	20·22	12·46	11·25
Hornblende	15·30	3·1	11·1	1·64	22·3	3·3	47·65	10·05	4·20	6·27	3·14
Accessories	0·02	0·4	1·8	1·99	0·6	0·2	2·11	tr.	tr.	0·36	tr.
TOTALS	101·92	100·0	99·9	100·73	99·9	100·1	100·08	99·48	100·00	99·89	99·23
Heavy minerals	Apatite Ore Sphene	Apatite Sphene	Zircon Apatite Sphene Allanite	Zircon Apatite Sphene Allanite	Zircon Apatite Sphene	Zircon Apatite Sphene	Zircon Ore Sphene	Zircon Apatite Sphene Allanite Ore Calcite	Zircon Apatite Sphene Allanite	Apatite Ore Sphene Epidote	Apatite
Composition of plagioclase	$An_{60}\pm_5$	$An_{50}\pm_5$	—	$An_{60}\pm_5$	$An_{35}\pm_5$	$An_{62}\pm_3$	$An_{56}\pm_5$	$An_{50}\pm_5$	$An_{40}\pm_5$	$An_{30}\pm_7$	$An_{35}\pm_3$

* Analyses made on stained polished slices.
All others made on thin sections.

Their texture is variable, hypidiomorphic granular to lepidoblastic. The grain size is most commonly medium coarse though may be coarse or fine locally. Quartz is present as interlocking anhedral granules and varies in amount from 8 to 35 per cent of the rock. Microcline, absent in most specimens, occurs as subhedral grains in a few. Plagioclase is always abundant and is generally subhedral to euhedral containing finely spaced albite twin lamellae (sometimes preferentially altered). A small amount of myrmekite occurs in most specimens. Zoned crystals are present in nearly every thin section of the non-gneissose variety examined and are interesting in that a number of zonal variations may occur in the same specimen. For example, in specimen SM 147 there are three variations:

1) A grain showing low An content in the core and outer zone and a higher An content in the middle zone.
2) Another grain showing a low An content in the outer portion and a high An content in the inner zone.
3) A zoned crystal with a similar composition in every zone.

The relative An proportions were gauged from the maximum extinction-angle of albite twin lamellae in each grain.

Zoning of this nature is not readily explained either by metasomatism or by crystals moving about in a magmatic melt, though the latter hypothesis seems more feasible were it not for the differing characteristics of individual grains in the same specimen. Detailed study of this phenomenon lies beyond the scope of this work.

Biotite in the diorite is generally abundant though often found in subsidiary amounts to hornblende. It is of a dark-brown variety commonly containing zircon inclusions. In lepidoblastic rocks it shows weak to strong orientation with the basal cleavage parallel to foliation.

Hornblende of a dark-brown variety is present in all types of diorite. It occurs in gneissic rocks as sieve-like anhedral porphyroblasts and in the granitic types as subhedral to euhedral grains of random orientation. In hornblendites it occurs as coarse subhedral to euhedral crystals making up the bulk of the rock.

The diorite is characterised by a variety of accessories of which apatite, ore, zircon and sphene are the most common with allanite and epidote present in some. It seems significant that sphene is rare in other igneous rock-types examined, and is suggestive of a lower temperature stability field being present in the case of the diorite. Apatite is usually subhedral to euhedral, zircon subround to euhedral and occurring mostly as inclusions in biotite, sphene as abundant extremely irregular grains of variable size and allanite as small to medium-sized grains (< 1 mm) some of which are twinned. Calcite, rutile and epidote are rarely present. Of the ore-minerals examined ilmenite appeared to be the most common and was found in several specimens to enclose nuclei of pyrite. It occurs as small extremely irregular grains disseminated in the rock. One or two crystals contain exsolution lamellae of hematite. The generally minute size of the grains makes positive identification of some of the components uncertain.

(iv) *Other Rocks Associated with the Diorite:*

Hornblendite.- On Etusis 75 and Neikhoes 74 (B. 5) there are spectacular ring dyke-like outcrops of coarse-grained, hard, fairly homogeneous, black hornblende-rich rocks of doubtful origin. Similar small occurrences of these rocks were also found on Okongava Ost 72 (B. 5), near the Neu Schwaben-Otjimbingwe Reserve boundary (B. 5), on Palmental 86 close to the Donkerhuk road (C. 5) and on Stinkbank 62 (B. 3). Macroscopical1 all these rocks are extremely similar, being composed of hornblende and variable amounts of plagioclase and quartz. On Etusis 75 and Neikhoes 74 they are associated with a variety of diorites, granites and pegmatite and definitely predate the pegmatite.

The isolated occurrences of this rock on Okongava Ost 72 are associated with mafic-rich portions of quartz diorite and appear to be contemporaneous and of the same origin.

Thin-section examination of the hornblendite from Stinkbank 62 and Otjimbingwe Reserve 104 clearly indicates that these two outcrops are of uralitised olivine gabbro consisting of calcic plagioclase altering to a less calcic type, altered olivine, orthopyroxene altered to chlorite and hornblende with fairly abundant laths of biotite and prismatic zoisite. The Stinkbank rock is less highly uralitised than the other. The specimen from Etusis 75 is, however, more problematical; hornblende, clinopyroxene and plagioclase are all in a semi-altered state with hornblende being apparently derived from pyroxene and plagioclase altering to a less calcic variety. Sphene, epidote, clinozoisite and apatite are present in generally anhedral form. Quartz occurs as isolated round to elongate glomeroporphyroblasts and is not disseminated in the matrix as it does in the quartz diorite. There is no olivine in this specimen. In view of the uralitised nature of the rock examined the writer prefers to think of the ring-like disposition of hornblendite as uralitised gabbro intruded before the folding and the metamorphism. The quartz glomeroporphyroblasts may have been introduced during metamorphism and granite emplacement. In this case the occurrence of at least three of these rock-types within the Khomas Series may either be a coincidence or due to the fact that the gabbro was introduced in narrow dykes which fed sill-like intrusions in this group; the latter was subsequently folded. The possibility that these rocks could have been formed at the same time as the diorite, to which they may be genetically related, also exists. It may be pointed out here that the outcrops found on Etusis 75 and Neikhoes 74 would provide material for a fascinating detailed petrological study. Gevers (1931, p. 99) regards these rocks as being differentiates "from more deep seated portions of the same dioritic magma and hence were intruded, after the differentiation in higher regions had already progressed somewhat further".

Anorthosite.-The only anorthositic rocks found by the author occurred intercalated in a suite of metasediments described in the Lower Hakos Stage. Gevers (1931, p. 95), however, describes a dyke of white anorthosite studded with pyrite occurring in marbles on the northeastern slopes of the Potberg (C. 5) in the neighbourhood of Palmental 86. Acid plagioclase is the only major constituent with accessory quartz, sphene and idiomorphic garnet. This dyke is thought (Gevers, 1931) to be a derivative of the dioritic rocks outcropping to the north.

Granite and Diorite-porphyrite.-The granitic texture of the diorite and their close association with biotite granite of the Salem type on Neikhoes 74 and Etusis 75 have already been referred to. In addition to these rocks there is a complex suite of intrusives in the vicinity of the windmill on the Neikhoes-Etusis boundary. A traverse in the stream-bed southward from the marble-granite contact towards the windmill crossed from the banded marble immediately into biotite schist containing lenses of Salem-type granite which develops into large homogeneous bodies southwards. Large dyke-like hornblendite bodies are situated in the granite and dip from vertical to about

45° to the south. The writer did not see any critical feature indicating whether or not the hornblendite pre- or post-dated the Salem granite emplacement. To the south of the Salem granite body the traverse crosses a belt of coarse quartzofelspathic schist containing abundant lenticular stripes and bands of granitic rock (see pI. XIX). The igneous-looking lenticles range from biotite gneiss through typical Salem-type granite to hornblende-quartz dioritic rock, and from their strongly banded and gradational character would appear to be autochthonous. These rocks pass into Salem-type granite containing a little hornblende (thus close to the quartz diorite in appearance), which occupies the bulk of the Etusis-Neikhoes Syncline. At the windmill there occur over a very localised area in this granite-diorite assemblage two extraordinary rock-types.

The first of these is composed of odd-shaped quartz diorite orbicles in a matrix of Salem-type allotriomorphic granular rock (pI. XXI), a specimen of which (SM 119) was composed of 35 per cent quartz, 11 per cent potash felspar, 43 per cent plagioclase (An30±5) and 12 per cent biotite with accessory zircon, apatite and sphene. A specimen of the orbicular diorite (SM 118) had a hypidiomorphic to allotriomorphic granular texture and was composed of very abundant euhedral hornblende set in a matrix of anhedral quartz and altered subhedral plagioclase (An60±5). Quartz is also present in round aggregates. It seems clear that the quartz diorite was intruded by the granite (see pl. XXI).

The other rock-type, in close proximity to the one just described, consists of abundant coarse pegmatitic fragments of variable size contained in a matrix of pale buff-coloured porphyritic rock (see pl. XXII). A finer grained specimen of a pegmatitic inclusion (SM 117) contains 22 per cent quartz, 53 per cent microcline and 24 per cent plagioclase (An12±5), some myrmekitic, in an allotriomorphic to hypidiomorphic, interstitially holohyaline texture. The host-rock (SM 116) consists of euhedral, generally altered, plagioclase (An30±5) set in a ground-mass of fine radially disposed myrmekite and biotite-chlorite, some of which is microcrystalline. Zircon and apatite constitute accessories. The rock has in general a hyalo-ophitic texture and closely resembles similar intrusive bodies occurring in the Upper Hakos Stage on the boundary between Habis A 71 and Habis B 71 and where the Donkerhuk road crosses the marble on Habis B 71. These rocks, though andesitic and intrusive, may not be true andesite as the composition of the plagioclase may not be ubiquitously andesine, and are difficult to name. Gevers (1931, p. 98) has termed rocks of similar appearance diorite-porphyrite which is, perhaps, a better though wider term.

(v) *Chemical Composition*.-A chemical analysis was made of specimen SM 181 which had a closest to mean composition of all the diorite volumetrically analysed in table 12. The analysis together with the derived cation proportions is compared with those of Khomas schist and Salem granite in table 7; and with that of the red gneissic granite in table 14. It may be observed here that the chemical composition of the diorite approaches that of the Khomas schist more closely than that of any other igneous type. The significance of these comparisons will be discussed at the end of this section.

(d) *Intrusive Granite and Pegmatitic Granite*

These rock-types are shown on the maps and are deemed by their field relations to have been intrusive or partly so.

(i) *Distribution*.- The largest of these bodies occur at the Geisterberg and Okatjeneberg (inset), in and around the Otjimbingwe Reserve 104 (C. 5), on Ubib 76, Kubas 77, Gamikaub West 115 and Dorstrivier 15 (C. 4). There are numerous other bodies of lesser size scattered throughout the region in all stratigraphic positions.

(ii) *Macroscopic Character and Field Relations*.- This group consists entirely of homogeneous non-foliated reddish to buff or pale-grey granite or very coarse-grained pegmatitic granite. In general it is poor in ferric minerals, but on Ubib 76, Gamikaub West 115, Kubas 77 and Dorstrivier 15 the greyish granite has a biotite content comparable with the Salem granite and indeed cannot in hand-specimen be distinguished from that mapped as Salem granite on Neu Schwaben 73, as was previously mentioned. The deciding factor for including the above granite in the intrusive group is its locally distinct transgressive nature with regard to the metasediments. On Ubib-West 76 there is a clear-cut intrusive contact between this kind of granite and the steeply dipping quartzite of the Lower Nosib Stage. In the vicinity ofthe Naibberg (C. 4) the granite cross-cuts the foliation of the Khomas schist as well as that of the Salem gneiss. On Gamikaub West 115 the distribution of the granite has been generalised as it is here intricately associated with - biotite schist remnants and quartz diorite bodies.

The granite in the east has a reddish to buff colour and is characterized by low biotite, but significant muscovite content. The Geisterberg (inset) is an outstanding example of this type of granite which is commonly morphologically prominent, especially to the south of this region in the neighbourhood of Donkerhuk. In all cases where contact relationships with gneissic and metasedimentary rocks are observable, the granite is found to be paragenetically younger.

One of the most remarkable features of this granite is its relation to the metamorphosed carbonate rocks of the Hakos Series. Even in localities where distinct intrusive relationships with other rocks can be found, the marble beds remain apparently undisturbed. The best example of this is found on Ubib 76 and Kubas 77 (C. 4) where two large bodies of granite are separated by only a narrow band of homogeneous crystalline marble. A few hundred yards away on the east-facing Chuos scarp, the bedding of the quartzite is truncated by the granite which also intrudes the metasediment in veinlets. A similar relationship between granite and marble occurs on Meyersrust 118 (inset). (See pl. XV.) These features show the remarkable stability of the carbonates in a magmatic environment and not only indicate that the marble must have been subjected to high pressure to maintain chemical stability, but also that the mechanism of granite intrusion was extremely subtle in that it did not disrupt these beds.

There are several instances of marble capping large bodies of pegmatitic granite associated with the red granite-gneiss of the Nosib Formation. The gneiss domes bordering the Lower Khan Gorge area are excellent examples of this phenomenon. Such concentrations of pegmatite below the marble point strongly to the fact that volatile constituents promoting the concentration of silica and alkalies, especially potash, were locally “dammed up” by the overlying marble. This may be (as will be discussed later) an important factor in the localisation of many of the late-stage mineralised pegmatites in the marble horizon.

TABLE 13.—VOLUMETRIC ANALYSES OF INTRUSIVE GRANITE AND PEGMATITE

Specimen No.	SM 135	SM 139	SM 180	SM 150	SM 182	SM 162*	SM 86	SM 69*	SM 197	SM 114	KR 10
Rock-type	Granite						Pegmatite				
Intrusive into	Nosib Formation			Khomas Series			Upper Hakos Stage			Khomas Series	
Quartz	36·08	27·25	31·85	30·78	18·45	31·75	52·40	36·08	18·55	24·25	22·46
K felspar	22·99	30·65	29·41	35·50	71·46	29·16	15·54	53·15	43·80	54·20	60·26
Plagioclase	32·08	35·40	30·20	29·00	7·86	35·70	27·62	10·61	37·65	21·10	14·89
Biotite	8·92	6·35	8·57	4·98	—	0·51	} 4·38	0·27	—	0·45	2·57
Muscovite	—	—	—	—	—	1·91		—	—	—	—
Hornblende	—	—	—	—	2·42	—	—	—	—	—	—
Accessories	tr.	tr.	0·14	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.
TOTALS	100·07	99·65	100·17	100·26	100·19	99·03	99·94	100·11	100·00	100·00	100·18
Heavy minerals	—	—	—	—	Sphene	Ore Garnet	Zircon	Ore Uraninite	—	Ore	Ore Apatite
Composition of plagioclase	$An_{30}\pm_5$	$An_{30}\pm_5$	—	—	—	$An_5\pm_3$	—	—	An_3	$An_{18}\pm_3$	—

* Analysis made on stained polished slice.

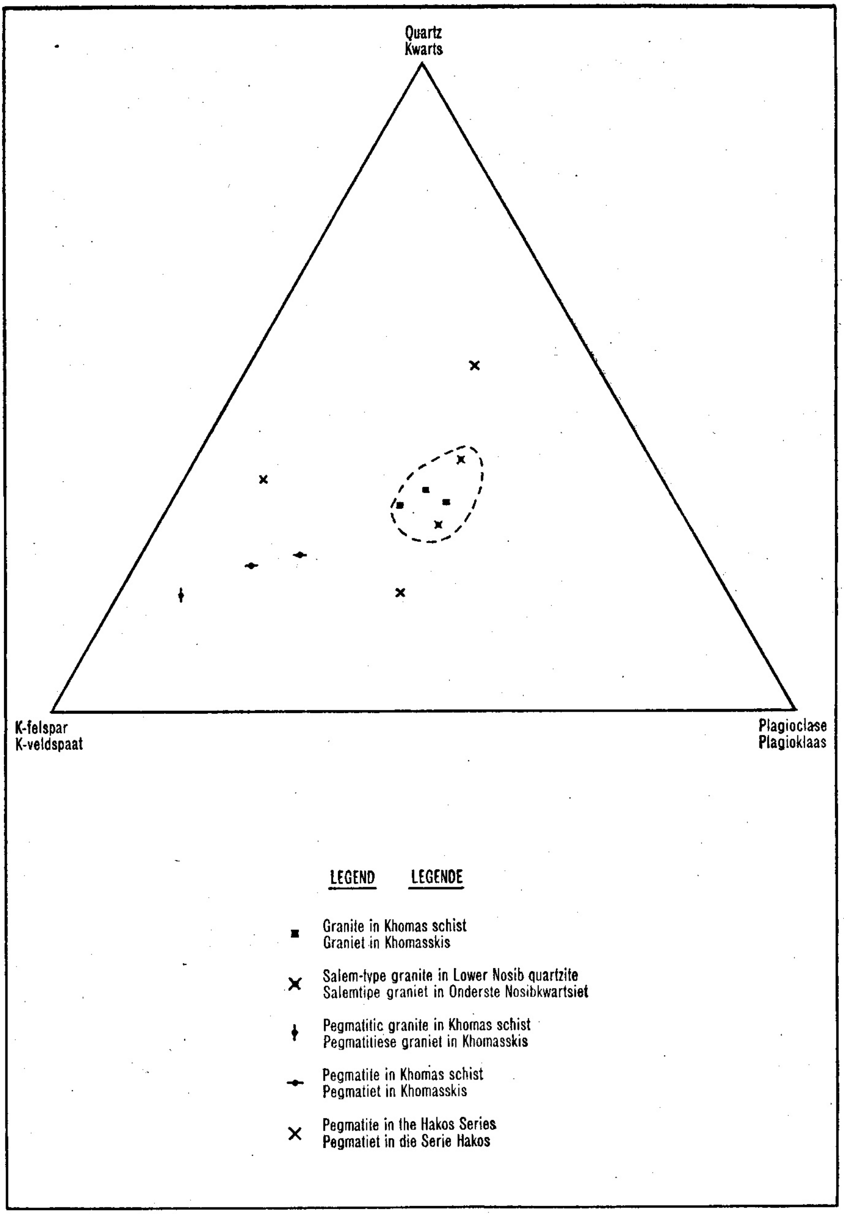


FIG. 7.—SiO_2–$KAlSi_3O_8$–$Na,CaAl_2Si_3O_8$ plot for granite showing intrusive relationships/*SiO_2–$KAlSi_3O_8$–$Na,CaAl_2Si_3O_8$-uittekening vir graniet wat intrusiewe verhoudings toon.*

