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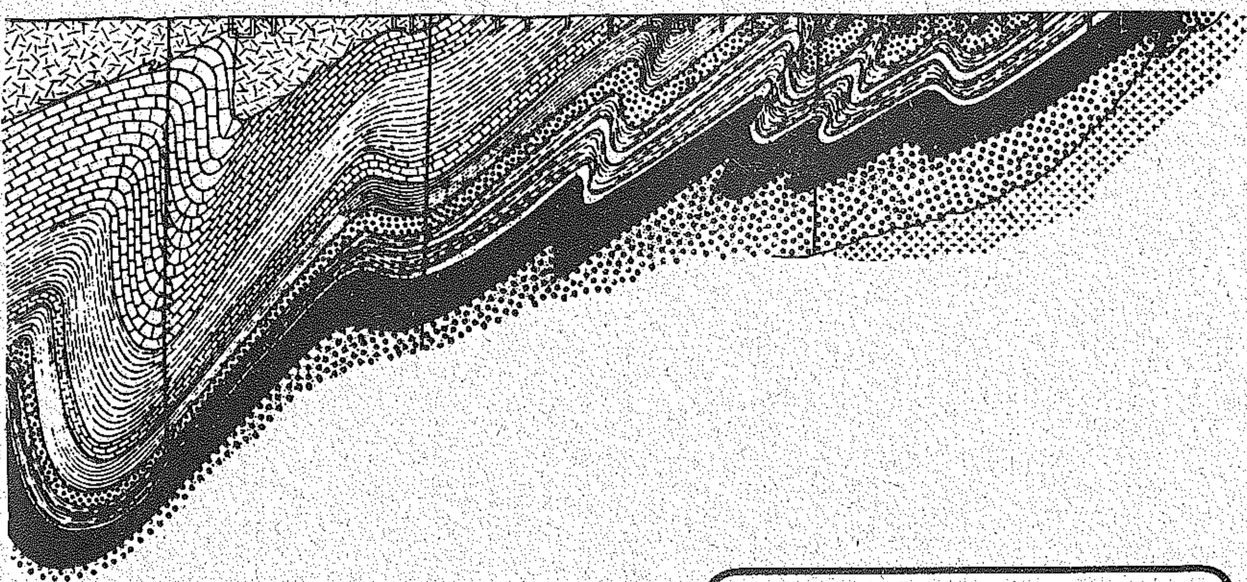

ECONOMIC GEOLOGY

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UNIVERSITY OF THE WITWATERSRAND

JOHANNESBURG

METAMORPHISM, GRANITIZATION, STRUCTURE AND MINERALIZATION BETWEEN THE KHAN AND SWAKOP RIVERS, SOUTH WEST AFRICA.

by

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ABSTRACT

A sparsely-populated and arid area of some 3,000 square miles, underlain largely by highly folded, metamorphosed and partially granitized rocks of the Damara System, located in the region of the Khan and Swakop rivers in South West Africa, was mapped on aerial photographs during 1959 and 1960.

Two major morphological units, typical of 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 and discharge into the South Atlantic Ocean at Swakopmund.

Rocks of the pre-Cambrian Abbabis System outcrop in two anticlinal cores in the area mapped. They consist largely of a quartzo-felspathic 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 pegmatites and a lesser number of basic igneous dykes of uralitised gabbro.

These older rocks were already highly metamorphosed, invaded by granite and pegmatite, and folded prior to the deposition of the Damara System.

The Damara metasediments consist of the Chuos Quartzite Series, the Lower Marble Series, the Chuos Tillite, the Upper Marble Series and the Khomas Schist Series.

The Damara sediments were deposited under relatively shallow water conditions probably between 500 and 600 million years ago. The lower arenaceous members (Chuos Quartzites) were 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 Marbles) after which cold conditions set in, accompanied by tillite deposition from a continental ice-sheet. After retreat of the ice, carbonate, alternating with argillaceous, sediments were deposited (Upper Marble Series) on a flat surface at moderate depths. The final and prolonged phase of argillaceous sedimentation (the Khomas Schists) was completed

prior to the onset of tectonic deformation.