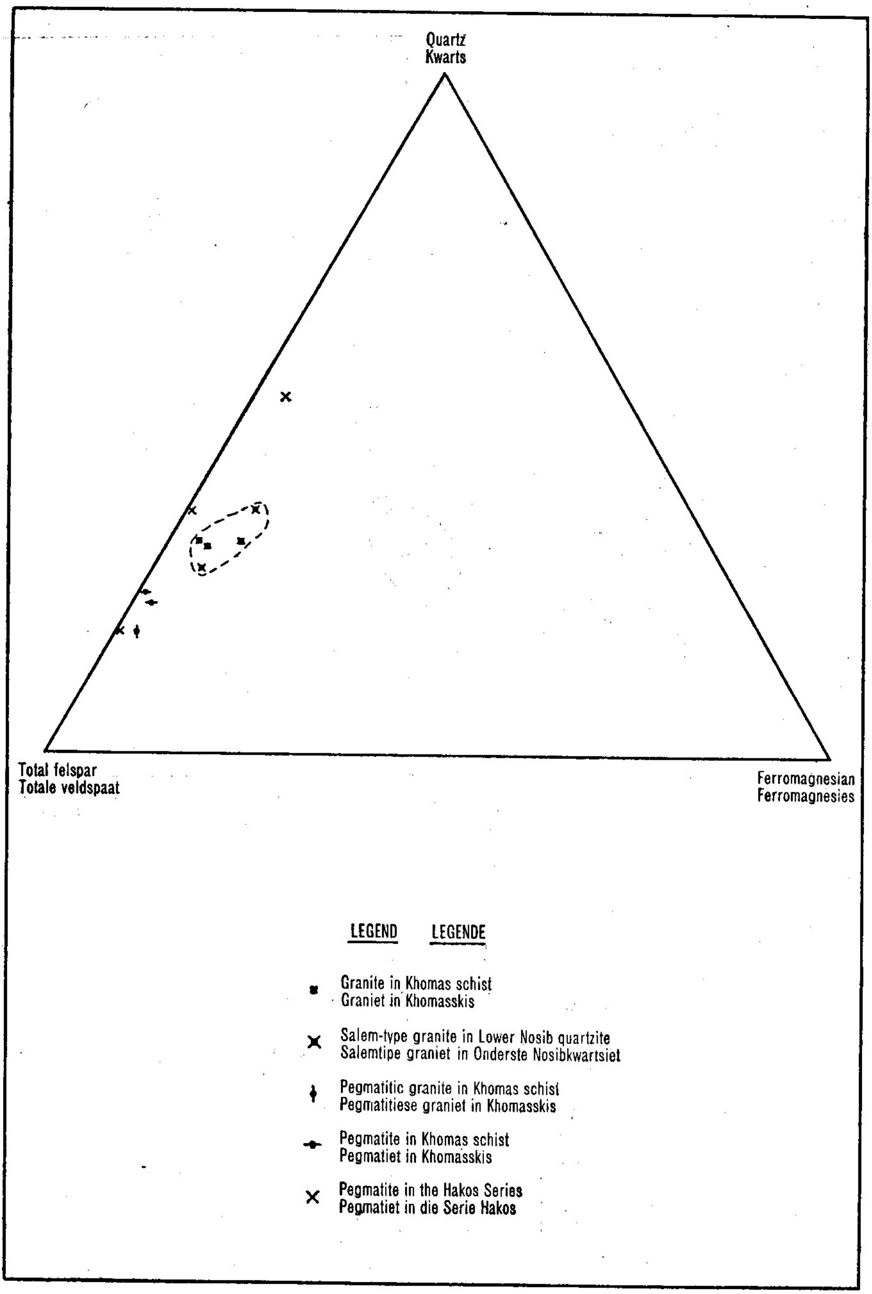


FIG. 8.—SiO_2–($KAlSi_3O_8$+$Na,CaAl_2Si_3O_8$)–(biotite+hornblende) plot for granite showing intrusive relationships/*SiO_2–($KAlSi_3O_8$+$Na,CaAl_2Si_3O_8$)–(biotiet+horingblende)-uittekening vir graniet wat intrusiewe verhoudings toon.*

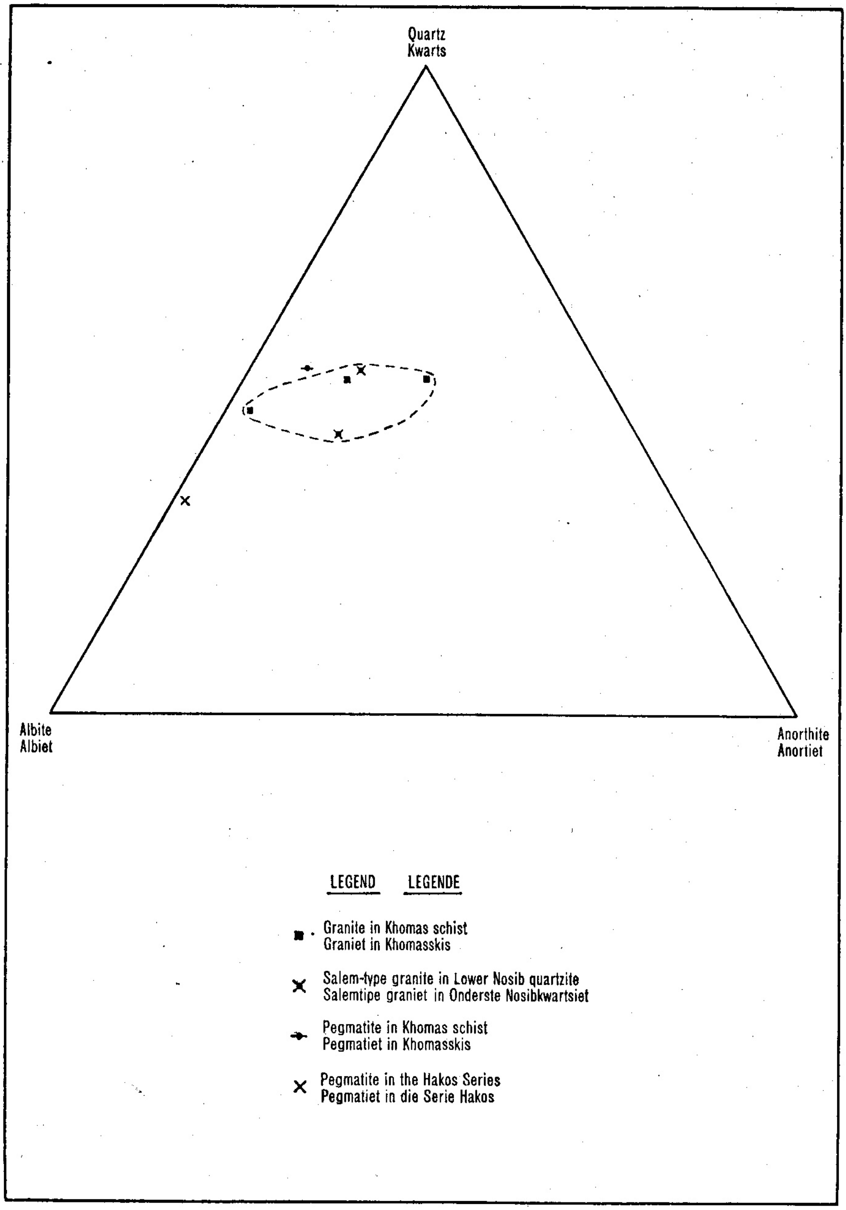


FIG. 9.—SiO_2–$NaAlSi_3O_8$–$CaAl_2Si_2O_8$ plot for granite showing intrusive relationships/*SiO_2–$NaAlSi_3O_8$–$CaAl_2Si_2O_8$-uittekening vir graniet wat intrusiewe verhoudings toon.*

(iii) *Petrography*.- Comparatively few specimens of this granite were studied in detail. The volumetric analyses of specimens from six different granite bodies (see fold. 3) are shown in table 13 and plotted on triangular diagrams in figures 7, 8 and 9.

With the exception of the pegmatitic granite specimen from the Otjimbingwe Reserve 104, which contains a very high potash felspar content, the remainder of the samples are of fairly similar composition and fall within the composition-zones of the red gneissic granite and Salem granite on the diagrams in figures 3, 4 and 5 (cf. fig. 7, 8 and 9). It is interesting to see that there is very little difference in composition between the granite occurring in the Khomas schist on Kubas 77 and that occurring in the Lower Nosib quartzite on Ubib 76. Also the Geisterberg type (SM 162) has very similar characteristics to the granite underlying the marble in the Okatjeneberg (inset).

The texture of the granite is typically medium to coarse-grained allotriomorphic or very coarse-grained in the pegmatitic types. Quartz is present as anhedral interlocking grains and micro cline is the most common felspar being frequently associated with quartz as micropegmatite. Plagioclase is often surprisingly calcic in composition, being andesine in some cases (SM 138 and SM 139) though generally albite or oligoclase. In several cases it is more abundant than potash felspar in the specimens examined. Biotite is the most common accessory mineral present, usually occurring in unoriented brown laths. In the Geisterberg area muscovite is more abundant than biotite. Black tourmaline is locally present in subsidiary amount and is particularly associated with pegmatitic bodies. Zircon, apatite, ore and garnet are the most common minor accessories present.

The present study has been extremely limited with regard to these types of granite. Insufficient specimens were studied in detail to establish whether or not marked differences occur in the mineralogy of intrusive granite situated in various stratigraphic horizons. As in the study of all the igneous rock-types dealt with, there is tremendous scope for detailed and exhaustive individual investigations.

(e) *Pegmatite and Vein-quartz*

One of the most outstanding features of the rocks in this central portion of the Damara Geosyncline is the abundance of pegmatite and of the pegmatitic granite bodies mentioned earlier. It is interesting to see that in areas beyond the limits of granite emplacement to the north and south of the area discussed, the place of pegmatite is taken by abundant quartz veins situated in low-grade schist and phyllitic rocks. Quartz veins in the area reviewed have similar structural characteristics to pegmatite, but are relatively rare.

(i) *Distribution*.- Pegmatite is generally distributed throughout the area in all rock-types, but in detail certain formations are apparently particularly unfavourable for their localisation. Such formations include the massive Lower Nosib quartzite in the Otjipatera and Chuos Mountains as well as Upper Nosib quartzite in the Rössing Mountain. Similarly the homogeneous units of the Upper Hakos Stage are largely devoid of pegmatites. Although the Khomas schist is a favourable site for the emplacement of these dykes it is noticeable that the coarsely crystalline variety contains fewer pegmatites than the well-bedded types as can be seen to the southeast of the Karub Gorge and Khan River on Namibplaas 93 (C. 3). (See pl. XXIII.) The effect of bedding on the abundance of pegmatites is also very well illustrated in the Khan quartzite surrounding the dome near SJ Claims (C. 2). In many of the homogeneous quartz diorite bodies, pegmatite is relatively subordinate in amount.

(ii) *Macroscopic Character and Field Relations*.- In general all pegmatites are macroscopically similar, being composed of clear to milky quartz, fleshcoloured microcline (often graphically intergrown with quartz), subordinate white plagioclase and accessory biotite or tourmaline. Certain differences are, however, locally apparent. In the Khomas schist they are often noticeably richer in biotite; in marble they are frequently found to be poor in potash felspar; in Salem granite and gneiss bodies as well as in diorite, they are commonly tourmaline rich. In all the pegmatites the grain size is seldom uniform throughout and there is often a zonal distribution of minerals even in the common concordant types (see pl. XXIV).

An important feature of the pegmatite bodies is that they are obviously of various ages with regard to structural and metamorphic events. They form a sequence in time from very early syntectonic to post-tectonic; although all are generally similar in mineral composition and texture, their structural character is different.

In a following chapter on structure it is found that one of the earliest fold movements produced isoclinal folds trending northwest. One such fold, the Karub Syncline, has been only slightly disturbed by later movements so that in this immediate vicinity the early pegmatite bodies are relatively undisturbed. Here it was found that the pegmatite, largely concordantly emplaced in the strata of this fold, is of prefold age and has been both boudinaged and folded in a parasitic manner together with other competent units involved in the folding of the largely incompetent strata. These pegmatite dykes, when in contact with homogeneous marble, contain calc-silicate minerals (diopside and scapolite) in narrow contact reaction-zones which, together with their accessory zircon content in the main body of the pegmatite, indicate that they were originally intrusive. There are numerous highly folded pegmatite and quartz veins including some which show fold interference patterns of two phases, localised particularly in the hinge-zones of major folds.

The identification of pegmatites of intermediate age is not readily made, but there are in a few places (Lower Khan Gorge) signs of pegmatite having formed in the folded axial planes of the earliest identified set offolds. There are certainly a large number of pegmatites situated in the axial planes of the second set of folds as can be seen in the Blauer Heinrich Syncline which crosses the Nose Structure Anticline (see fold. 1 and 2). Many of these pegmatites are of the secretion type (Ramberg, 1952). (See pl. XXV.) Isolated pegmatite nodules found in some metasedimentary strata may also have formed at this time as metamorphic products contemporaneous with the foliation of early granite-gneiss. This phase of pegmatite formation is apparently earlier than that of the true dyke pegmatites described below since some of them have been bent by a weak third phase of folding.

In many of the granite and granite-gneiss bodies as well as in quartz diorite rocks and metasediments, there are numbers of linear dyke-like pegmatites and aplites of extremely uniform dimensions. They commonly form two or three sets at right angles to one another in the granitic rocks.

One or two of these sets are sometimes faulted with a horizontal displacement showing that at the time of their emplacement fairly brittle conditions were already manifest. To this group of pegmatites also belong a number of zoned mineralised, usually discordant, bodies associated in at least one instance with pegmatite actually occupying a fault-plane (Roering, 1961, p. 131). The pegmatite of Karlsbrunn, Brockmann's, Rubicon and Helikon as well as Brockmann's beryl-bearing pegmatite at Tsoabismund (c. 4), are fairly definitely late stage, while those on Etusis 75, Habis 7], Dernburg and many other lesser ones are probably contemporaneous with these as well as the large non-mineralised dykes in the Abbabis System in the area B. 4.

(iii) *Petrography*.- Owing to the extremely coarse-grained nature of these rocks they do not lend themselves to microscopic study. The petrography of the mineralised group has been studied by Gevers and Frommurze (1929a), Cameron (1955) and is at present being investigated by Roering in greater detail. By far the greater bulk of pegmatites are of simple mineralogy, being compJsed of euhedral to subhedral felspar and largely anhedral quartz. It was found, however, that slight macroscopic differences in mineralogy occurred in pegmatites in different stratigraphic situations. In view of this three finer grained specimens from the Hakos Series and two from Khomas schist were examined. The volumetric analyses of these are shown in table 13 and plotted on triangular diagrams together with the intrusive granite group in figures 7, 8 and 9. Two of the specimens in the marble show high ratios of plagioclase to potash felspar. A more thorough study of these apparent differences is necessary before categorically stating that the stratigraphic position of these pegmatites effects their composition; but if this is so, it throws interesting light on their origin.

The pegmatites showing uranium mineralisation in the Lower Khan Gorge are conspicuously associated with biotite schist bands in the Lower Hakos Stage, though there are exceptions. Here the pegmatites are most characteristic in mineral assemblage containing dark smoky quartz, deeppink microline and black biotite which contains small euhedral uraninite grains as inclusions. Similar rocks with a lower biotite content contain monazite with a high thorium content at Louw's Claims (C. 1). These pegmatites as well as those containing copper, will be further discussed in the final chapter on "Economic Geology".

Generally speaking, the pegmatites show a similar grade of metamorphism to their host-rocks, i.e. amphibolite to granulite facies (400-600° C).

(f) *Aplite*

Aplite occurs in all the Damara rocks, but is extremely subordinate in amount to pegmatite and is largely of identical mineralogy and structural situation to these. It is, however, not usually associated with mineralised bodies.

5. PETROGENESIS OF THE GNEISS AND GRANITE

In the region considered about 70 per cent of the area covered by igneous rock-types is occupied by gneissose varieties which include migmatite and metasediment remnants. These, either by their concordant foliation or rare lineation and micro fold structures, are either paragneiss or intruded rocks subjected to subsequent tectonic stress. Their distribution, mineral and chemical compositions (potash-rich red gneiss in the lower strata and biotite-rich Salem gneiss and plagioclase-hornblende-rich diorite gneiss in the Khomas Series) suggest that they are products of either granitisation or magmatic assimilation.

It is unlikely that metamorphism and granite emplacement occurred at different times. The fact that recrystallisation in the metasediments generally post-dates the major fold events indicates that the granitic rocks were emplaced at a late-tectonic stage and that the foliation exhibited is more likely to be relict than flow-structure, although a certain amount of orientation may be due to slight compression.

If large bodies of granite intruded the sediments at any stage up to the complete close of fold movements, one would expect to find such bodies transgressing from one horizon to another. No such transgression of gneissic rocks was seen. In cross-section, as in plan, there is evidence that the granitic bodies in the Khomas schist are underlain by marble. The marble limbs of the syncline on Mon Repos, for example, dip inwards at moderate angles toward the centre and the fold axis plunges inwards from the extremities. Any cross-sections through such a syncline, of which there are many, would demand narrow pipe-like or dyke-like feeders penetrating the marble of the Hakos Series at the bottom of the syncline according to the magmatic intrusion hypothesis. It seems too fortuitous to think that all such feeders should be obscured from view. The writer. has therefore concluded that the gneissic rocks are all autochthonous and produced by high-grade metamorphism.

The non-foliated granitic rocks which form the remaining 30 per cent of the igneous types associated with the Damara Orogeny in this region do in part show intrusive cross-cutting relationships and paragenetically post-date the gneiss. At the time of their crystallisation there must have been a minimum of tectonic stress. In the Okatjeneberg these rocks may have transgressed the marble since the granite below and above it is markedly similar. On Ubib 76 where the most spectacular intrusive contacts are exposed, the granite, although not here occurring in the Khomas Series, has a very similar composition to the Salem granite. It is difficult to envisage intrusion of the latter downwards or sideways through the Hakos marble as the contacts indicate an upward movement of the granite. It is suggested that they may have originated from the ultrametamorphism of biotite schist, similar to the Khomas schist, extensively developed in the Abbabis Formation into which this granite is intrusive. The intrusive granite associated with the diorite on Etusis 75 apparently represents portions that were mobilised at a very late stage; some of these portions were quickly cooled as is evident from their occasional hyalo-ophitic texture. The large pegmatitic granite bodies generally capped by marble have already been referred to. The mineral assemblages and disposition of these granitic types indicate that for the most part they have moved only short distances from their place of origin (i.e. they seldom transgress the Upper Hakos Stage). They are probably products of usually slight metamorphic differentiation of the autochthonous gneiss as the difference in chemical composition of the Salem granite and the Salem gneiss in table 14 indicates.

The field relationships, distribution, macroscopic and microscopic features of these rocks are generally indicative of granitisation resulting in the production of magmatic rocks on a minor scale. In view of this an attempt was made to establish the chemical changes involved in such a change. The Khomas schist was selected for study by. virtue of its apparent uniformity and the fact that it and the granitic rocks associated with it, are underlain by homogeneous marble through which granitising solutions are unlikely to have passed freely to any great extent.

TABLE 14.—COMPARISON OF CATION PROPORTIONS

Sample No.	SM 218	SM 181	SM 97	SM 153	SM 214A
Si..............	60·50	56·10	63·11	63·68	63·49
Al..............	19·70	21·80	17·38	18·78	20·75
Fe^{+3}...........	0·62	1·31	2·67	0·56	1·44
Fe^{+2}...........	4·72	3·19	2·08	1·24	1·18
Mg..............	5·38	3·60	2·19	1·07	1·61
Ca..............	1·99	5·28	2·82	3·79	1·98
Na..............	4·17	5·82	4·62	7·81	3·08
K..............	2·94	2·26	4·38	2·46	6·26
Ti..............	0·16	0·59	0·44	0·13	0·29
P..............	0·10	0·14	0·22	0·09	0·11
TOTALS......	100·28	100·09	99·91	99·61	100·19

SM 218. Pseudochannel-sample of Khomas schist.
SM 181. Quartz diorite of mean mineralogical composition.
SM 97. Salem gneiss.
SM 153. Salem granite. Average of two analyses of specimen of mean mineralogical composition.
SM 214A. Red gneissic granite of mean mineralogical composition.

Sampling problems and the extremely limited facility for procuring chemical analyses have not been entirely overcome in this investigation. The results, therefore, are by no means conclusive. The following factors must also be taken into consideration: (1) The pseudochannel-sample (SM 218) across 950 feet of Khomas schist, excluding pegmatite, was taken some 30 miles away from the diorite and granite specimens; (2) both the gneissic granite and the diorite are mineralogically inhomogeneous from one sample to another, and those selected for analysis are means, not averages, since a true average composition would involve an intensive and detailed study on a large scale. The cation proportions of the rocks in table 14, therefore, should give a broad but not exact comparison of the different rock-types.

In table 14 the compositions of the Khomas schist, diorite and Salem granite are all comparable with the exception of magnesium in the schist and calcium in the diorite which are higher than in the others. This comparison points to the fact that the isochemical change from schist to granite or diorite seems possible only within the limits of ± 2·5 per cent Fe+2, Ca, Mg, Na and K. This figure is rather high, but considering the variable composition of both the diorite and the Salem granite and gneiss, it is not excessive. The points derived from the norm of the Khomas schist (SM 218) plot within the zone of volumetric analyses plots for Salem granite (fig. 10, 11 and 12). This shows that an isochemical change from Khomas schist to Salem granite is possible, but that the dioritic rocks are of very different composition on the whole.

The reason for the difference in chemical and mineralogical compositions of the Salem gneiss and the quartz diorite which are not seen in contact, is not readily explained. It has already been pointed out that the presence of sphene and hornblende as well as the contact relationships in the diorite are indicative of a somewhat lower temperature of formation than for the granite and Salem gneiss. The diorite-gneiss is also particularly inhomogeneous, varying in hornblende plus biotite content from 18 to 57 per cent. Whether or not these differences are due to the original composition of the schist or to metamorphic differentiation cannot be decided from the available evidence. The diorite

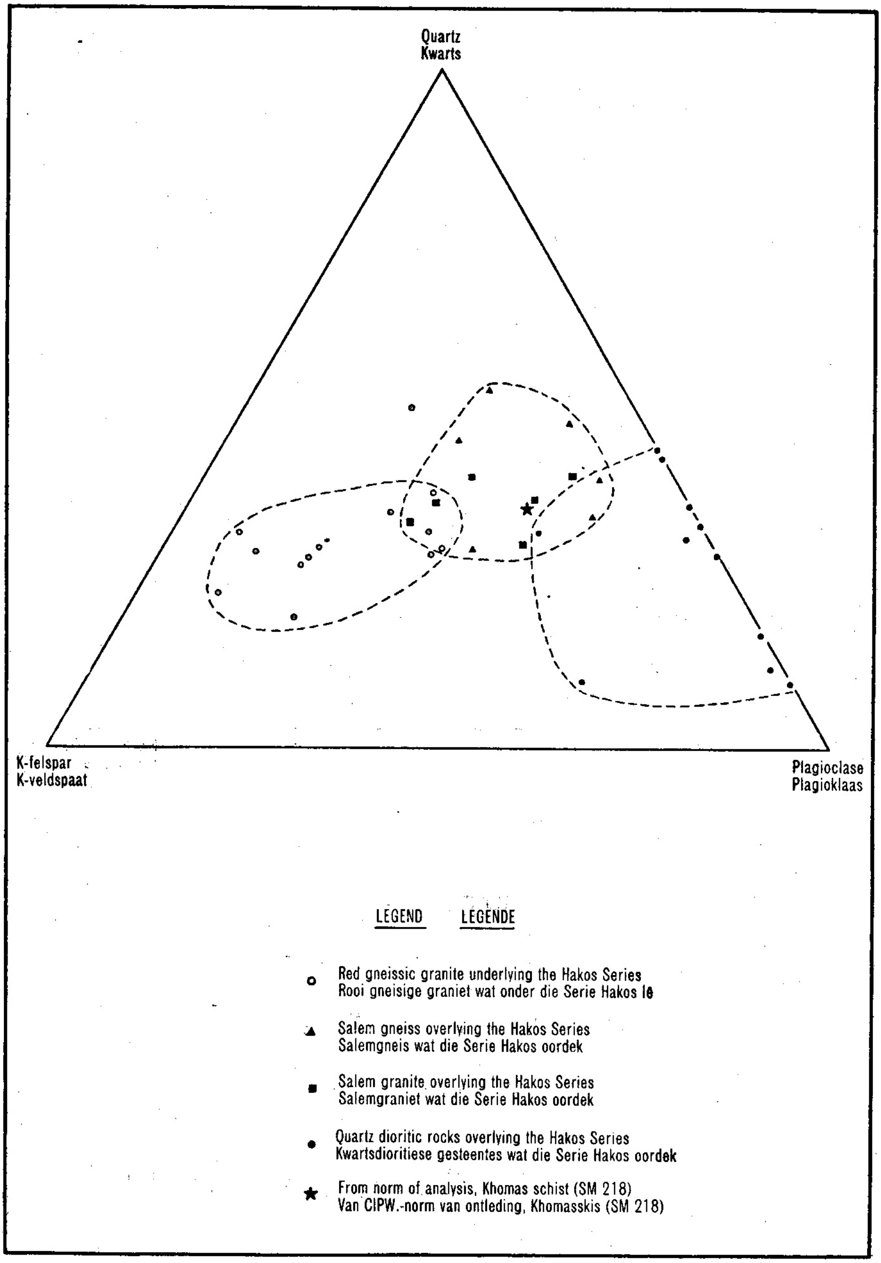


FIG. 10.—SiO_2–$KAlSi_3O_8$–$Na,CaAl_2Si_3O_8$ plot for igneous rocks of autochthonous character with position of norm of Khomas schist channel-sample/*SiO_2–$KAlSi_3O_8$–$Na,CaAl_2Si_3O_8$-uittekening vir stollingsgesteentes met outochtone kenmerke met posisie van norm van Khomasskisgroefmonster.*

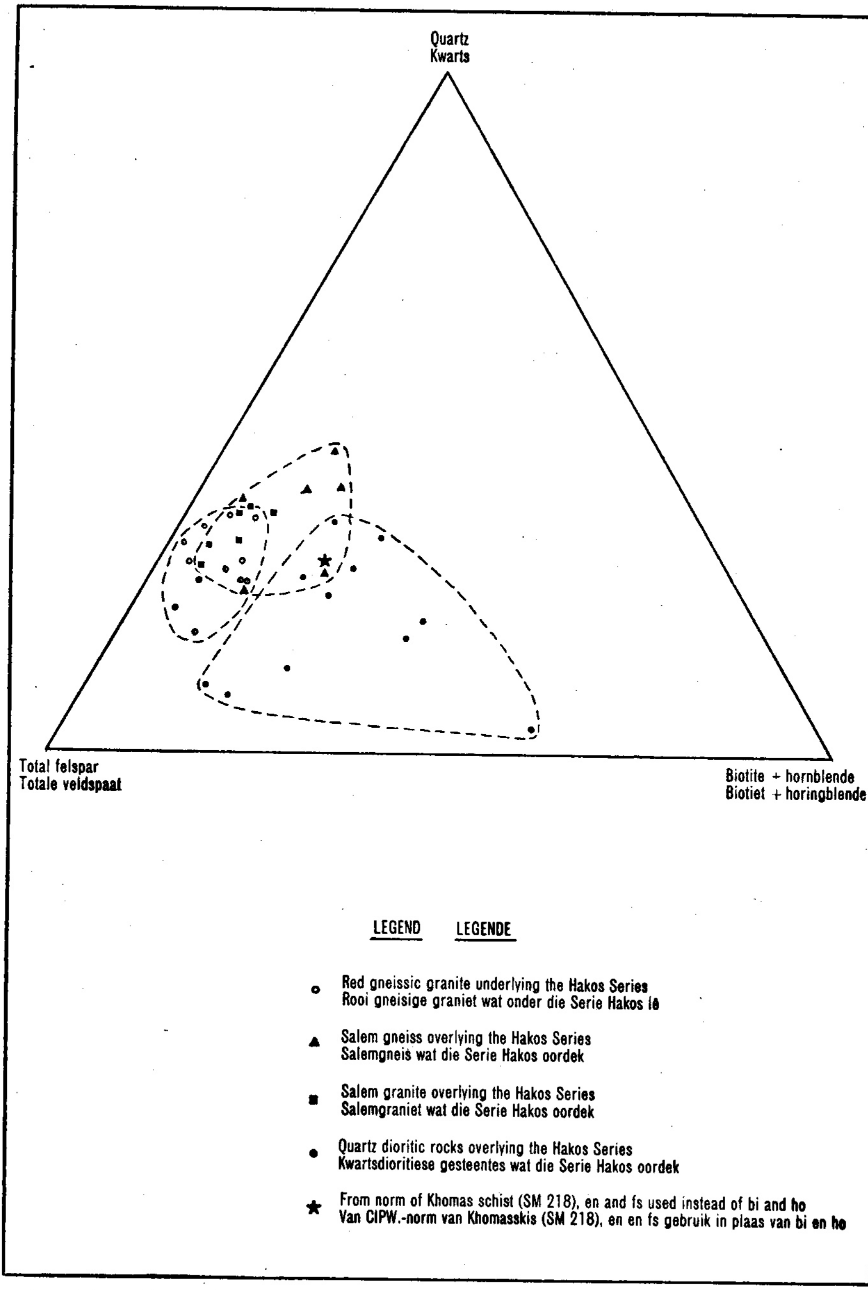


FIG. 11.—SiO_2–($KAlSi_3O_8$+Na,$CaAl_2Si_2O_8$)–(biotite+hornblende) plot for igneous rocks of autochthonous character with position of norm of Khomas schist channel-sample/*SiO_2–($KAlSi_3O_8$ + Na,$CaAl_2Si_2O_8$)–(biotiet + horingblende)-uittekening vir stollingsgesteentes met outochtone kenmerke met posisie van norm van Khomasskisgroefmonster.*

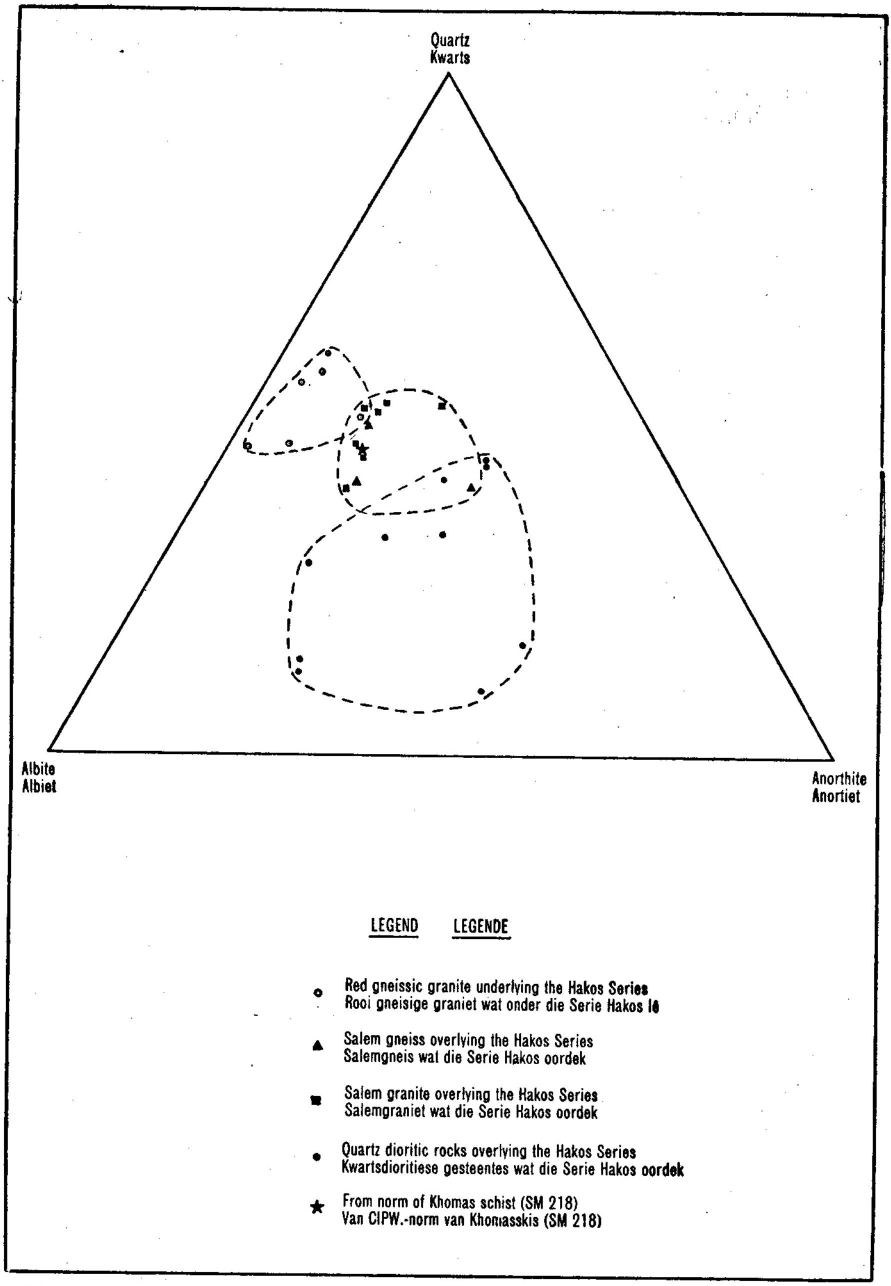


FIG. 12.—SiO_2–$NaAlSi_3O_8$–$CaAl_2Si_2O_8$ plot for igneous rocks of autochthonous character with position of norm of Khomas schist channel-sample/*SiO_2–$NaAlSi_3O_8$–$CaAl_2Si_2O_8$-uittekening vir stollingsgesteentes met outochtone kenmerke met posisie van norm van Khomasskisgroefmonster.*

does not occur west of Kubas 77 (C. 4) in the region mapped. This is a significant feature, but could be due to metamorphic grade and/or chemical variation in the Khomas schist. According to the magmatic intrusion hypothesis which would have to rely on assimilation to produce granites of differing characteristics in different stratigraphic horizons, the problem of mineralogical and chemical differences between Salem gneiss and quartz diorite remains.

With regard to these problems there is abundant scope for studies on the lines of that made by Engel and Engel (1958) in the Northwest Adirondacks in the United States.

6. PETROGENESIS OF PEGMATITE

The differing ages and structural situation of the pegmatites have been described. The earliest pegmatite was apparently largely concordantly emplaced in relatively unfolded strata. This group is perhaps the largest. The macroscopic appearance of many of these is suggestive of an intrusive petrogenesis for the following reasons: They occur in marble as well as in other sediments; those in marble contain zircon and mica not generally associated with pure marble beds; the pegmatite occurs in bedding-planes as well as in cross-cutting dilation cracks, the latter showing that they are not volume-for-volume replacements. On the other hand, they do not, for example, transgress from below the Hakos marble into the Khomas schist. It is thought, therefore, that although locally intrusive, they are in general derived from the sediments in their immediate environment. In some cases they are actually replacement products. The influence of the rock competence on the abundance of these pegmatites indicates that they were introduced in low-pressure zones in the rocks.

The second group associated largely with second fold axial planes and a higher grade of metamorphism must have been both intrusive as well as secretionary in origin. The formation of pegmatitic material may have been continuous right through the metamorphic and fold history.

The third group associated with faults and probably cooling tensioncracks in granitic rocks is almost exclusively of intrusive character, though here again the quartzofelspathic material may not necessarily have been derived from great distances. The abundance of pegmatite in the roof-zone of Nosib quartzite domes is suggestive of a concentration of volatiles promoting such accumulation and coarse crystallisation. Tension-cracks in all the rocks of low plasticity in the later stages must have been potential sites for accumulation of pegmatite and quartz. Especially favourable conditions must have existed for the formation of the zoned mineralised group.

7. THE METAMORPHIC SEQUENCE

Early metamorphic events have been largely obliterated by the more intense later ones. The first signs of metamorphism appear in the production of pegmatite followed by the first phase of folding which, by its similar character, is indicative of the rocks behaving in a plastic manner. Metamorphism increased in intensity during the second fold phase producing in addition to pegmatite the crystallisation of biotite in axial planes. At this stage too, and also possibly during the previous folding, amphibole had already become stable as the boudinaged amphibolite bands indicate. The incompetent rocks were apparently highly plastic during the second fold phase. Towards the end of this period metamorphism must have reached a peak, resulting in crystallisation of porphyroblasts of many kinds in the sediments and granisation, differentiation and mobilisation in the cores of synclines and anticlines. For some reason low-pressure centres must have been present in these cores in which catalysing volatiles were concentrated.

The temperature and pressure conditions prevailing during the peak of metamorphism can only be guessed at from the mineral assemblages. In the metasediments, temperatures of between 400 and 650°C probably existed during the peak of metamorphism while in the mobilised magmatic portions temperatures up to 800°C may have occurred. Wyllie and Tuttle (1960) have established that melting of granitic rocks may occur at 650°C at a depth of 20 km and at higher temperatures closer to surface.

It seems unlikely that temperatures as high as 800°C were common, however, since the marble bands show remarkable stability and have only in a few places been melted and lost their bedding features, e.g. marbles within the granite-gneiss in the Lower Khan Gorge. The temperature of melting of pure carbonate rocks is about 740°C in the presence of water at a pressure equivalent to a depth of 24 km, and with the addition of CO_2 to the water the melting temperature rises so markedly that they are not likely to have been melted at all (Wyllie and Tuttle, 1960, p. 231). Few of the carbonaterocks in this region are pure, however, so that their melting temperatures. could have been lower than 740°C.