Probably a short time only elapsed after sedimentation and deep burial of the sediments and before the commencement of metamorphism. 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 the phase, as well as throughout the following intense compressional fold phase directed from the northwest and southeast. Locally strong interference patterns were developed where early isoclinal folds existed. Metamorphism reached a peak towards the close of the second, major tectonic phase, resulting in the granitization and local melting and mobilisation of the rocks. The felspathic quartzites below the Marble Series were transformed into red granitic gneisses. Biotite schists and biotite-quartz schists of the Khomas Schist Series overlying the marbles were transformed into quartzo-felspathic biotite gneisses and granites (Salem granites and gneisses) and quartz diorite rocks. This transformation was largely isochemical. The gneissic rocks were locally mobilized and differentiated (mainly in the east) forming several intrusive dioritic, granitic and pegmatitic bodies. The Marble Series was only locally melted and not granitized. Maximum temperature conditions of 600 - 650°C. at about 18 Km. depth at the height of metamorphism are postulated.

After the cessation of metamorphism brittle conditions, accompanied by minor fracturing and wrench faulting, set in. Pegmatitic fluids associated with differentiated concentrations of volatiles from metamorphic and magmatic rocks were introduced into tension zones. Lithium-beryllium pegmatites are associated with these. This phase, followed shortly afterwards by uplift and erosion, completed the 510 ± 40 million-year old Damara geosynclinal cycle.

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.

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

METAMORPHISM, GRANITIZATION, STRUCTURE AND MINERALIZATION BETWEEN THE KHAN AND SWAKOP RIVERS, SOUTH WEST AFRICA

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METAMORPHISM, GRANITIZATION, STRUCTURE AND MINERALIZATION BETWEEN THE KHAN AND SWAKOP RIVERS, SOUTH WEST AFRICA

INTRODUCTION

A. GENERAL STATEMENT

The contents of this Information Circular form part of a Ph.D thesis titled: "The Geology of the Area Around the Khan and Swakop Rivers in South West Africa", which was submitted to the Department of Geology, University of the Witwatersrand.

This circular cannot stand entirely on its own for the following major reasons:

(a) portions of the thesis dealing mainly with the stratigraphy, lithology and sedimentation of the metasediments involved in granitization and tectonism have been omitted

(b) it has not been possible to reproduce a large regional map and a number of photographs which illustrate many of the important points in the work.

B. REGIONAL GEOLOGICAL SETTING

The area under review occupies a portion of Western Damaraland in the region of the lower Khan and Swakop rivers in South West Africa (see Maps 1 and 2). It includes the localities in which the more important mineralized pegmatites of the Karibib District occur.

Members of the highly folded, metamorphosed and granitized Damara System constitute about 95% of the rock outcrop in the area. These are unconformably underlain by the dominantly gneissose Abbabis System which outcrops in the cores of two brachy-anticlines, one at Abbabis Farm (see Map 2) and the other near the Khan Mine.

The Abbabis System is divided into the following groups:

(3) Biotite Schist Group

(2) Dolomitic Marble and Calc-silicate Group

(1) Quartzo-felspathic Gneissose Group (Abbabis Gneiss).

Included in the above succession are a number of amygdaloidal lava flows. The whole succession was folded, considerably metamorphosed, and intruded by pegmatites, granite and diabase prior to the deposition of the Damara rocks.

The stratigraphy and lithology of the Damara System is briefly outlined in Table 1.

THE GENERATION OF IGNEOUS ROCK-TYPES

A. INTRODUCTION

The investigation of the igneous rock-types present in 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 was placed on mineralogical composition and on texture in placing the granitic rocks into different groups.

B. LABORATORY METHODS

Some 50 specimens were volumetrically analysed using a Swift automatic point counter after the method of Chayes (1949). For rocks of an average grain size of more than 2 - 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 was sufficiently fine-grained (less than 0.3 mm.) to become subject to the "superposition error" outlined by Elliott (1952). Rocks exhibiting lepidoblastic texture were sectioned across the foliation and analysed on diagonal transverses.