Assuming the not unreasonable geothermal gradient of 30°C/km (Wyllie and Tuttle, 1960, p. 228) to have been present in this orogen, the depth of burial of the rock was of the order of 18 to 24 km (11-15 miles) at the time of maximum metamorphism. The most intense folding which predates the formation of the bulk of the granitic rocks, is likely to have occurred at slightly shallower depths where temperatures of 350 to 500°C, associated with earlier amphibolite facies metamorphism and pegmatitisation, were operative. At the present stage of our knowledge, however, it is difficult to envisage a cover of 18 km for even the lower parts of the Khomas Series at the time of folding, so that it is necessary to suppose that other factors, e.g. fluxes, played a role or that the geothermal gradient was considerably higher.

8. THE AGE OF THE DAMARA METAMORPHISM AND GRANITE EMPLACEMENT

Eight separate age measurements are being made by Nicolaysen, Burger and Rethemeyer (personal communication) on rocks associated with the metamorphism and granite emplacement in the Damara System. (See table 15.)

The pegmatites at Panner's Gorge and SJ Claims are associated with either the pre-first or second phase of folding and that at Louw's Claims is of post-granitisation age. The euhedral monazite in marble on Eureka 99 is randomly oriented and probably of post-fold age. An additional measurement is at present being made on uraninite from a late-stage mineralised zoned pegmatite in the Erongo Schlucht to the north of this area and is expected to have a similar age to those in table 15.

These determinations indicate that the metamorphic and fold events, as also deduced from the pegmatite history, occurred within a relatively narrow margin of time which may be regarded as provisionally established at 510 ± 40 million years.

TABLE 15.—AGE MEASUREMENTS

Mineral	Host-rock	Locality	Age (m.y.)
Davidite........	Pegmatite in Lower Hakos Stage	Panner's Gorge (D. 2)	Provisional mean age 510 ± 40
Davidite........	Pegmatite in red gneissic granite	Louw's Claims (C. 1)...	
Yttrotantalite.... Yttrocolumbite....	Pegmatite............	Jakalswater, near old station (not on map)	
Davidite........	Pegmatite............	Cox's Claims (not on map)	
Biotite..........	Pegmatite in Lower Hakos Stage	SJ Claims (C. 2).......	
Biotite..........	Pegmatite in Upper Hakos Stage	SJ Claims (C. 2).......	
Uraninite........	Pegmatite............	Bore-hole, Louw's Claims (C. 1)	
Monazite........	Marble..............	Eureka 99 (B. 3).......	

The sedimentation of the Damara System must have commenced later than 1700 ± 60 million years ago (Clifford, Nicolaysen and Burger, 1962) which is the age of the formation of the Pre-Damara granite near Fransfontein. Although there is no molasse-type deposit known to show that sedimentation continued during tectonism it is possible that the sedimentation cycle of the Damara preceded the folding and metamorphism by only a very short period.

C. STRUCTURE*

In addition to the regional mapping of the area during which a large number of structural features were noted, two type areas were selected for detailed investigation. Folder 2 and figure 13 of the Khan Mine area and the Karub Gorge area, respectively, resulted from these investigations. The writer is particularly indebted to Dr. Ramsay of the Imperial College for his assistance and advice given at the later stages of the detailed investigations

1. THE REGIONAL STRUCTURE

The regional structural style of the area is well displayed on the accompanying geological maps as a well-defined fold pattern consisting of elongate synforms and antiforms trending northeast-southwest.

Closer examination of the map reveals that in several localities there are fold interference patterns which indicate either two distinct phases of folding or distortions in a single fold movement caused by constant horizontal pressure directed southeast and northwest. The most striking examples of these fold interference patterns are located at Rössing Mountain (C. 1), the Nose Structure in the Khan Mine area (D. 1), the Karub Gorge area (C. 2-3), around Horebis Nord 61 (C. 4) and in the area extending from Karibib Townlands 57 to Kaliombo 119 (A. 5-6, B. 5 and inset). A part of the last-named area was investigated by Roering (1961).

A feature apparently associated with the fold interference pattern is the very consistent plunge to the northeast of a large proportion of the folds.

* This section is a summary of the chapter on structure presented in the original thesis.

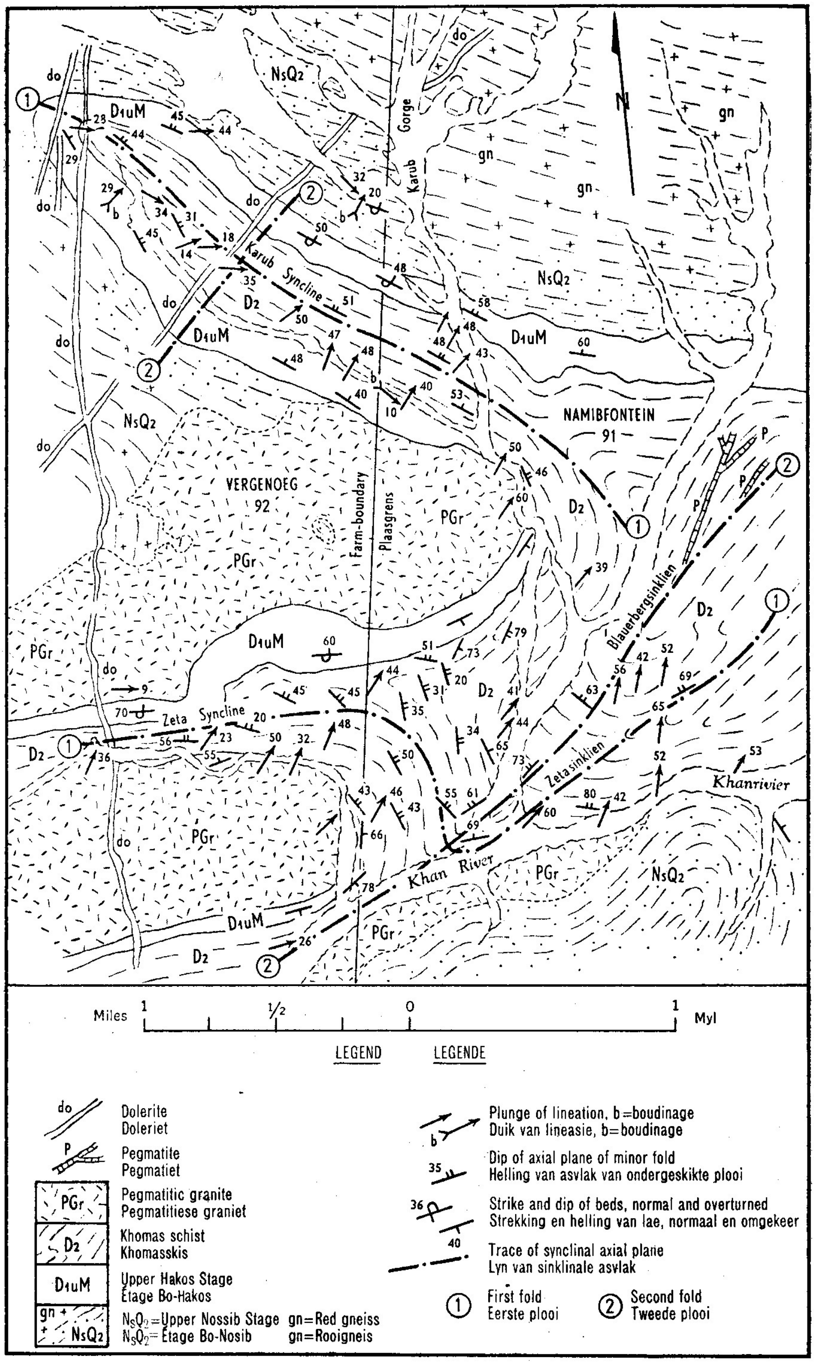


FIG. 13.—Structural map of the Karub Gorge locality/*Struktuurkaart van die Karubklooflokaliteit.*

The major linear folds whose axial traces can be followed in many cases right across the mapped area, maintain a fairly constant wave length of 6 to 8 miles and an amplitude of 4 to 5 miles. In most cases both flexure and similar fold-types are present and are dependent largely on the competence of the folded strata, ,e.g. marble zones are ubiquitously similarly folded. The axial planes of the major folds are nearly always vertical. The configuration of the fold cross-sections (e.g. section A-B on the regional map) indicates that crustal shortening of 40 to 50 per cent has been caused by horizontal pressure directed largely from northwest to southeast.

The whole area is remarkably free of large-scale faulting, a feature characteristic of rocks deformed while in a plastic state.

2. RESULTS OF DETAILED STRUCTURAL INVESTIGATIONS

Examination of meso- as well as macro structures in the two type localities referred to above, revealed the following outstanding structural features:

(1) Folded axial-plane structures exhibiting two fold interference patterns. The two folds were nearly always found to be co-axial.

(2) Slightly bent second fold axial planes which may be indicative of a third gentle fold phase.

(3) A remarkable and strong linear deformation of tillite pebbles and boulders which are drawn out parallel to the second fold axis. This pebble elongation, by definition as well as by Ramsay's method (1960, p. 88) of plotting the a tectonic axis in a superimposed fold, was shown to lie in the direction of maximum tectonic transport.

(4) Both minor and major folds containing similar-folded incompetent material as well as concentrically folded competent material. Measurements on some of the minor folds revealed a shortening of 40 to 50 per cent (see pl. XI) which is comparable to the amount measured on a macroscale.

(5) Pegmatite veins which have (a) been folded together with bedding-planes into two fold interference patterns, (b) been emplaced as veins parallel to the axial planes of the second folds and (c) been intruded into tension-zones and faults cross-cutting all fold structures. These features are thought to prove that pegmatites were formed during, before and after the major fold movements occurred.

(6) Boudinage structures associated with the earliest folds and involving pegmatite and amphibolite in the competent layers that yielded these structures. These factors indicate that at least some pegmatite and amphibolite were formed prior to the major tectonic movements.

(7) Some granite-gneiss and metasediments containing numbers of porphyroblasts with no preferred orientation and some gneiss with well-orientated porphyroblasts. The presence of unorientated porphyroblasts was interpreted as indicating post-stress crystallisation, while oriented crystals suggest contemporaneous or prestress crystallisation.

Many of the above observations were also made and recorded by Roering (1961) in the Johann Albrechtshöhe-Kaliombo area near Karibib.

3. INTERPRETATION OF THE TECTONIC HISTORY

The interference patterns caused by the superimposition of two fold phases are largely very similar to one another. For example those in the Khan Mine area (Welwitsch Syncline, Paviaan Syncline, etc.) have similar configurations to the Zeta Syncline in the Karub Gorge area. In every case the earlier fold does not have the same axial-plane orientation as the second dominant fold trend. This is especially apparent in the Rössing Mountain structure where the early fold is not co-axial with the later one. For these major reasons it is considered that the two sets of folds were formed by differently orientated stress fields. The original stress orientation cannot be accurately determined, but was apparently in a northeast-southwest direction. The second and major stress was most definitely oriented northwest and southeast.

The alternative to the above interpretation is that there was only one major orientation of the stress field and that the interference patterns were formed by distortions of the folds caused by extension of the deformed rock parallel to the major fold axis.

The third phase of folding is considered to have been caused by extension parallel to the second fold axes resulting in many of the elongate dome structures found in the area.

The consistent northeastward plunge of many of the major interference structures (e.g. the Welwitsch-Nose Structure folds) is thought to be due to the original orientation of the earliest axial planes which must have been largely oriented northwest-southeast and dipping to the northeast. Many of these were later co-axially folded with the second fold phase, some, such as the Rössing Mountain structure, were folded on a differently oriented axis.

The tectonic history is summed up in the following stages:

(1) Sedimentation followed by deep burial and the raising of the temperature and pressure to produce amphibolite grades of metamorphism accompanied by pegmatite formation.

(2) The formation of northwest-trending folds by pressure exerted from the northeast and southwest accompanied by continued metamorphism and pegmatite formation.

(3) Either a change in stress field to the southeast and northwest or the overshadowing of the first stress by a very powerful stress from northwest and southeast, causing the refolding of the earlier folds and the formation of the major northeast-trending structures as elongate synforms and antiforms. Metamorphism continued and intensified to produce vast volumes of granitic material: red gneissic granites from the Nosib Formation and Salem gneiss and diorite-gneiss from the Khomas Series.

(4) The cessation of stress was then followed by intense metamorphism resulting in the mobilisation and intrusion of some of the granitic material into low-pressure zones. Metamorphism then declined, the rocks became brittle and were gently fractured in some places. The closing stages of granitisation and mobilisation were marked by pegmatite intrusions, some of which were highly mineralised.

14. THE ORIGIN OF THE FOLDING

Carey (1958), Belousov (1961 and 1961a) and others have stressed the importance of vertical and relative unimportance of horizontal movement in geosynclinal tectonics. Carey suggests the mechanism of rheid folding to produce complex fold structures without horizontal movement and Belousov demonstrates that vertical movement of rigid blocks acting as "pistons" can produce these structures.

In the area considered the possibility of vertical tectonics being the cause of folding was carefully considered, but rejected for the following major reasons:

(1) The nature of the folding is generally concentric or similar and analysis of the similar folds showed that they were not of the rheid (or flow-fold) type. There is, therefore, no supporting evidence for Carey's theory of fold mechanics in this region.

(2) The axial planes of nearly all the major folds are close to vertical. Since the P-maximum direction or c tectonic axis is normal to the axial plane of a fold, the indications are that the forces responsible for the fold pattern were dominantly horizontal. Furthermore, the rigid blocks required for Belousov's fold mechanics could not have existed in this deeply buried zone in which all the rocks, especially the Basement granitic types, must have been in a fairly plastic state during the period of major fold activity.

It is concluded, therefore, that this region of the Damara Geosyncline was deformed by horizontal compressive forces which caused crustal shortening to the extent of 40 to 50 per cent. The Damara fold belt is over 200 miles wide and probably contains folded strata once occupying a flat area of between 80 and 100 miles wider than the above figure.

VII. KARROO SEDIMENTS, EXTRUSIVES AND INTRUSIVES

This group is similar to the rocks found in the Erongo area (Cloos, 1919; Frommurze, Gevers and Rossouw, 1942) and with the exception of dolerite dykes, is of extremely limited distribution in the region mapped.

A. SEDIMENTS

A narrow band of partly baked shales, ± 30 feet thick, overlies Damara quartz diorite with an unconformable contact at the Sargdeckel and Jungfrau on Okongava Ost 72 (B. 5). The elevation of the unconformity is about 5600 feet; considerably less than that of the Otjipatera Range (± 6000 feet) which must, at the time of deposition of these sediments, have projected from the Pre-Karroo plane.

B. LAVA-FLOWS

A thickness of 150 to 300 feet of basalt, responsible for the baking of the shales, caps the Sargdeckel and Jungfrau. The basalts represent an extrusive phase, possibly related to the dolerite dykes, and must once have covered large areas of the country.

C. DOLERITE DYKES

There are two major trends of dykes in the area mapped. The one strike is north-northeast and such dykes are largely concentrated as a swarm in sector B. 2 of the area, and the other trends east-northeast.

The dykes, some of which can be followed for about 30 miles along strike, attain widths of up to 900 feet (e.g. Schwarzrticken) and form morphologically prominent black ridges across the country.

The dolerite was emplaced from great depth along linear sets of fissures which were apparently contemporaneous. Where dykes intersect there is no evidence of one post-dating the other. The major dyke-swarm referred to makes a conspicuous lineament trending towards the Gross Spitzkoppe to the north of the area mapped. The majority of the dykes have a vertical dip, but some have attitudes between the horizontal and the vertical.

In hand-specimen the rocks vary from fine to medium coarse-grained. The fine-grained varieties are limited to margins and very thin dykes. Large bodies exhibit grain sizes of up to 5 mm. Some dykes contain porphyritic zones.

Under the microscope the few specimens examined had similar mineralogy and texture and were typical olivine-bearing dolerite containing laths of labradorite, subhedral olivine, ophitic augite and accessory amounts of biotite, chlorite and magnetite.

Even where country-rock xenoliths occur in dolerite there is little to no contact metamorphic effect. This is due to the already high grade of metamorphism of the older rocks.

VIII. SUPERFICIAL DEPOSITS

Large areas of the Damara rocks are covered by deposits of relatively very recent geological age. These deposits consist of both cemented and uncemented terrestrial sand, gravel and conglomerate as well as boulder scree. The cemented group, occurring largely on high-level terraces, is differentiated on the map from the unconsolidated sand and gravel as well as from the scree.

A. HIGH-LEVEL CALCRETE TERRACE DEPOSITS

This is the oldest of superficial deposits found in this area and covers wide areas of the Namib Plain both to the north and to the south of the region discussed. In the area mapped the deposits are found mainly as terraces along the south bank of the Lower Swakop River and on the inselberg plains between the Khan and Swakop Rivers.

They consist essentially of lime-cemented felspathic grit with a large number of fluviatile conglomeratic layers and numerous isolated pebbles. The pebbles are typically river worn near the Khan and Swakop Rivers, but closer to the Chuos Mountains, for example, they are angular and represent fanglomerate derived from a nearby source.

They were laid down on an uneven surface where they fill depressions and overlap prominences. At places along the southern margin of the Khan Gorge the base of these beds can be seen occupying a predepositional drainage-pattern, e.g. at Welwitsch (D. 2) and on Tsawisis 16 (B. 3). This clearly indicates that the major drainage-pattern existed in its present position prior to the deposition of these beds which were apparently largely deposited during a stage of aggradation.

No fossils have yet been found in these beds. They are regarded as being of Tertiary age by Martin (personal communication).

B. LOW-LEVEL TERRACE DEPOSITS

Terraces bearing lime-cemented deposits of very similar appearance to those described above occur at intervals along the Khan and Swakop Rivers as well as in some of their tributaries. These beds lie from a few to 40 feet above the present drainage level. They are apparently contemporaneous with the Upper Pleistocene beds occurring near Usakos (Frommurze, Gevers and Rossouw, 1942, p. 50).

C. UNCONSOLIDATED SEDIMENTS

Unconsolidated sand, gravel and surface-limestone of very recent age cover large areas of older rocks in this region. These young deposits consist of alluvium, eluvium (largely scree) and aeolian sand. The last-named, deposited largely by the prevalent southwest winds, is concentrated on eastfacing slopes of prominences such as the Khan and Rössing Mountains.

The sand and gravel, typical of arid-cycle erosion, contain fresh grains of felspar, calcite, mica, etc. in addition to quartz.

There are numerous sites in the area where stone implements are found on the surface. Amongst these Middle Stone Age implements were noted most frequently.