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. Plagioclase was stained red and biotite green (as distinct from hornblende) with potassium rhodizonate, using the methods of Bailey and Stevens (1960).

Series	Thickness (ft.)	Lithology
Khomas Schist Series	less than 10,000	well-bedded, magnesian-rich quartz-biotite schists; cordierite, garnet, amphibole, sillimanite might be present.
Upper Marble Series	0 - 1,800	generally thick-bedded-to-massive, blue, grey, yellowish or white dolomitic, crystalline marble with subordinate calc-silicate bands; tremolite, forsterite, garnet might be present locally.
Chuos Tillite Series	0 - 2,000	locally developed glacial conglomerate containing assorted pebbles and boulders of Basement rocks in a granular-to-schistose matrix.
Lower Marble Series	0 - 600	generally thick-bedded, white, crystalline, marble with intercalated biotite schist, amphibole schist, quartzite, pyritic chert, local conglomerate.
Quartzite Series	0 - 10,000	local basal conglomerate overlain by massive-to-thick-bedded, red, felspathic quartzites (Chuos Quartzites), green-grey or bluish-grey, thick-bedded-to-massive calc-granulites (Khan Quartzites) and amphibole hornfels or schist.

Table 1: Stratigraphy and lithology of Damara System.

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% 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% for any mineral on stained sections or slices, e.g. quartz 29·10% ± 1·8, plagioclase 29·00% ± 1·8, biotite 4·98% ± 1·8, etc. It could therefore be assumed that the accuracy was fairly constant in all the analyses, though inhomogeneity in the rocks might have provided a greater variation.

C. CHEMICAL ANALYSES.

A study of this nature should have been supported by a large number of total rock and mineral analyses. Facilities for accurate analyses were extremely limited. Only 9 analyses of doubtful accuracy were available resulting in weak chemical support for the arguments on petrogenesis raised at the end of this section.

D. GENERAL

The following granitic types were distinguished in the field by virtue of their structural position, macroscopic appearance and mineralogical character:

(a) red gneissic granites

(b) grey biotite-rich gneisses and granites (Salem gneisses and Granites)

(c) quartz diorites and diorite gneisses

(d) homogeneous intrusive granites

(e) pegmatites and quartz veins

(f) aplites

(a) Red Gneissic Granites

(i) Distribution

These rocks, underlying large areas in the region mapped, occur only in domes, brachydomes and anticlines within strata

below the Upper Marble 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 and Koliombo to Dorst Riviermund.

(ii) Macroscopic Character

In the field these gneisses and granite gneisses 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 distinguishable from that showing distinct intrusive relations. The gneissic rocks are, however, by far the most predominant and are exceptionally well exposed in the lowest portion of the Khan Gorge, as well as in the Kuduberg and at Otjua, where they are topographically prominent. Less striking exposures occur at many other places.

The contacts between gneisses and metasediments are mostly ill-defined within the Quartzite Series, though granitic types may exhibit quite sharp contacts against sillimanite- or biotite-rich gneisses or metasediments. 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 rocks is well exposed in a section from Welwitsch to Blauer Heinrich. Similar, though less distinct transitions, occur in most of the antiform structures where the gneisses do not occupy the whole of the Quartzite Series, leaving some sediments preserved below the Lower Marble Series. 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. Here, as for example at Louw's Claims, the gneiss occupies the tillite horizon and the Lower Marble Series remains as skarn and marble xenoliths in the gneiss. The contacts with the marble and with xenoliths are sharp, though, in the former case, 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 Okatjeueberg on Meyersrust the rock underlying, as well as overlying, the Marble Series, which remains undisturbed, is a homogeneous granite, weathering into large exfoliated blocks, containing no gneissic structure. Although possibly largely autochthonous, it is thought to have moved and been intruded into the overlying Khomas Schist horizon, and is classified as an intrusive granite of the Geisterberg type. In other places too, smaller homogeneous bodies of apparently magmatic character have been classed as intrusive even though they may have only moved very short distances. These bodies of red granite are, however, very subordinate in volume to the moderately homogeneous granite gneisses which are characteristic of a great many domes in the area.

(iii) Petrography

The petrography of the gneisses is variable, especially in the inhomogeneous banded varieties. Individual bands may vary from granular, felspar-quartz-biotite rocks of granitic composition to quartzo-felspathic, biotite-sillimanite and biotite-amphibole schistose or gneissose types. An apparent metamorphic sequence of this nature was examined in detail at Louw's Claims.

Three specimens comprising a biotite-sericite schist (SM34), a quartzo-felspathic, thinly-banded, biotite gneiss (SM35), and a comparatively homogeneous, red, quartzo-felspathic granitic gneiss (SM36) were taken from a single outcrop in which these rocks are intimately related. It was apparent in the field that the mica schist had been progressively metasomatised by potash-rich solutions which had 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 comprising the bulk of the core of the brachy-anticline, and the banded gneiss of intermediate types. The results of the laboratory investigations of the specimens is shown in Table 2 A and B.

From Table 2 A it can be seen that the modes, which were carefully calculated from several thin sections of each specimen, do not compare very well with the calculated compositions (katanorms). Despite the fact that these specimens are within themselves heterogeneous, the considerable contrast shown in SM36, in particular, is not to be expected even by diverse methods of calculation. The differences in quartz content of 9%, in total felspar of 14%, and in iron oxides of over 5% are unreconcilable. It is difficult to conceive of such heterogeneity within SM36, and it is concluded that this chemical analysis must be suspect. This is unfortunate since a comparison of the cation proportions in Table 2 B 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 (the latter with reservations for the above reasons) is indicative of an addition of mainly K and Si, on a small scale at least, to produce the granite gneiss from mica schists of SM34 type, and not of a simple isochemical reaction. This may not necessarily be true on a larger scale.

The textures and mineral assemblages of the three specimens are interesting in the light of progressive metamorphism. SM34 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. SM35 has similar orientated biotite bands, with no sphene, set in a matrix of quartz and microcline-perthite. SM36 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 (SM36) to form a type of rapakivi texture. This textural feature is commonly found in higher-grade potash felspar-bearing metasediments, especially where the felspar is concentrated into glommero-porphyroblasts, as in certain felspathic biotite quartzites in the Lower Marble Series in Pinnacle Gorge. The texture of SM34, the biotite-sericite schist, is not indicative of retrograde metamorphism since there is no sign of parent felspars 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 granites throughout the area, specimens of the most homogeneous, most widely developed and most typical varieties were collected and their mineralogical compositions determined volumetrically by the methods outlined above. The results are shown in Table 3 and are plotted together with the Salem granite and quartz diorite types in the triangular diagrams in Fig. 1 A, B and C. On these diagrams the red gneisses indicate that they belong to a distinct mineralogical group of potash felspar-rich, ferromagnesian-poor and calcic plagioclase-deficient rocks. Furthermore, the specimens collected from the east of the area, SM154, 157, 161 and 166, (locality shown on Map 2) exhibit a different sub-grouping from those in the west as shown in Fig. 2. Within the major group all these gneissic granites show a fair range of composition which is probably present on micro-, meso-, and macroscopic scales.

In hand specimen, these rocks are coarse-medium to fine-grained granular, containing abundant pink-to-red potash felspar, pale plagioclase and clear quartz, with subsidiary amounts of black biotite arranged in bands. Some specimens have well-oriented felspars.