IX. ECONOMIC GEOLOGY

A. INTRODUCTION

A great variety of minerals occurs within the region mapped. The bulk of these were discovered late in the last century and early in this century, and have subsequently been proved to be largely of little economic value. The most important mines at the present time are Rubicon, Helikon and Karlsbrunn which produce beryllium and lithium minerals with subordinate quantities of associated pegmatitic minerals.

The region has been thoroughly prospected for the more obvious metals (copper, lead, zircon, gold, etc.). The country is generally easy of access and contains large areas of rock outcrop. The meagre quantity of exploitable ores found so far is, therefore, a good indicator of the limited potentialities .of the area. A contributing feature to the small tonnages in “ore bodies” is the fact that by far the bulk of ore occurrences are associated with pegmatites which exhibit sporadic or “pockety” concentrations.

A large number of prospects referred to hereunder date back to before 1914 and have little or no records of tonnages mined, calculated reserves, etc. Many of these occurrences are called” mines”, but it is doubtful whether some of them ever produced at all.

B. ASBESTOS

The occurrences of asbestos in the Hakos Series at Pforte (south of the map) a few miles southwest of the Geiseb Spitz (C. 3) was recorded by Wagner (1916, p. 84) to be of no economic importance.

Chrysotile was occasionally seen associated with serpentinised forsterite and dolomite within marble. Large concentrations of this mineral seem unlikely to be found.

C. COPPER

No copper has been mined in the region mapped since the Khan Mine closed down in 1918.

A large number of copper prospects exist. Almost all of these are associated with pyroxene-bearing pegmatite situated in a stratigraphic horizon in the Nosib Formation a short distance below the Lower Hakos Stage, or where this is absent, below the Upper Hakos Stage. Exceptions to this stratigraphic positioning occur at the Pot and Gamikaubmund Mines situated within the Upper Hakos Stage and lower part of the Khomas Series, respectively. Also excepted are several very small prospects including the Ubib Mine situated in Abbabis rocks on Tsawisis 16 and Naob 69 (B. 4). The mineralogy of the copper occurrences is generally very similar.

1. KHAN MINE

The Khan Mine is situated some 35 miles east-northeast of Swakopmund and 4½ miles due south of Arandis in sector D. 1-2 of the map. It is by far the largest of the copper prospects in the region.

Accounts of the mine have been given by Voit (1908), Stutzer (1914), Wagner (1916), Reuning (1923), Ramdohr (1938) and Söhnge (1939). The last-named gave a detailed paragenesis of the pegmatite.

The mine was developed and equipped prior to 1914 by the Khan-Kupfergrube-Gesellschaft and continued operating until 1918. The milling figures from November 1915 to January 1918 showed 32,454 tons* of ore milled and 964 tons of copper recovered. The ore grade over this period was 3·87 per cent copper. Concentrates contained in addition to copper 5·10 oz.† of silver per ton, 0·6 dwt. of gold per ton and 0·146 per cent selenium and tellurium (Se 95 per cent, Te 5 per cent)‡.

The mine was dewatered in 1925 and sold by public auction. Since that time it has been prospected by several mining groups and is at present held by the Johannesburg Consolidated Investment Co., Ltd.

The mineralised pegmatite has a width of 3 to 5 feet, a strike length of some 1000 feet and has been proved to extend down dip for at least 700 feet. It is concordantly placed within thick-bedded calc granulites in the upper portions of the Upper Nosib Stage which dips at variable angles (70-45°) to the northwest in the vicinity of the mine (see fold. 1).

The fact that the pegmatite conforms closely to the folded beds and is located in some places within necks between boudinaged amphibolite bands, indicates that it is of early syntectonic age. The mineralogy of the body, containing in addition to quartz and felspar such minerals as diopside, sphene, sahlite, hornblende, phlogopite, wollastonite and epidote (Sohnge, 1939, p. 29), is suggestive of at least a partially metasomatic origin. The localisation of numbers of copper occurrences within this stratigraphic horizon points strongly to an original sedimentary control of copper deposition; subsequently reconcentrated by metasomatic processes.

* 1 ton= 2000 lb.

† 1 ounce=28’35 grams.

‡ Information obtained from files of the Tsumeb Corp., Ltd.

The ore-minerals present in order of paragenesis are sphalerite, chalcopyrite, bornite, chalcocite and malachite (Söhnge, 1939, p. 29). Borniteis the most abundant of the ore-minerals which are concentrated in two major zones known as the north and the south ore-bodies.

The ore-reserves are generally considered to be small. An estimate in 1927 indicated 5080 tons of metallic copper in ore of a grade between 5 and 6 per cent copper (files, Tsumeb Corp., Ltd.). A consistent and substantial increase in the price of copper would be required to make this mine payable.

2. KAINKAGCHAS MINE

The Kainkagchas Mine is located in the marginal "bad lands" on the south side of the Khan River on Namibplaas 93 (C. 2).

The mineralised zone, some 12 to 40 feet wide and 1500 feet long, occurs in amphibole schist and marble beds associated with the lowest beds of the Lower Hakos Stage. The ore, bornite, chalcocite and subordinate chalcopyrite, occurs within both calc-silicate bands and hornblende-quartzmicrocline rocks.

Prospecting operations have been carried out along a strike length of ± 1500 feet. Several trenches and pits have been excavated together with one 50 to 100-foot shaft (now sand-filled) which is situated on the north bank of a dry river-bed transgressing the outcrop. Grab-samples obtained by Tsumeb Corp., Ltd. assayed at ± 1·5 per cent copper.

The mineralised area contains few zones of concentration. No estimates of reserves are available. The deposit is unlikely to be of economic value.

3. EBONY MINE

Located some 4½ miles east-southeast of Ebony on Namibfontein 91 (B. 3), the Ebony" Mine" consists of one vertical sand-filled shaft and a few prospecting-trenches. The only sulphide mineralisation visible on the surface consists of a few specks of chalcopyrite and bornite contained in a crosscutting pegmatite, 5 to 10 inches wide.

The shaft is located in calc granulite of the Upper Nosib Stage and was sunk prior to 1914.

4. HENDERSON AND EHLER MINES

These prospects are located on Naob 69 some 8 miles south-southwest of Usakos (B. 4).

They were developed in 1914 by the Otavi Minen- und Eisenbahngesellschaft (O.M.E.G.) in search of pyrite for fluxing purposes. A shaft was sunk to the fourth level (depth unknown).

Mineralisation occurs within sahlite-bearing pegmatites (aplite at Ehler Mine) situated in hornblende schist and calc-silicate rocks at the top of the Nosib Formation. The mineralogy of the deposit is similar to that of the Khan Mine. Native gold is also present.

The occurrences have been prospected by diamond drilling, but have not been proved to be of economic interest.

5. UBIB MINE AND ASSOCIATED PROSPECTS IN ABBABIS ROCKS

At Ubib Mine on Naob 69 (B. 4) and immediately north of the KleinChuos Mountains copper mineralisation occurs in both biotite schist and quartzofe1spathic gneiss belonging to the Abbabis Formation.

The prospects, developed before 1914, have largely been filled in. Waste-rock examined contained disseminated chalcopyrite, bornite and chalcocite and at the Ubib Mine was commonly stained by malachite and azurite. A windmill conceals the shaft of the Ubib Mine.

6. POT MINE

The Pot "Mine" is located on an " island" in the bed of the Swakop River about 50 yards* from the Karibib-Donkerhuk main road. An outcrop of garnetiferous calc-silicate rock has been trenched and pitted at several places over a strike length of about 300 feet. Occasional showings of malachite, chrysocolla, chalcopyrite and bornite were seen on surface.

It is unlikely that any copper ore was produced from this occurrence. No records are available.

7. GAMIKAUBMUND PROSPECT

This occurrence is located immediately to the northeast of the Gamikaub-Swakop confluence on Ukuib 84 (C. 4). The mineralised zone is associated with felspathic quartzite beds intercalated in highly folded biotite schist of the Khomas Series. Some of the ore is contained in pegmatitic zones and some is disseminated in the felspathic quartzite. Chalcopyrite, bornite, chalcocite and molybdenite are present in small quantities.

The prospect is small and unlikely to be of economic interest.

8. OTHER PROSPECTS

In addition to the prospects listed above there are a large number of lesser occurrences widely spread throughout the area. The more interesting of these are associated with pegmatite and, like those described above, are of little economic importance for this reason.

The mineralised pegmatites are often of vast dimension, but the concentration of sulphides within them is ubiquitously sporadic.

In many of the diamond drill holes sunk during investigation of uraniferous ores, minor copper sulphide mineralisation was encountered both in the marble and in the intercalated schist.

It is, however, of some significance that most of the copper occurrences noted, occur in or in close proximity to the upper portions of the Nosib Formation. Particular attention should therefore be paid to this as well as to marble of the Lower Hakos Stage when prospecting for copper in this area.

D. GOLD

Gold prospects occur at several places in the Chuos Mountains. The most notable of these is the Sphinx Mine (C. 3) which is located on the crest of the ridge close to the Nordenburg-Bergrus farm-boundary.

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* 1 yard=0·9144 metre.

Small amounts of gold were recovered from a mineralised quartz vein, but no record exists. Prospecting was abandoned in about 1927.

Gold is also purported to have been mined from quartz veins situated in Abbabis gneiss close to the, northwestern boundary of Abbabis 70 (B. 4).

E. GRAPHITE

Graphite deposits are of little economic importance. No known prospects for this mineral occur in the region considered. Graphite is, however, present in quantity in some of the marble and occasional specimens contain up to 10 per cent of this mineral, but large zones containing consistent values have not been observed.

F. LEAD AND ZINC

The Usakos lead-mine is the only prospect of any size containing galena and sphalerite in the region mapped. This mine is located some 2 miles to the southeast of Usakos. Mineralisation occurs in a distinct stratigraphic zone in marble of the Upper Hakos Stage a short distance above the contact with the amphibolite facies of the Nosib Formation. The outcrop is high up on the slope of the prominent dark hills overlooking Usakos.

The prospect has been extensively explored, and 22,500 tons of ore were mined and concentrated at a plant located on the outskirts of Usakos. The concentrates amounted to 116 tons of lead and 227 tons of zinc (0·5 per cent lead, 1 per cent zinc and 0·3 oz. of silver per ton of ore). The mining venture ended in failure due to lack of ore tonnage and has not been reconsidered for exploitation.

Disseminated galena also occurs in the Upper Hakos Stage on Navachab 58 (B.4) close to the contact with the Abbabis gneiss. The extent of the mineralisation is apparently small. It has not been prospected.

G. LIMESTONE

The bulk of the Hakos Series, widely developed throughout the region, is composed of dolomitic marble. Calcite zones do, however, occur and have been prospected by Anglo-Alpha Cement, Ltd. in 1955-56. One prospect near Karibib and another on the Swakop River just outside Swakopmund have been proved to be exploitable.

H. MARBLE

Extensive deposits of marble are found in the vicinity of Karibib to the north of the area. These were worked largely before 1914, the marble being sent to Germany for monumental and decorative purposes. The colour range of the marble is considerable, the varieties being blue grey, white, dark grey, blackish, cream, greenish and reddish.

Present-day production, largely from quarries located immediately to the north of Karibib, is small. Production in 1960 amounted to 170 tons (Republic of South Africa, Department of Mines, 1961).

I. MICA

There has been no production of mica in recent years. Several old mica (biotite and phlogopite) prospects occur in the vicinity of Rössing where they are associated with high-grade metamorphism of amphibole schist situated within and beneath the Lower and Upper Hakos Stages. Books of mica up to 18 inches across are sometimes developed in moderate quantities.

J. MOLYBDENUM*

An occurrence of molybdenum on Navachab 58 (B. 4) was reported in 1964. Impregnations of sulphides are localised in the middle of a belt of marble, 2 to 3 km wide, near the contact of the Damara System and intrusive granite. The development of the granite-marble contact was favourable to local mineral concentration.

The marble is crowded with elongate fragments of epidote-actinolite-tremolite-garnet hornfels in which the sulphides are concentrated. The granite shows much abnormal textural variation and is locally cut by crisscrossing quartz stringers within a few feet of the contact. All these features are typical of a contact-metamorphic environment with erratic mineralisation.

Pyrrhotite, pyrite and molybdenite, and microscopic traces of bornite and chalcopyrite are encountered. The pyrrhotite and pyrite are largely weathered to limonite. The mineralisation is not likely to show persistence in any direction. Only one of the four prospecting-pits has shown a notable percentage of molybdenum. A picked sample assayed 4.5 per cent molybdenum. At best a few tons of 5 per cent molybdenum may be recovered and the occurrence is considered to be of no interest as a mining proposition.

K. MONAZITE

Monazite containing a high thorium content (as determined by high radiometric assay and low U3O8 value) occurs in pegmatites at Louw's Claims. Mineralised zones are extremely patchy and of little economic interest.

An interesting monazite deposit was discovered on Eureka 99 in 1959. It occurs in the Upper Hakos marble which is covered to a large extent by surface-limestone. Monazite occurs as euhedral crystals up to 4 inches across disseminated in the marble host. Grab-samples, weighing between 3 and 10 lb.†, contain up to 75 per cent by volume of monazite. The occurrence, where opened up in a pit about 20 feet wide and 5 feet deep, is extremely rich and should be well worth prospecting should the demand for this rare-earth mineral increase.

A specimen analysed as follows (Von Knorring and Clifford, 1960):

SiO_2	0·13
P_2O_5	30·10
Ce_2O_3	33·65
La_2O_3	23·00
Nd_2O_3	10·00
R_2O_3	2·18
ThO_2	0·70
TOTAL	99·76

L. PEGMATITE MINERALS

1. DISTRIBUTION

The major lithium-beryllium-bearing pegmatites occur in the eastern areas of the regional map. The most important bodies are listed in table 16 which shows that the majority are contained in the Upper Hakos Stage. There is no distinct zonal distribution of these pegmatites, they occur both in metasediments and in igneous types.

* This section was extracted from a report by Dr. P.G. Söhnge of the Tsumeb Corp., Ltd.

† 1 pound=0.4536 kilogram.

TABLE 16.—THE MAJOR LITHIUM-BERYLLIUM-BEARING PEGMATITES OF THE KARIBIB DISTRICT

Name of pegmatite	Locality	Stratigraphic position	Minerals exploited	Remarks
Dernburg	Navachab 58	Lower Nosib quartzite	Amblygonite, lepidolite, beryl, tantalite	Ceased production
Macdonald's	Etusis 75	Upper Hakos Stage	Amblygonite, petalite, lepidolite, beryl, bismuth	Small producer
Fricker's	Okatjimukuju 55	Upper Hakos Stage	Tantalite, beryl, petalite	Small producer
Karlsbrunn	Kaliombo 119	Upper Hakos Stage	Lepidolite, amblygonite, petalite, beryl, columbite	Largely ceased production
Brockmann's	Kaliombo 119	Upper Hakos Stage	Lepidolite, amblygonite, columbite, beryl	Ceased production
Berger's	Kaliombo 119	Upper Hakos Stage	Lepidolite, amblygonite, columbite, beryl	Small producer
Helikon I & II	Okongava Ost 72	Upper Hakos Stage	Lepidolite, amblygonite, petalite, beryl, columbite	Large producer
Rubicon	Okongava Ost 72	Khomas Series	Lepidolite, amblygonite, petalite, beryl, bismuth, columbite	Large producer
Becker's	Otjua 37	Upper Hakos Stage	Lepidolite, tourmaline, (beryl)	Small producer
Brockmann's	Gamikaubmund	Lower Nosib quartzite	Beryl, columbite-tantalite	Large producer of beryl

2. STRUCTURAL SETTING

Nearly all these bodies are dyke-like and discordantly situated with regard to the foliation of their host-rocks. Their emplacement at a very late stage in the tectonic history of the Damara rocks is evident from the fact that they are not deformed and are associated in some cases with a period of faulting (Roering, 1961, p. 11).

3. ORIGIN

The fact that the mineralised pegmatites are of fairly uniform composition and occur as dykes in host-rocks of very variable composition, is indicative of a magmatic origin (Roering, 1961, p. 35). They are related to a period of granitisation resulting in the production of granitic and dioritic magmas, rocks derived from which occur extensively in the environment in which the pegmatites are found. The fact that the majority of the lithiumberyllium-bearing pegmatites occur in the Upper Hakos Stage is probably due to the damming effect on volatiles by marble of this group, which also created structural traps for pegmatitic melts in tension-zones.

4. MINES AND PRODUCTION

The more important mines, both past and present, are listed in table 16. Of these Helikon and Rubicon, controlled by South West Africa Lithium Mines, are by far the most important and account for the bulk of the lithium, beryllium and bismuth produced in South West Africa.

Production statistics for individual mines are not available. The approximate monthly tonnages of ores produced in 1956 from Helikon and Rubicon are as follows (Luyt, 1957, p. 48):

	Tons
Lepidolite (3-3·6 per cent Li)	100
Amblygonite (6-8 per cent Li)	60-100
Petalite (3-4 per cent Li)	400-500
Beryl	20-25
Columbite	0·5

These figures vary considerably depending on both production and marketing. Figures for mineral production from January to December 1960 in the territory of South West Africa (Republic of South Africa, Department of Mines, 1961) showed the following:

	Tons
Amblygonite	161
Lepidolite	972
Petalite	3,909
Beryl	413
Bismuth	1,048 lb.

In addition to the above minerals a certain amount of pollucite, tantalite and columbite is produced.

5. RESERVES

There are considerable reserves of lithium-beryllium ores in the Karibib District, which must amount to several millions of tons. The reserves are, however, scattered throughout the area in numbers of small pegmatites as well as in the larger ones already mentioned. Large pegmatites containing fairly evenly disseminated beryl have been reported but not investigated.

More refined metallurgical techniques in future may result in the upgrading of quantities of low-grade lithium and beryllium ores which would then become exploitable on a larger scale.

M. SEMIPRECIOUS STONES

A small trade in semiprecious stones derived from within the region mapped is carried on from time to time. The pegmatite claims located a few miles to the north of Rössing (C. 1) have produced green beryl, aquamarine and heliodor (Wagner, 1916, p. 84) in the early nineteen hundreds. These pegmatites are apparently worked out.

Gem-quality tourmaline has been won from a few drusy pegmatites located near the Usakos lead-mine, on Neu Schwaben 73 (Herring's Claims) and from Becker's Claims on Otjua 37 as well as at several other places of lesser importance.

Aquamarine of gem quality is also occasionally found.

N. TIN

Very little tin is produced from this region. Various tin claims exist, largely on pegmatite situated in the Khomas Series, but have mainly been worked out and are of little importance.

The most important deposit within this region is the Arandis tin-mine which produced substantial amounts of cassiterite [14·52 metric tons* in 1929 (Gevers, 1929, p. 170)] in the late 1920's and 1930's. The deposit is unusual in that it does not occur in pegmatite, is associated with pyrrhotite, arsenopyrite, pyrite, chalcopyrite, bornite and bismuth ore, and is considered (Gevers, 1929, p. 170) to be of hydrothermal origin. The mine is located some 20 miles north of Arandis in highly folded Upper Hakos marble and has been described by Gevers (1929) and Ramdohr (1935). An unusual mineral, arandisite (tin silicate), occurs there (Partridge, 1929).

O. URANIUM

The discovery of the occurrence of davidite in the 1920's at Louw's Claims near Rössing eventually led to the prospecting for prescribed minerals in 1955-58. The Louw Syndicate which discovered the occurrence of uranium ores in pegmatite at Louw's Claims and elsewhere, ceded its ground under option to the Anglo American Prospecting Company. Substantial sums were spent on prospecting by the above company and further search revealed a large number of uraniferous zones, most of which are associated with pegmatite situated in the Lower Hakos Stage.

The largest concentration is located at SJ Claims (C. 2) which were thoroughly prospected by diamond drilling and trenching as well as underground development.

Uranium occurs in the form of complex oxides as well as in euhedral, very fine-grained uraninite which is generally contained as inclusions in biotite concentrated in mica-rich selvedges in several zones in a large pegmatite body. The pegmatite is of syntectonic age and partly metasomatic in origin as is evident from its partial replacement of biotite schist and biotite quartzite intercalated in highly folded Lower Hakos beds in the Dome Synclinorium. The

* 1 metric ton=2204·6 1b.

mineralogy of the uraniferous pegmatites is generally very similar. The typical mineral assemblage is dark' smoky, anhedral quartz, subhedral salmon-pink microcline and black biotite. Yellow gummite and green metatorbanite are abundant on cleavage and fracture surfaces of minerals and rocks.

U_3O_8 values of up to 11 lb. per ton were obtained at SJ and Louw's Claims, but zones containing such high values are small and extremely patchy. Large volumes (several million tons) of low-grade (1 lb. per ton) ore were proved at SJ Claims, but were deemed to be unpayable. These claims are held by the Louw Syndicate.

P. MINERAL DISTRIBUTION PATTERN WITH REFERENCE TO THE ORIGIN OF THE ORES

As mentioned already, the mineralisation in the area is confined almost exclusively to pegmatites. Lithium and beryllium in particular are confined, in the Damara System, largely to the Karibib District which is underlain by rocks recrystallised in the deeper portions of the geosyncline where granitic rocks were developed on a vast scale. The Damara rocks in this region are also stratigraphically deeply eroded. The Khomas Series is preserved only in the deeper synclines and large areas Of Hakos Series and underlying rocks are exposed. In regions to the north and south the lower stratigraphic levels are often poorly exposed and granite is less well developed (if at all). It can be said, therefore, that both stratigraphic level and granite emplacement have directly influenced the distribution of these mineral concentrations.

Although the bulk of the lithium-beryllium-bearing pegmatites occur in the Upper Hakos Stage it is felt that the material of which they are composed is not derived from the nearly pure carbonate marble, but was introduced, into structural traps within them as well as within other strata from underlying granitised and mobilised metasediments. Roering (1961, p. 35) has suggested that lithium and beryllium are likely to have been derived from rocks which were originally marine shales, e.g. the Khomas schist. This seems unlikely, however, since so many of the lithium-beryllium-bearing pegmatites occur both structurally and stratigraphically below these rocks (see geological column and table 16) where there are only minor biotite schist intercalations.

Tin-bearing (cassiterite) pegmatites are almost exclusively restricted to the Khomas schist. This is indicative of an originally high trace content of this element in the schist and of subsequent concentration by granitisation processes into pegmatites within these rocks.

Tantalite and/or columbite occur in pegmatites in all stratigraphic positions; no distinct preference for anyone is apparent.

Copper occurrences are wide-spread within the Damara System and the Nosib Formation. In the region mapped they are mainly limited to the upper zones of the Nosib Formation. Those occurring south of Windhoek are apparently confined to similar stratigraphic horizons (Martin, personal communication). No documentation of the position of all these deposits has been made, however. The stratigraphic control on copper mineralisation suggests that it was introduced during the sedimentation of the Upper Nosib Stage and of the dolomite of the Otavi Series in which there are some 290 copper showings mainly in the Otavi Mountain-land (Söhnge, 1958).

This thesis of original sedimentary control of copper mineralisation in the region mapped, is strongly supported by the distribution of uramum mineralisation in pegmatites of dominantly metasomatic type, confined almost exclusively to the Lower Hakos beds in a highly folded region in the Lower Khan Gorge. The mineral assemblage of the Khan Mine pegmatite as well as of many other copper-bearing pegmatites, is also indicative of a partly metasomatic origin (Söhnge, 1939, p. 29).

Lead and zinc are found only in the Upper Hakos marble in this region and at the Usakos lead-mine have a definite stratigraphic distribution within the marble.

The hydrothermal-type deposit at the Namib lead-mine may be a reconcentration of original sedimentary material.

The relation between stratigraphy and mineralisation in the Nosib Formation and the Damara System is strong. Copper, though seldom found in large concentrations, is widely distributed and is possibly related in time of deposition to the deposits in the Katanga System which is of comparable age and stratigraphy to the Damara System.

The stratigraphic approach to exploratory geology is, on the basis of the above findings, of prime importance.

DIE GEOLOGIE VAN DIE GEBIED OM DIE KHAN- EN SWAKOPRIVIER IN SUIDWES-AFRIKA

OPSOMMING IN AFRIKAANS

deur

M. H. Martin, Ph.D.

INLEIDING

Die gekarteerde gebied beslaan 'n oppervlakte van nagenoeg 3000 vierkante myl. Sedert die einde van die vorige eeu word daar in die gebied geprospekteer, en die resultate van vroeere geologiese werk sluitin verslae van mynmaatskappye en van Reuning (1923), Wagner (1921) en Söhnge (1939). Verskeie verkenningsopnames is deur Gevers (1931, 1931a en 1934) uitgevoer.

Die westelike gedeelte van die gebied vorm 'n deel van die Namibwoestyn terwyl die oostelike gedeelte 'n halfwoestyn is wat 'n mate van ekstensiewe boerdery toelaat. Die jaarlikse reënval varieer van omtrent 50 mm in die weste tot 100 na 150 mm in die ooste. Die plantegroei is yl en by die klimaatsomstandighede aangepas. Die gebied is gevolglik yl bewoon deur blanke skaapboere en deur Damaras in die Otjimbingwereservaat. Die dorp Usakos lê op die noordgrens van die gebied wat ook deurkruis word deur die spoorlyn en hoofpad vanaf Usakos na Swakopmund en Walvisbaai en origens in sy geheel goed toeganklik is.

Die gebied word deur die Swakop- en die Khanrivier gedreineer. Die grootste gedeelte van hulle opvanggebiede lê buite die betrokke gebied in streke met 'n hoër reënval. Vloede is sporadies en tot die somermaande beperk. Hierdie riviere en hulle goed geïntegreerde sytakke het diep klowe in die wye erosieoppervlak van die Namib wat deur eilandberge onderbreek word, ingekerf.

GEOMORFOLOGIE

Twee fossielerosieoppervlakke word herken: (1) Die Triassiese VoorStormbergoppervlak wat in die omgewing van Karibib 'n duidelike *gipfelflur* met twee oorblyfsels van Stormbergsedimente en lawa vorm, en blykbaar taamlik ongelyk was met eilandberge waarvan oorblyfsels tans nog die hoogste punte van die Otjipatera- en Chuosberge en die Rössingberg vorm. (2) Die Namibvlak wat waarskynlik van Tersiêre ouderdom is, en geleidelik vanaf die kus na die binneland styg waar dit aan die oostelike grens van die gebied hoogtes van 3600 tot 4000 voet (1100-1200 m) bereik. Verder oos, buite die gebied, vorm hierdie breë valleie in die eskarp. Die Namiboppervlak is gegradeer na die van die hoër, kalkgebonde gruisterrasse van die groot riviere. Hierdie terras het in die westelike deel van die gebied ‘n hoogte van omtrent. 500 voet (150 m) bokant die huidige vloer van die groot riviere. Al die eilandberge styg vanaf die Namibvlak wat langs die groot riviere erg verkerf is deur ‘n jonger erosiesiklus. Oorblyfsels van erosievlakke in die vorm van skouers aan die berge kan tussen die Voor-Stormberg- en die Namiboppervlak herken word; daar kom ook terrasse voor tussen die hoër terrasse en die huidige rivierloop.

GEOLOGIESE FORMASIES

Nuwe benamings word voorgestel vir die onderafdelings van die Sisteem Damara en die skeiding van die Formasie Nosib (voorheen Serie Kwartsiet) van daardie sisteem, soos in die volgende tabel blyk:

Kwaternêr en Tersiêr			Waaisand Glooiingspuin, eluviale en alluviale ongekonsolideerde en kalkverkitte sand en gruis Hoëvlakterrasafsettings, kalkgebonde
	Diskordansie		
Na-Karoo			Dolerietgange
Sisteem Karoo	Serie Stormberg		Basalt wat op skalie lê
	Diskordansie		
Laat- tot Na-kinematies			Graniet en pegmatiet
Fasies Swakop van Sisteem Damara	Serie Khomas		Kwartsveldspatiese biotietskis, gneis en graniet
	Serie Hakos	Boonste Étage	Dolomitiese marmer met tussenlae van biotietskis en amfiboolskis
		Middelste of Étage Chuos	Tilliet
		Transgressiewe oorvleueling	
		Onderste Étage	Dolomitiese marmer, kwartsiet, tussenlae van biotietskis
Formasie Nosib		Boonste Étage	Kwartsiet, amfiboolgranuliet, biotiet-kwartsskis
		Onderste Étage	Veldspatiese en suiwer kwartsiet, tussengelaagde biotietskis
	Diskordansie		
Formasie Abbabis			Gneis, biotietskis, plaaslike kalk-silikaatgesteente

FORMASIE ABBABIS

Die oudste gesteentes in die gebied dagsoom in twee antiklinale kerns en word onder die naam Formasie Abbabis saamgevat. Hierdie formasie bestaan hoofsaaklik uit ‘n groep kwarts-veldspaatgneis, ‘n dun groep dolomietmarmer en kalk-silikaatgesteentes, en ‘n groep biotietskis met ‘n paar lae amandelhoudende lawa. Al hierdie gesteentes was reeds geplooi, gemetamorfoseer en deur pegmatiete en basiese gange van geüralitiseerde gabbro binnegedring voordat die afsetting van die Formasie Nosib begin het.

FORMASIE NOSIB

Die daaropvolgende siklus begin in hierdie gebied met die afsetting van kwartsitiese gesteentes wat tot 10,000 voet dik is en met die Formasie Nosib gekorreleer word. Hierdie klastiese sedimente is in aparte komme van wisselende diepte afgeset. In die gebied onder bespreking word 'n onderste étage van hoofsaaklik veldspatiese kwartsiet en 'n boonste étage wat uit meer kalkige kwartsiet opgebou word, onderskei. Laasgenoemde is net in die westelike deel van die gebied aanwesig, waar dit deur metamorfose in kalkgranuliet verander is. In die oostelike gedeelte word 'n groep gesteentes bestaande uit amfiboolhoringfels met tussengelaagde biotietkwartsiet aangetref.

SISTEEM DAMARA

Die gesteentes van die Sisteem Damara is in hierdie gebied nie deur 'n diskordansie van die Formasie Nosib geskei nie. In plaas van 'n diskordansie wat in ander gebiede wel voorkom, vind hier 'n geleidelike oorskryding van die marmer van die Sisteem Damara oor die kwartsiet van die Formasie Nosib tot op die gneis van die Formasie Abbabis plaas. Aangesien die Damarasedimente konkordant op die boonste Nosiblae volg en daar in sommige gebiede ook 'n geleidelike litologiese oorgang ontwikkel is, is dit nie oral moontlik om die basis van die Sisteem Damara presies te bepaal nie.

Die siklus begin met die afsetting van die Serie Hakos. Dit bestaan uit 'n onderste étage van kalksteen (marmer) en kwartsiet wat net in die weste ontwikkel is; 'n middel- of Chuosetage wat uit tilliet en geassosieerde ysafsettings bestaan; en 'n boonste étage wat hoofsaaklik deur 'n dik opeenvolging van marmer opgebou word. In sommige dele van die gebied gaan die massiewe marmer oor in 'n afwisseling van marmerbande en mikaskislae. Die Serie Hakos bereik 'n dikte van tot 4400 voet (1300 m) in hierdie gebied.

Konkordant hierop volg die Serie Khomas wat uit goedgelaagde biotietskis en biotiet-kwartsskis bestaan. Aangesien daar nog marmerlae op sekere plekke taamlik hoog op in die skis voorkom, kan die grens tussen die Serie Hakos en die Serie Khomas nie akkuraat getrek word nie. Die Serie Khomas bereik in hierdie gebied 'n dikte van omtrent 10,000 voet (3000 m), maar dit is nie die volle dikte nie, aangesien die top van die serie nêrens behoue gebly het nie.

Die Sisteem Damara het baie van die kenmerke van 'n geosinklinale opeenvolging wat 'n insinkende trog geleidelik gevul het. Die sedimentasie van die Damaragesteentes is deur 'n orogenese van groot intensiteit beëindig. Dit het aanleiding gegee tot hewige plooiing, hoëgraadse metamorfose, migmatitisasie, granitisasie en die indringing van graniet en pegmatiet. Die laaste, na-kinematiese pegmatiete is 510 ± 40 miljoen jaar oud.

Te oordeel na die interferensie van plooistrukture was daar waarskynlik meer as een fase van plooiing. Die laaste en intensiefste fase het plooie met 'n noordoostelike strekking teweeggebring en metamorfose het daartydens die hoogste graad bereik met die vorming van kordiëriet, granaat, andalusiet, sillimaniet, forsteriet, wollastoniet en skapoliet. Oor uitgestrekte gebiede was die metamorfose so hewig dat granitisasie op groot skaal en plaaslik ook anateksis en mobilisasie plaasgevind het. Deur hierdie prosesse is veldspatiese kwartsiet van die Formasie Nosib in rooi gneis en graniet omvorm, en die biotietskis en biotiet-kwartsskis van die Serie Khomas in veldspatiese biotietgneisen porfiroblastiese graniet (Salemgraniet) en plaaslik ook in kwartsdioriet.

Die rooi graniet en gneis is altyd deur marmer van die Serie Hakos van die Salemtipe-graniet geskei. Weens die feit dat die Salemgraniet in geslote sinkliene, van marmer voorkom, was die granitisasie waarskynlik grotendeels 'n isochemiese proses. Hierdie gevolgtrekking word deur petrografiese en chemiese ondersoeke bevestig. Net 'n gedeelte van die gegranitiseerde materiaal was so mobiel dat dit op 'n groter skaal intrusief geword het.

Die groot, laat- tot na-kinematiese pegmatiete bestaan uit magmatiese materiaal. Dit word bewys deurdat hulle die dik marmer van die Étage Bo-Hakos binnegedring het, waar hulle nie deur afskeiding uit die wandgesteente kon gevorm het nie. Desnieteenstaande is die mineralisasie van die pegmatiete afhanklik van die stratigrafiese posisie waarin hulle voorkom. Koperhoudende pegmatiete is feitlik tot die boonste deel van die Formasie. Nosib of die basale deel van die Serie Hakos beperk. Aangesien 'n mate van kopermineralisasie ook wydversprei is in dieselfde stratigrafiese sones buitekant die hoogs gemetamorfoseerde gebied, is dit waarskynlik dat die koper van singenetiese oorsprong is en later gedurende die metamorfose 'n redistribusie ondergaan het. Pegmatiete met konsentrasies van Be, Li, Bi en Cs is hoofsaaklik tot die marmer van die Étage Bo-Hakos beperk. Die konsentrasie juis in hierdie sone is waarskynlik toe te skryf aan die opdamming van die vlugtige bestanddele van die pegmatitiese magma deur die marmerlae. Uraan kom hoofsaaklik in pegmatiet in 'n sekere biotietskissone in die Étage Onder-Hakos voor. Tin is feitlik tot pegmatiete in die Serie Khomas beperk. Hierdie stratigrafiese afhanklikheid van die mineralisasie dui daarop dat die minerale waarskynlik oorspronklik in die wandgesteentes versprei was om dan deur die metamorfose saam met die pegmatitiese magma gemobiliseer te word.

SISTEEM KAROO

Vanaf die einde van die metamorfose en pegmatietindringing gedurende die Kambrium (510 mj) tot die afsetting van Stormberg-sedimente en uitvloeiing van lawa in die Bo-Trias is daar geen geologiese rekord nie. Die gesteentes van die Serie Stormberg is beperk tot twee klein skalievoorkomste met basaltiese lawa daarop. Hierdie lae kroon twee berge in die nabyheid van Karibib. Oliviendolerietgange wat hoofsaaklik noordnoordoos en oosnoordoos strek, deurkruis die hele gebied.

TERSIÊRE TOT RESENTE AFSETTINGS

Die kalkgebonde rivierterrasgruis wat plek-plek in die valleie van die Swakop- en die Khanrivier op hoogtes vanaf 200 tot 600 voet bokant hulle huidige vlak aangetref word, is waarskynlik van Bo-Tersiêre ouderdom. Jonger kalkverkitte terrasgruis en puin, en oppervlakkalksteen is wydversprei langs die riviere en ook as 'n dun bedekking op die rotsvloere wat die Namibvlakte vorm. Hierdie afsettings is van Pleistoseenouderdom. In die heel westelike deel van die gebied is die oppervlakkalksteen aan die oppervlak in gips verander. Waaisand is teen die oostelike en noordoostelike hange van sommige van die eilandberge in die westelike deel van die gebied opgehoop.

Klipwerktuie, vernaamlik van die Middel-Steentydperk, kom wydversprei voor.

EKONOMIESE GEOLOGIE

In die gebied is daar spore en klein afsettings van asbes, bismut, goud, koper, lood, mika, molibdeniet, monasiet, sink, tin en uraan. Al hierdie afsettings is te klein om ontginning te regverdig of hulle is, soos die Khankopermyn en die Arandistinmyn, reeds uitgewerk. Die gebied produseer tans net geringe hoeveelhede litiumminerale en beril saam met kleiner hoeveelhede kolumbiet-tantaliet en pollusiet

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PLATE I.—Inselbergs and sand flats on Ubib 76 (B. 4). NslQ=red felspathic quartzite, G_1=red gneissic granite.