A

MODE				KATANORM			
Spec. No.	SM34	SM35	SM36	Spec. No.	SM34	SM35	SM36
Quartz	12.91	25.31	13.13	Quartz	22.59	29.27	22.00
K-Felspar	(Seri- (cite	49.40	59.40	K-Felspar	13.05	34.15	42.20
Plagioclase	(45.15 (	11.20	14.48	Plagioclase	20.20	18.15	16.80
Biotite	20.92	10.40	8.66	Biotite	15.36	6.00	4.00
Iron Ore	17.20	3.00	2.95	Iron Ore	13.90	8.16	8.60
Accessories	3.78	0.68	1.47	Sphene	5.10	0.66	0.72
TOTAL	99.96	99.99	100.09	Apatite	1.11	0.27	0.47
Major Accessories	Ap. Epid. Zirc. Py. Hnbld. Sphene	Ap. Clino-zois.	Zirc. Sillim. Ap.	Corundum	9.17	3.85	5.30
				TOTAL	100.48	100.51	100.09

B

Chemical Analysis				Cation Proportions			
	SM34	SM35	SM36		SM34	SM35	SM36
SiO_2	47.19	64.76	61.03	Si	48.53	62.90	58.90
Al_2O_3	16.05	13.35	15.53	Al	19.21	15.28	17.60
Fe_2O_3	10.34	6.46	7.14	Fe'''	7.95	4.72	5.15
FeO	5.81	3.58	3.74	Fe''	4.96	2.90	3.01
CaO	3.60	0.60	0.40	Ca	3.91	0.62	0.41
MgO	3.61	1.33	1.01	Mg	5.45	2.21	1.45
Na_2O	1.30	1.77	1.80	Na	2.57	3.41	3.36
K_2O	3.50	6.12	7.25	K	4.53	7.58	8.94
TiO_2	3.48	0.83	1.65	Ti	2.69	0.76	1.16
MnO	0.34	0.05	0.04	Mn	0.31	0.04	0.05
P_2O_5	0.43	0.11	0.07	P	0.37	0.09	0.06
H_2O+	2.19	0.18	0.39				
H_2O-	1.19	0.28	0.21				
CO_2	1.06	0.29	-				
TOTAL	100.09	99.73	100.26	TOTAL	100.48	100.51	100.09

Table 2: Analyses of schist and gneiss from Louw's Claims (Chemical Analyses by Division of Chemical Services, Pretoria)

In thin section, textures vary from allotriomorphic granular to lepidoblastic and prophyroblastic or porphyritic. Microcline, microcline-perthite and plagioclase (An_{5-30}) are the dominant felspars, plagioclase being more commonly altered than microcline. Quartz is present in irregular grains and biotite, or rarely muscovite, in disorientated or orientated laths. Zircon, apatite and ore are common accessories, the first two being present in round, sub-round and sub-angular grains. Sillimanite is locally abundant and intimately associated with biotite. Its presence is indicative of a metamorphic rather than magmatic origin. Sphene is conspicuously absent and is thought to be unstable in this group of rocks.

The rock textures, especially those of porphyroblastic type, are generally indicative of late syntectonic-to-post-tectonic crystallization. In some of the coarse-grained prophyroblastic 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 conditions of gentle compression during crystallization. No cleavage or mylonitization 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.

Specimen No.	SM 122+	SM 154+	SM 157	SM 161	SM 166+	SM 216	SM 214A
Quartz	41.90	33.25	25.12	27.10	28.82	33.56	28.52
K-felspar	24.25	28.11	31.89	32.18	31.78	37.35	46.10
Plagioclase	18.39	28.25	31.14	32.73	29.91	26.23	19.91
Biotite	14.56	10.30	10.85	8.40	7.98	2.82	4.34
Accessories	0.30	0.09	0.88	0.08	0.91	0.04	1.15
TOTAL	99.40	100.00	99.88	100.33	99.20	100.00	100.02
Heavy Minerals	Zircon	Zircon	Zircon	Zircon	Zircon	Zircon	Zircon
	Apatite	Apatite		Apatite	Apatite	Apatite	Apatite
	Sphene					Ore	Ore
Plag. Comp.	-	An 10 ± 3	An 5 ± 2	An 15 ± 3	An 30 ± 5	An 15 ± 5	An 15 ± 5

Specimen No.	SM 154+	SM 15	SM 35	SM 36	SM 6*
Quartz	34.18	30.84	25.38	13.17	21.16
K-felspar	28.91	58.84	51.81	61.91	62.56
Plagioclase	27.61	8.47	11.38	14.31	10.61
Biotite	8.70	1.68	9.39	7.72	5.29
Accessories	tr.	0.20	1.99	2.95	0.33
TOTAL	99.40	100.04	99.95	100.06	99.95
Heavy Minerals	Zircon	Zircon	Zircon	Zircon	Zircon
	Apatite	Apatite	Apatite	Ore	Apatite
		Ore	Ore	Silli-manite	Ore
			Clino-zoisite		

Table 3: Volumetric analyses of gneisses in the Quartzite Series.