PLAAT I.—*Eilandberge en sandvlakte op Ubib 76 (B. 4). NslQ=rooi veldspatiese kwartsiet,* G_1*=rooi gneisige graniet.*

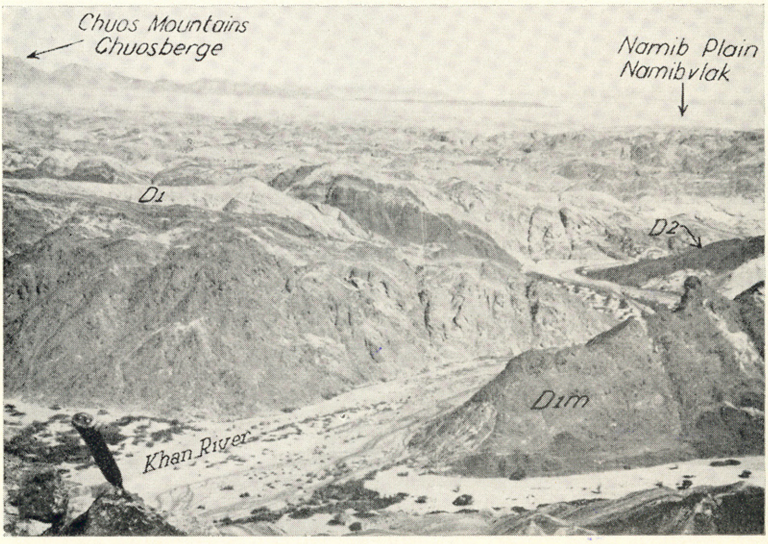


PLATE II.—The incised bed of the Khan River and marginal " bad lands ". D_1= marble, D_1m=tillite, D_2=schist.

PLAAT II.—*Die ingekerfde bedding van die Khanrivier en randstandige dongaveld.* D_1*=marmer,* D_1*m=tilliet,* D_2*=skis.*

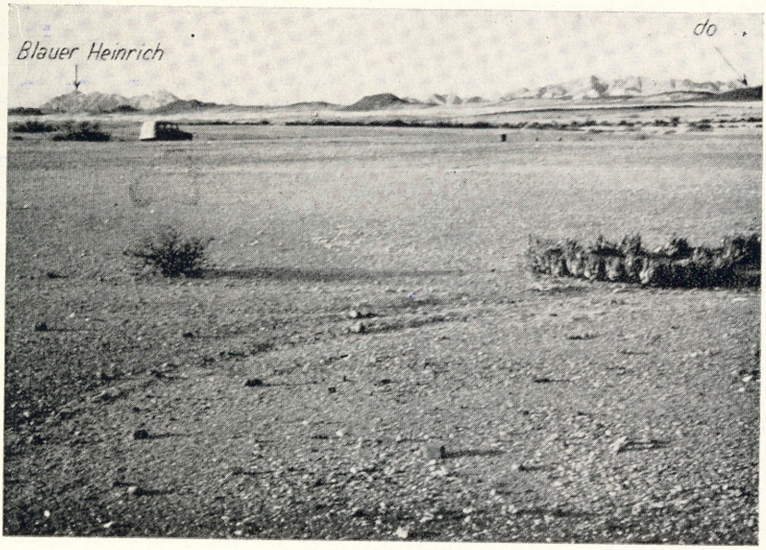


PLATE III.—Undulations in the plain and the character of the surface in the western areas. do=dolerite.

PLAAT III.—*Golwings in die vlakte en die kenmerke van die oppervlak in die westelike gebiede. do=doleriet.*

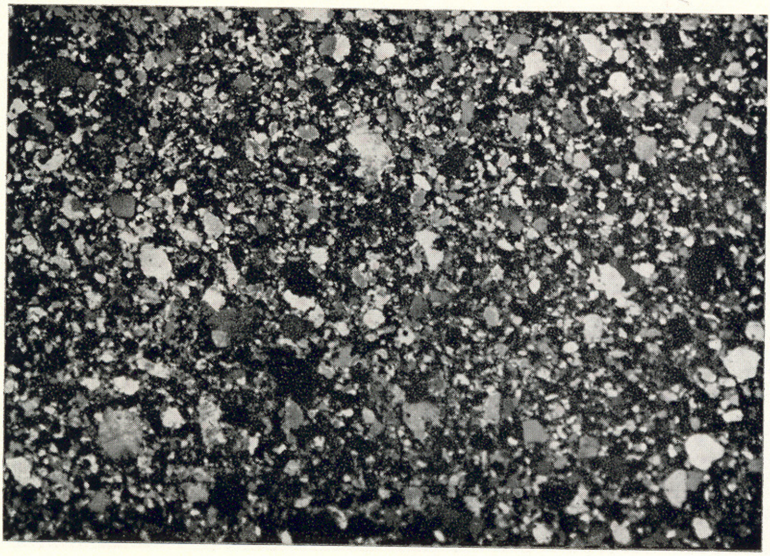


PLATE IV.—Etusis quartzite from Abbabis Poort (B. 4). (Sample SM 107.) Detrital grains of quartz and felspar. Crossed nicols, ×7.

PLAAT IV.—*Etusiskwartsiet van Abbabispoort* (*B.* 4). (*Monster SM* 107.) *Detritale kwarts- en veldspaatkorrels. Gekruiste nicols,* × 7.

PLATE V.—" Striped Series " of the upper stage of the Nosib Formation. Both quartzofelspathic and amphibole material boudinaged.

PLAAT V.—" *Gestreepte Serie* " *van die boonste étage van die Formasie Nosib. Kwartsveldspatiese en amfiboolmateriaal albei vervorm in boudinagestrukture.*

PLATE VI.—Contact between Khan and Etusis quartzites in Lower Khan Gorge. D_1l=marble, NslQ=Etusis quartzite, NsuQ=Khan quartzite. (Copied from aerial photograph by A.A.C.)

PLAAT VI.—*Kontak tussen Khan- en Etusiskwartsiet in Benede-Khankloof. D_1l=marmer, NslQ=Etusiskwartsiet, NsuQ=Khankwartsiet. (Gekopieer vanaf lugfoto deur A.A.C.)*

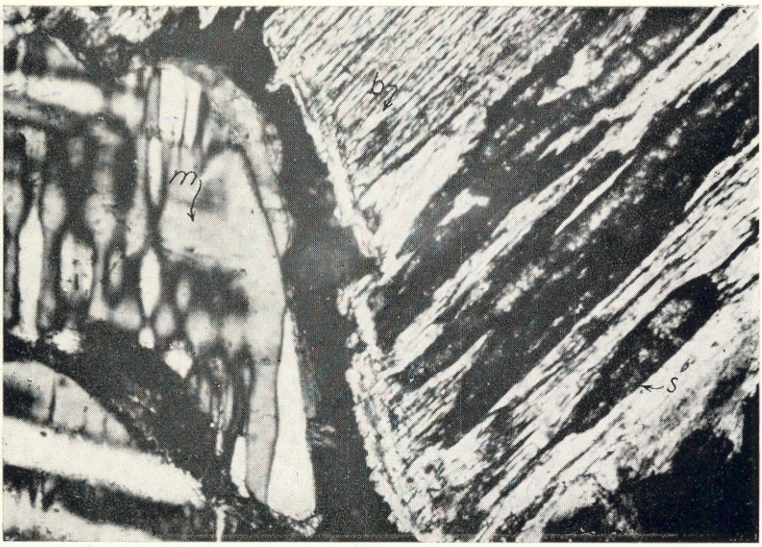


PLATE VII.—Anhedral sphene (s) situated in and parallel to the basal cleavage of biotite (b). (Sample SM 71.) m=microcline. Crossed nicols, ×100.

PLAAT VII.—*Oneievormige sfeen (s) in en ewewydig aan die basale splyting van biotiet (b). (Monster SM 71.) m=mikroklien. Gekruiste nicols, × 100.*

PLATE VIII.—Chuos tillite in Pinnacle Gorge (C. 2) showing an assortment of angular rock fragments in a granular to gneissose matrix. Coarser material is flattened roughly parallel to the bedding-planes.

PLAAT VIII.—*Chuostilliet in " Pinnacle "-kloof (C. 2) wat 'n verskeidenheid hoekige rotsbrokke in 'n korrelrige tot gneisagtige matriks toon. Growwer materiaal is naastenby ewewydig aan die laagvlakke afgeplat.*

PLATE IX.—Chuos tillite in Dome Gorge (C. 2). An undeformed porphyritic granite boulder in a schistose matrix. Smaller fragments are flattened parallel to bedding and schistosity.

PLAAT IX.—*Chuostilliet in " Dome "-kloof* (*C.* 2). *'n Onvervormde porfiritiese graniet-rolblok in 'n skisagtige matriks. Kleiner brokke is afgeplat ewewydig aan die gelaagdheid en skisteusheid.*

PLATE X.—Marble of Upper Hakos Stage on Gross Aukas 68 (B. 4) showing intense plastic deformation (70 to 80 per cent flattening and no shear component).

PLAAT X.—*Marmer van Étage Bo-Hakos op Gross Aukas* 68 (*B.* 4) *wat intense plastiese vervorming toon* (70 *tot* 80 *persent afplatting en geen skuifskeurkomponent*).

PLATE XI.—Silicate-banded marble of Upper Hakos Stage on Gross Aukas 68 (B. 4) showing boudinage and parasitic folding. Silicate bands are flexure folded (shortening ± 46 per cent) and marbles are of similar fold-type showing 60 to 90 per cent flattening.

PLAAT XI.—*Silikaatgestreepte marmer van Étage Bo-Hakos op Gross Aukas* 68 (*B.* 4) *wat boudinage- en neweplooiing toon. Silikaatbande toon fleksuurplooiing* (*verkorting* ± 46 *persent*) *en marmer gelykvormige plooiing wat* 60 *tot* 90 *persent afplatting toon.*

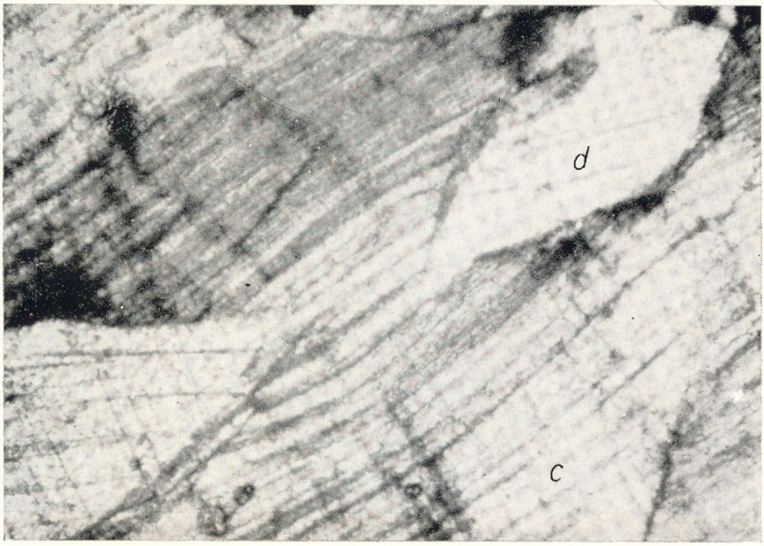


PLATE XII.—Marble of Upper Hakos Stage (sample KR 42). Bent calcite (c) cleavage-planes. Dolomite (d) relatively unaffected. ×50.

PLAAT XII.—*Marmer van Étage Bo-Hakos* (*monster KR* 42). *Gebuigde kalsietsplytvlakke* (*c*). *Dolomiet* (*d*) *betreklik onaangetas.* × 50.

PLATE XIII.—Aerial photograph showing concordant pegmatites in Khomas Series. D_2=Khomas schist, D_1m=tillite, D_1u=marble, pe=pegmatite.

PLAAT XIII.—*Lugfoto wat konkordante pegmatiete in Serie Khomas aantoon. D_2=Khomasskis, D_1m=tilliet, D_1u=marmer, pe=pegmatiet.*

[Photo/*Foto:* A.A.C.]

PLATE XIV.—Khomas schist (sample SM 149). Photomicrograph showing glomero-porphyroblasts of quartz with biotite-rich selvedges in a fine-grained quartz-biotite schist. Porphyroblasts apparently slightly " rotated ". Crossed nicols, × 5.

PLAAT XIV.—*Khomasskis (monster SM 149). Mikrofoto wat glomeroporfiroblaste van kwarts met biotietryke selfkante in 'n fynkorrelrige kwarts-biotietskis toon. Porfiroblaste skynbaar effens " gedraai ". Gekruiste nicols,* × 5.

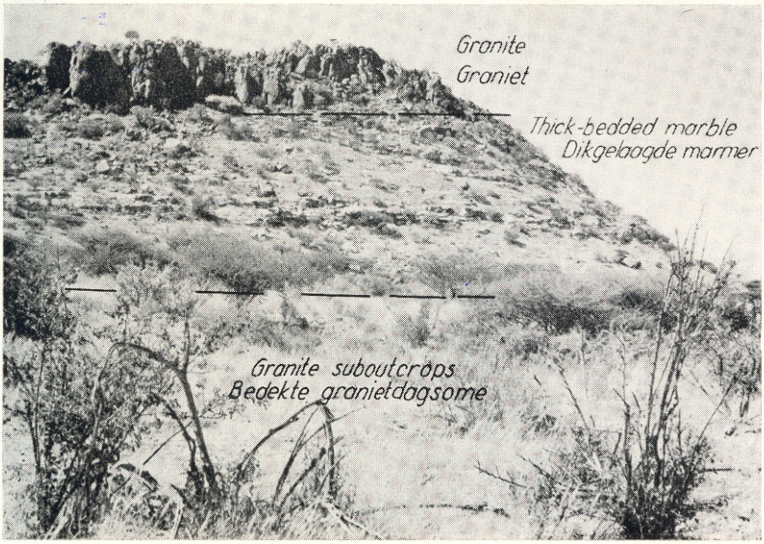


PLATE XV.—Geisterberg-type granite overlying and underlying thick-bedded Upper Hakos marble in the Okatjeneberg on Meyersrust 118 (inset).
PLAAT XV.—*Geisterbergtipe-graniet wat bo en onder dikgelaagde Bo-Hakosmarmer in die Okatjeneberg op Meyersrust* 118 (*inlas*) *lê.*

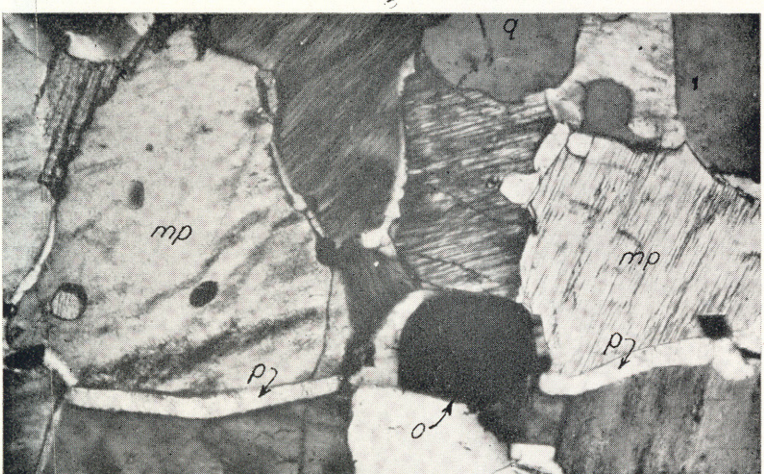


PLATE XVI.—Photomicrograph of rapakivi-type texture in red granite-gneiss at Louw's Claims (C. 1). (Sample SM 36.) q=quartz, p=plagioclase, mp=microcline-perthite, o=ore. Crossed nicols, × 32.
PLAAT XVI.—*Mikrofoto van rapakivitipe tekstuur in rooi granietgneis by Louw se Kleims* (*C.* 1). (*Monster SM* 36.) *q=kwarts, p=plagioklaas, mp=mikroklienpertiet, o=erts. Gekruiste nicols,* × 32.

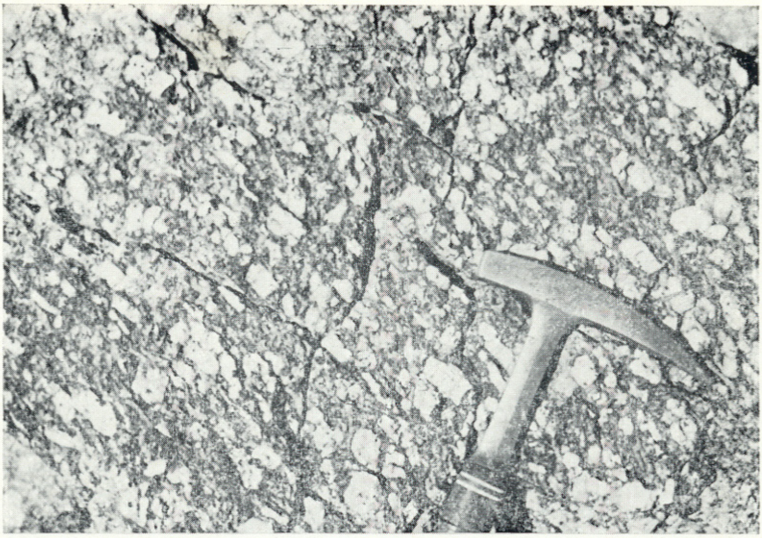


PLATE XVII.—Porphyritic Salem gneiss on Neu Schwaben 73 (B. 5). Phenocrysts of potash felspar showing general orientation which is parallel to the foliation in neighbouring metasediments.

PLAAT XVII.—*Porfiritiese Salemgneis op Neu Schwaben* 73 (*B.* 5). *Kaliveldspaat-eerstelinge wat 'n algemene orientasie ewewydig aan die foliasie van aangrensende metasedimente toon.*

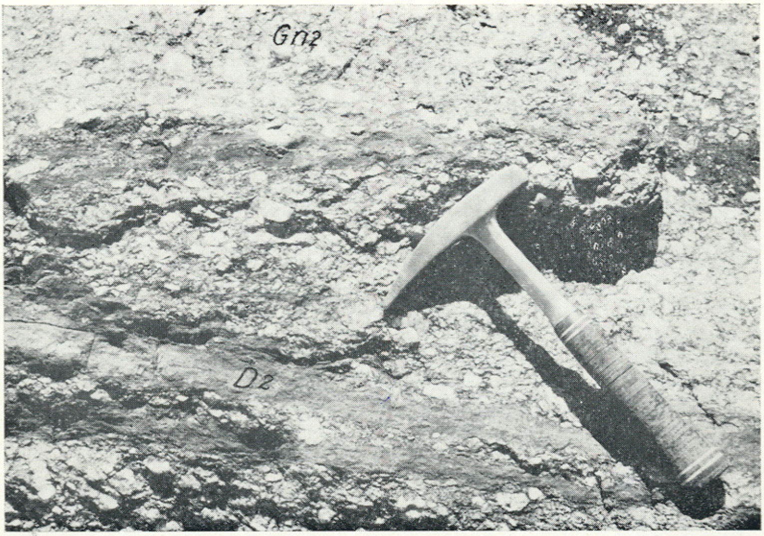


PLATE XVIII.—Porphyritic Salem gneiss (Gn_2) in contact with Khomas schist (D_2) xenoliths on Neu Schwaben 73 (B. 5).

PLAAT XVIII.—*Porfiritiese Salemgneis* (Gn_2) *in kontak met xenoliete van Khomasskis* (D_2) *op Neu Schwaben* 73 (*B.* 5).

PLATE XIX.—A subtle relationship between Khomas schist (D_2), diorite-gneiss (SdGn) and Salem granite (G_2) near windmill on Etusis 75.
PLAAT XIX.—*Intieme verband tussen Khomasskis (D_2), diorietgneis (SdGn) en Salem-graniet (G_2), naby windpomp op Etusis 75.*

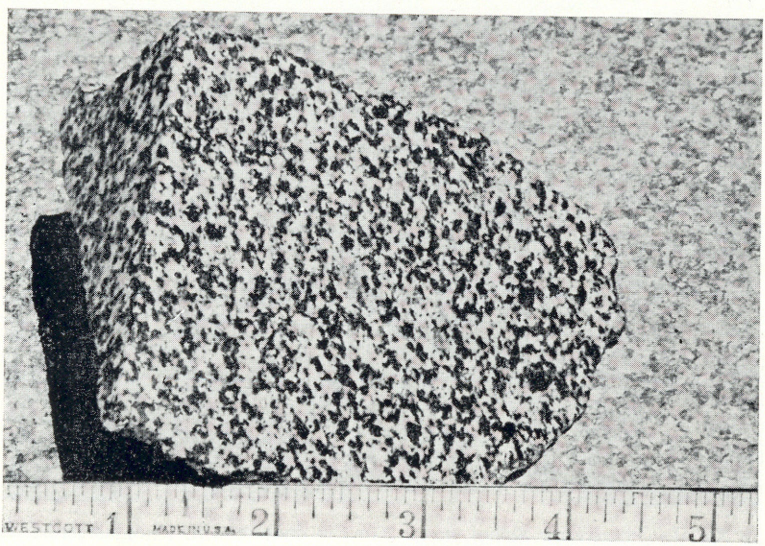


PLATE XX.—Hand-specimen of hornblende-rich quartz diorite.
PLAAT XX.—*Handmonster van horingblenderyke kwartsdioriet.*

PLATE XXI.—Orbicular diorite xenoliths in biotite granite at windmill on Etusis 75.
PLAAT XXI.—*Koeëlvormige xenoliete van dioriet in biotietgraniet by windpomp op Etusis* 75.

PLATE XXII.—Xenoliths of coarse-grained pegmatite in diorite-porphyrite at windmill on Etusis 75.
PLAAT XXII.—*Xenoliete van grofkorrelrige pegmatiet in diorietporfiriet by windpomp op Etusis* 75.

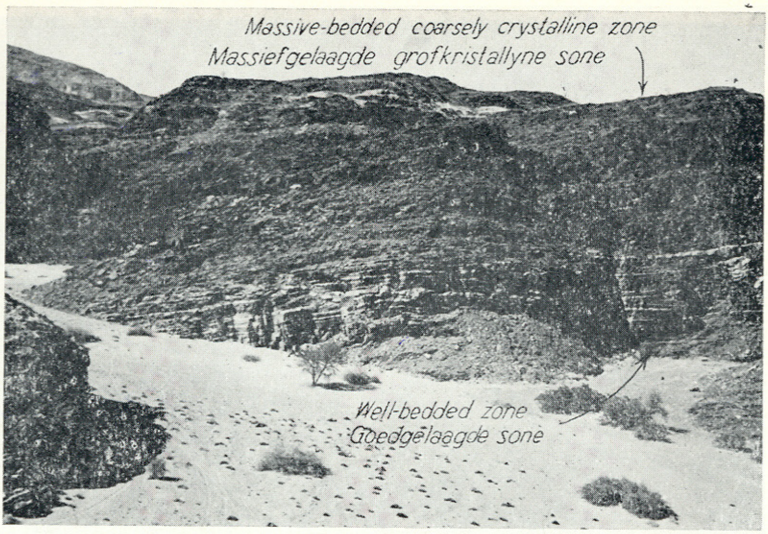


PLATE XXIII.—Concordant pegmatites in Khomas schist near Karub Gorge (C. 3).
PLAAT XXIII.—*Konkordante pegmatiete in Khomasskis naby Karubkloof* (*C.* 3).

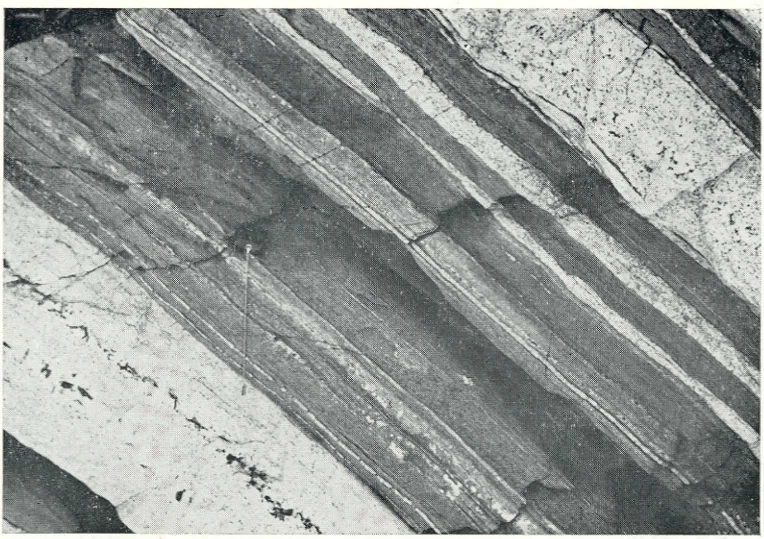


PLATE XXIV.—Close-up plate XXIII. Note faint banding and zoning in pegmatite. Black mineral is biotite.
PLAAT XXIV.—*Vlakby-opname van plaat XXIII. Let op dowwe gestreeptheid en sonebou in die pegmatiet. Swart mineraal is biotiet.*

PLATE XXV.—Secretion pegmatites situated parallel to second fold axial plane. Panner's Gorge.

PLAAT XXV.—*Sekresiepegmatiete geleë ewewydig aan asvlak van tweede plooi. Panner se Kloof.*

PLATE XXVI.—Part of the zone of parasitic folding in the synclinorium surrounding the dome. Dome Gorge.

PLAAT XXVI.—*Gedeelte van die sone van neweplooiing in die sinklinorium wat die koepel omring. " Dome "-kloof.*

INDEX

(Farm-names are *italicised*)

O

P

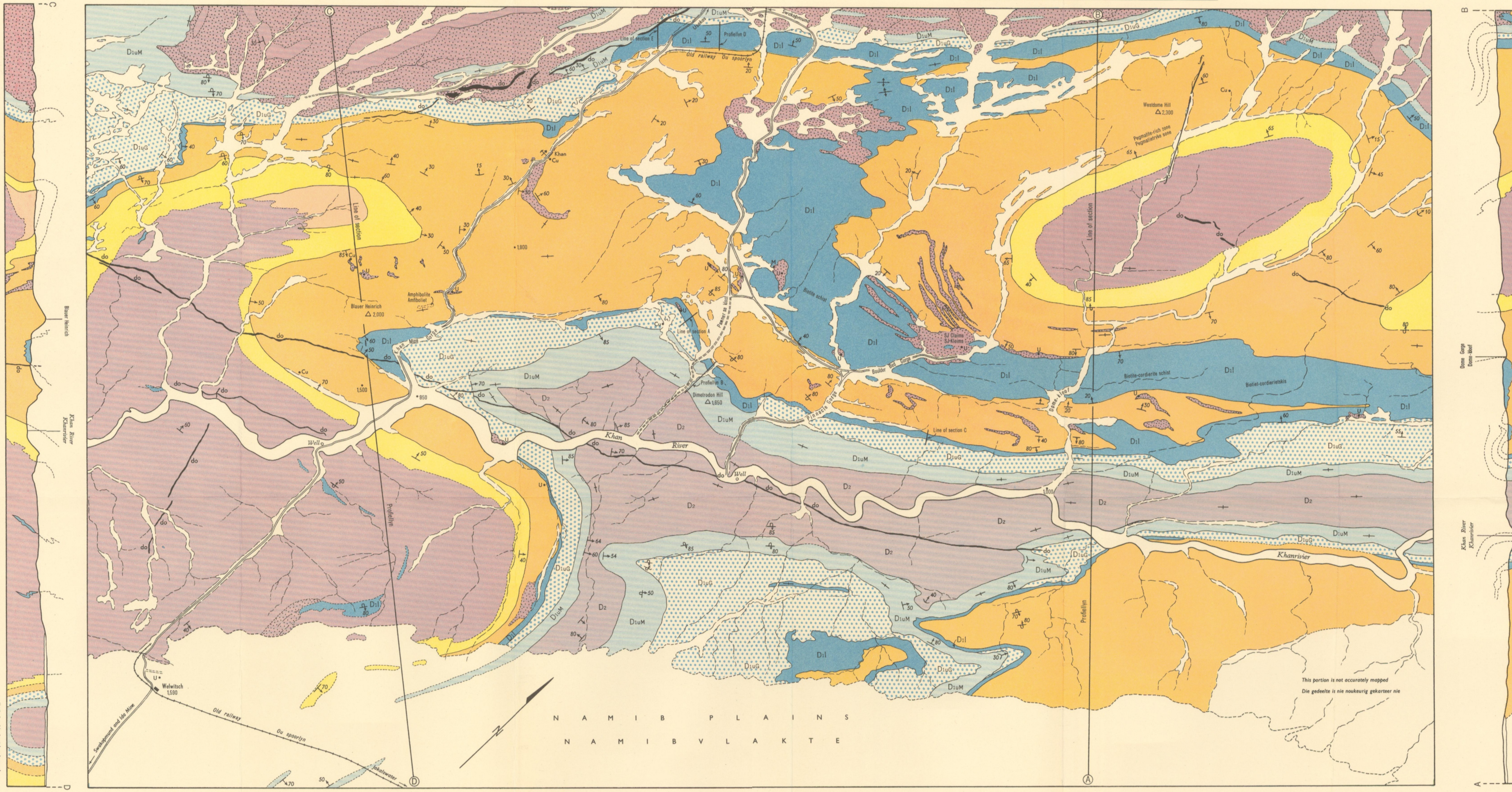
Q

R

S

GEOLOGICAL MAP OF PART OF THE LOWER KHAN GORGE

GEOLOGIESE KAART VAN 'N GEDEELTE VAN DIE BENEDE-KHANKLOOF



LEGEND — LEGENDE

(blank)	Recent deposits. Sand, gravel and surface-limestone Resente afsettings. Sand, gruis en oppervlakkalksteen		
do	Dolerite dyke, Post-Karroo Dolerietgang, Na-Karoo		
D_2	Khomas Series. Biotite-cordierite-garnet and quartz-biotite schist Serie Khomas. Biotiet-cordieriet-granaat- en kwarts-biotietskis		Damara System Sisteem Damara
$D_{1u}M$	Upper Stage. Blue marble, white marble and quartz-biotite schist Boonste Etage. Blou marmer, wit marmer en kwarts-biotietskis	Hakos Series Serie Hakos	Damara System Sisteem Damara
$D_{1u}G$	Chuos tillite Chuostilliet	Hakos Series Serie Hakos	Damara System Sisteem Damara
D_1l	Lower Stage. Marble bands with quartzite facies Onderste Etage. Marmerbande met kwartsietfasies	Hakos Series Serie Hakos	Damara System Sisteem Damara

Orange	Upper Stage. Calc granulite, schist and quartzite Boonste Etage. Kalkgranuliet, skis en kwartsiet	Nosib Formation Formasie Nosib
Yellow	Lower Stage. Quartzite and quartz-biotite schist Onderste Etage. Kwartsiet en kwarts-biotietskis	Nosib Formation Formasie Nosib
Light orange	Archaean gneiss? Sillimanite and quartzofelspathic augen-gneiss Argeïese gneis? Sillimaniet- en kwartsveldspatiese augengneis	Abbabis Formation? Formasie Abbabis?
Stippled purple	Pegmatite and pegmatitic granite Pegmatiet en pegmatitiese graniet	Syntectonic Sintektonies
Purple	Quartzofelspathic rocks. Granite-gneiss and granite with sedimentary remnants Kwartsveldspatiese gesteentes. Granietgneis en graniet met sedimentêre oorblyfsels	Syntectonic Sintektonies

40	Dip and strike Helling en strekking
40	Inverted dip Omgekeerde helling
	Vertical strata Vertikale lae
f	Fault Verskuiwing
M •	Mica Mika
U •	Uranium Uraan
Cu •	Copper Koper
	Road Pad
	Mine Myn
• 1,800	Spotheight in feet (approximate) Punthoogte in voet (benaderd)

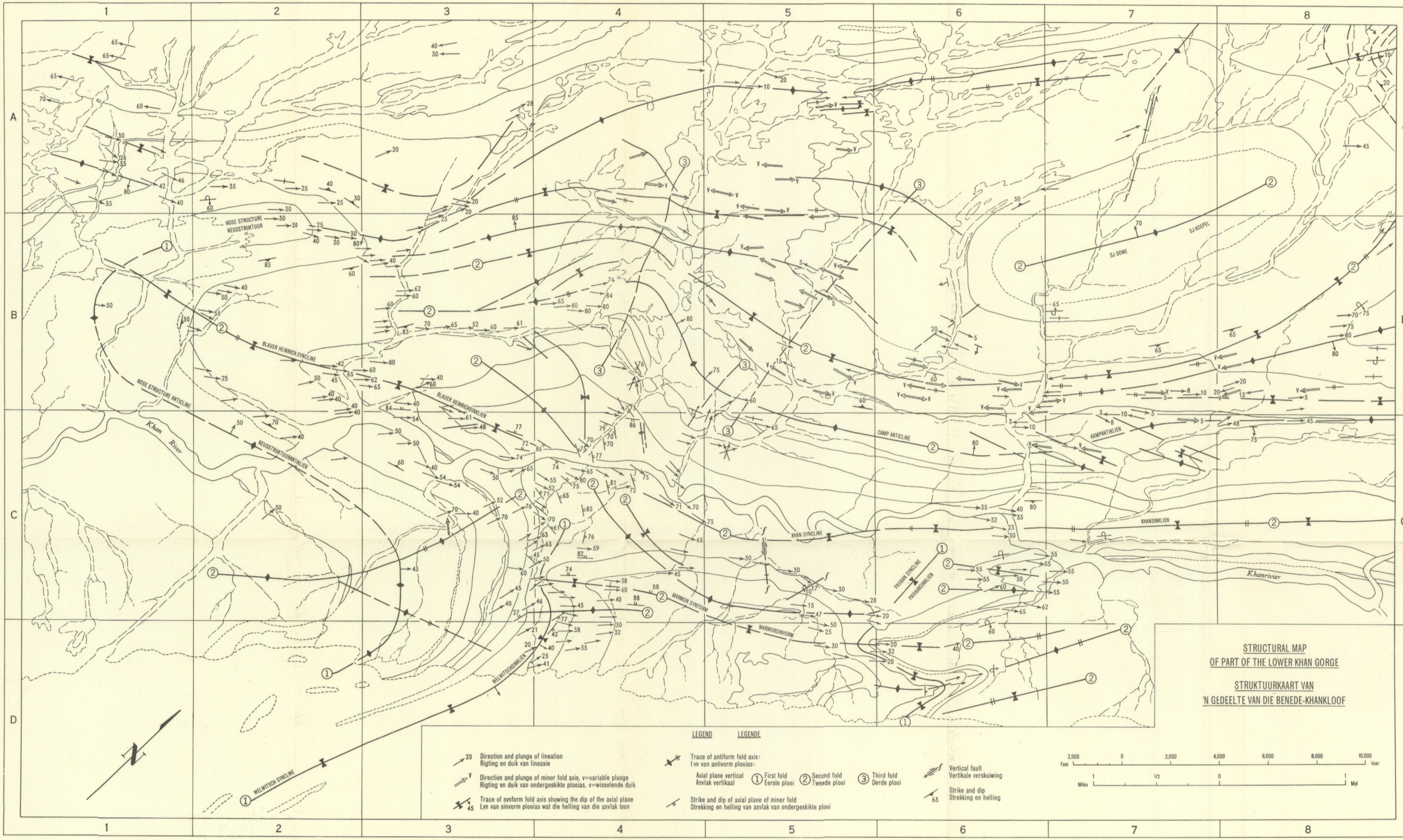
Feet 2000 1000 0 2000 4000 6000 8000 10000 Voet

Miles 1 ½ 0 1 Myl

Compiled with the aid of aerial photographs flown by Anglo American Corporation of South Africa, Ltd. Reference was also made to earlier mapping by Messrs. E. Hyman, J. B. Thomas, R. G. S. MacLennan and D. A. M. Smith.

Saamgestel met behulp van lugfoto's geneem deur Anglo American Corporation of South Africa, Ltd. Daar is ook na vroeëre kartering deur mnre. E. Hyman, J. B. Thomas, R. G. S. MacLennan en D. A. M. Smith verwys.

Sections A,B,C,D,E are shown in figure 1
Profiele A,B,C,D,E is aangedui in figuur 1


STRUCTURAL MAP
OF PART OF THE LOWER KHAN GORGE
STRUKTUURKAART VAN
'N GEDEELTE VAN DIE BENEDE-KHANKLOOF
LEGEND
LEGENDE
Direction and plunge of lineation
Rigting en duik van lineasie
Direction and plunge of minor fold axis, v=variable plunge
Rigting en duik van ondergeskikte plooias, v=wisselende duik
Trace of synform fold axis showing the dip of the axial plane
Lyn van sinvorm plooias wat die helling van die asvlak toon
Trace of antiform fold axis:
Lyn van antivorm plooias:
Axial plane vertical
Asvlak vertikaal
First fold
Eerste plooi
Second fold
Tweede plooi
Third fold
Derde plooi
Strike and dip of axial plane of minor fold
Strekking en helling van asvlak van ondergeskikte plooi
Vertical fault
Vertikale verskuiwing
Strike and dip
Strekking en helling
Feet
Voet
Miles
Myl
NOSE STRUCTURE
NEUSSTRUKTUUR
BLAUER HEINRICH SYNCLINE
BLAUER HEINRICHSINKLIEN
NOSE STRUCTURE ANTICLINE
NEUSSTRUKTUURANTIKLIEN
Khan River
SJ DOME
SJ-KOEPEL
CAMP ANTICLINE
KAMPANTIKLIEN
KHAN SYNCLINE
KHANSINKLIEN
PAVIAAN SYNCLINE
PAVIAANSINKLIEN
Khanrivier
MARMOR SYNFORM
MARMORSINVORM
WELWITSCH SYNCLINE
WELWITSCHSINKLIEN