Specimen No.	KR 4	KR 4 (i)	KR 43+	KR 28
Quartz	30.18	35.22	28.08	25.23
K-felspar	46.15	49.35	48.26	50.50
Plagioclase	22.50	9.84	19.50	17.92
Biotite	1.07	5.16	4.08	5.33
Accessories	tr.	0.49	tr.	0.52
TOTAL	99.90	100.06	99.82	99.50
Heavy Minerals	Zircon Ore	Zircon Ore	Leucox-ene	Zircon

Table 3 (contd.) : Volumetric analyses of gneisses in the Quartzite Series.

\+ polished slice

* unstained thin section

All other analyses carried out on stained thin sections.

(iv) Chemical Composition

Analyses of a banded gneiss (SM35) and a more homogeneous granitic gneiss (SM36) have been shown in Table 2 B. SM214A has been chosen as a sample showing the mean mineralogical composition of all the red granitic gneisses examined and has the chemical composition (analysed by Heymann's Laboratories, Johannesburg) and cation proportions shown in Table 4.

Wt.%		Cation Props.	
SiO_2	66.16	Si	63.49
Al_2O_3	18.38	Al	20.75
Fe_2O_3	2.01	Fe'''	1.44
FeO	1.48	Fe''	1.18
CaO	1.92	Ca	1.98
MgO	0.99	Mg	1.61
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

Table 4: Chemical analysis of typical Red Gneissic Granite.

These figures are accurate to $\pm$ 2·5% in Na and $\pm$ 1·0% in K. However, the red gneissic granite, as compared with the composition of the Salem granite and quartz diorite (Table 5 A and B) is, on the whole, considerably higher in K and lower in Na.

	Salem Granites & Gneisses					Khomas Schists		Quartz Diorite
	A	B	SM97	SM153a	SM153b	SM98	SM218	SM181
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
CaO	1.22	3.40	2.84	3.47	3.87	2.00	2.08	5.23
MgO	0.08	1.82	1.59	0.58	0.93	1.91	3.75	2.54
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
TiO_2	-	0.75	0.63	0.18	0.24	0.85	0.20	0.74
MnO	0.02	0.07	0.06	-	-	0.05	-	-
P_2O_5	0.03	0.26	0.28	0.11	0.12	0.20	0.12	0.18
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	-	-
TOTAL	99.51	99.60	99.74	98.69	96.93	100.44	98.21	98.70

Table 5 A: Comparative table of chemical analyses of Salem Granite and Gneisses, Khomas Schist and Quartz Diorite.

A. fine-grained granite from Zebra River, south of the Ugab River, S.W.A. (from Jeppe, 1952). Analysed by Chemical Services Div., Pretoria.

B. coarse-grained porphyritic granite from Brandberg West air-strip (from Jeppe, 1952). Analysed by Chemical Services Div., Pretoria.

SM97. coarse-grained porphyroblastic gneiss from Swakopmund Main Road. Analysed by Chemical Services Div., Pretoria.

SM153a and b. medium-grained granite from Etusis. Analysed by Heymann's Laboratories, Johannesburg.

SM98. Khomas Schist from same locality as SM97. Analysed by Chemical Services Div., Pretoria.

SM218. Khomas Schist from Lower Khan River Gorge. Channel sample over 950 feet. Analysed by Heymann's Laboratories, Johannesburg.

SM181. Quartz diorite from Gamikaub. Analysed by Heymann's Laboratories, Johannesburg.

	Salem Granites and Gneisses					Khomas Schist		Diorite
	A	B	SM97	SM153a	SM163b	SM98	SM218	SM181
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'''	0.56	0.78	2.67	0.55	0.57	0.94	0.62	1.31
Fe''	0.11	2.01	2.08	1.24	1.24	2.21	4.72	3.19
Ca	1.24	3.44	2.82	3.59	3.99	2.07	1.99	5.28
Mg	0.11	2.56	2.19	0.81	1.34	2.75	5.38	3.60
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
Mn	0.03	0.05	0.05	-	-	0.04	-	-
P	0.02	0.20	0.22	0.08	0.10	0.16	0.10	0.14
TOTAL	100.22	99.96	99.96	99.99	100.02	99.98	100.38	100.09

Table 5 B: Comparative table of cation proportions of Salem Granite and Gneisses, Khomas Schist and Quartz Diorite.

(i) SM153a and b, and SM218 are specimens selected as having a mean mineralogical composition from a number of volumetric analyses.

(ii) SM153a and b are identical samples crushed and quartered prior to analysis. The probable reliability of these samples is ± 1·0% for K, Si and Al; ± 0·5% for Fe''', Fe'', Ca and Mg; 2·5% for Na; and ± 0·08% for Ti and P. The other analyses are anticipated to have similar reliabilities.

(b) Grey Biotite-rich Gneisses and Granites (Salem Gneisses and Granites)

This group includes the typical porphyritic biotite granite originally described by Gürich (as quoted by Gevers, 1931a) 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 gneisses and granites in this group. With the exception of those occurring on Ubib and Kubas, which are non-gneissose intrusive types, the grey, biotite-rich gneisses and granites are the same as those mapped as Salem granite by Gevers (1934).

(i) Distribution

The Salem Gneisses and Granites are confined entirely to synclines occupied by the Khomas Schist horizon. Two major northeast-trending zones are present; one extending from southwest of Arandis to near Usakos, and the other from the south of Nord Horebis to Neu Schwaben.

(ii) Macroscopic Character and Field Relationships

In the field these rocks are generally physiographically inconspicuous 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 and the Tsaobis-Swakop River confluences. 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. The porphyroblasts are almost exclusively potash felspar and only rarely plagioclase. They are generally euhedral to subhedral and are found to be strongly orientated, or poorly orientated, or 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 schists.

Contacts of the Salem Granites and Gneisses with the Khomas Schist Series or the Marble Series are often very sharp. The xenoliths, in such cases, are usually orientated parallel to the contact and are composed of both dense biotite schist and lighter coloured quartzo-felspathic schist. In some cases, e.g. north of Roddy's Gorge, the granite looks as though it is intrusive into the Upper Marble Series, but there are isolated narrow marble horizons concordantly situated in the granite. To the northeast of the dome east of Arandis there are several intercalations of marble in the granite which, when followed along strike northeastwards, is found to grade into biotite schist horizons. A similar condition is present within the Upper Marble Series at Dorstriviermund.

The Salem granite types are not found in contact with the red gneisses described above, but on Goas a distinct relationship between a coarse-grained variety of porphyritic Salem granite and quartz diorite gneiss can be studied. 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 Stingbank a non-porphyritic granite type distinctly post-dates the gneissic variety. The granitic rock becomes indistinguishable in many places from the truly intrusive bodies found on Ubib and Kubas, so that although clearly separated on Map 2, parts of the areas classified as 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 and Etusis. It is apparent that the gneissic varieties are late syntectonic and autochthonous while the granitic varieties crystallized in non-compressive conditions and were locally mobilized and intruded.

Another interesting phenomena is the relation of the porphyroblastic Salem gneiss to the quartz diorite gneiss. The latter always contains hornblende but seldom potash felspar, whereas the Salem gneiss always contains potash felspar but seldom hornblende. In the vicinities of east Neu Schwaben and Gamikaubmund the two rock-types are in close association and at the former locality apparently in contact in the sub-outcrop. In the Gamikaubmund 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 twelve specimens of Salem granitic types were determined volumetrically and the results are shown on Table 6, and plotted on triangular diagrams in Fig. 4 A, B and C. The localities of the samples are indicated on Map 4.

In general, the granites show high potash felspar and low biotite contents. When plotted as a group they fall within a distinct zone on the diagrams (Fig. 1) but are of variable composition and overlap the Red Gneiss in Granites 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 amounts to plagioclase. It is also commonly altered to sericite. Plagioclase An_{25-56} is always abundant as sub- to euhedral grains and is rarely myrmekitic. Bent twin lamellae were noticed in several specimens which, together with undulose extinction of quartz, indicates 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 as well as a dark brown variety of biotite. Zircon, apatite and ore were found in nearly all specimens, but sphene in only two. Sillimanite and garnet are also locally present. Zircons from samples taken at the site of SM217 and SM97 were studied by Mathias (1961) who found the granite to contain a high proportion of colourless grains (78%) and the total to be made up of 3% angular, 85% subround and 12% rounded. The general conclusion drawn from the zircon study was that the Salem granite had an autochthonous character.

(iv) General Composition

The chemical analyses and cation proportions of four Salem types are compared with two Khomas Schist and one Quartz Diorite types in Table 5 A and B. Of the Salem group SM153 is probably the most representative as it was chosen from those listed on Table 6 as having the closest to the mean mineralogical composition. The most significant chemical difference between the Salem granites, Quartz Diorite, Khomas Schist and Red Gneissic Granite within this area is seen by

Specimen No.	SM 38+	SM 80*	SM 94+	SM 97*	SM 217+	SM 215+	SM 153
Quartz	38.95	39.20	35.78	31.57	26.05	24.36	34.99
K-felspar	21.80	7.90	9.00	17.29	10.80	27.21	16.00
Plagioclase	25.80	35.20	45.79	33.90	40.80	35.72	42.30
Biotite	13.50	17.40	7.49	11.44	22.25	12.79	6.66
Accessories	tr.	0.30	2.00	1.32	tr.	tr.	tr.
TOTAL	100.05	100.00	100.16	99.96	100.00	100.08	99.95
Heavy Minerals	Zircon	Zircon	Zircon	Zircon	Zircon	Zircon	
	Apatite	Apatite	Apatite		Apatite	Apatite	
	Ore		Sphene		Ore		
			Ore				
Plag. Comp.	-	-	-	An 32 ± 3	An 56 ± 3	An 30 ± 5	An 30 ± 5

Table 6: Volumetric analyses of the Salem Gneisses and Granites.

Specimen No.	SM 135	SM 121+	SM 150+	SM 180	SM 119+
Quartz	36.08	27.82	30.78	31.85	35.41
K-felspar	22.99	22.53	35.50	29.41	11.25
Plagioclase	32.08	43.40	29.00	30.20	42.65
Biotite	8.92	6.32	4.98	8.57	10.59
Accessories	tr.	tr.	tr.	0.14	tr.
TOTAL	100.07	100.07	100.09	100.17	99.90
Heavy Minerals		Zircon	Zircon	Zircon	Zircon
		Allanite	Apatite	Apatite	Apatite
		Sphene			Sphene
Plag. Comp.	An 30 ± 5	An 30 ± 5	An 25 ± 5	An 50 ± 5	An 30 ± 5

Table 6 (contd.): Volumetric analyses of the Salem Gneisses and Granites.

+ polished slice

* unstained thin section

All other analyses carried out on stained thin sections.

comparing the cation proportions in Table 9. These comparisons are discussed at the end of this section in the light of the petrogenesis of the igneous rocks.

(c) Quartz Diorites and Diorite Gneisses

(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, Gamikaub, Goas, Okongava Ost, Otjimbingwe, Ukuib and Komandibmund. They include those mapped by Gevers (1934) as diorite, granodiorite and Goas granite.

(ii) Macroscopic Character and Field Relationships

These quartz-hornblende-biotite-plagioclase-rich rocks of a dark to bluish-grey colour and of wide areal homogeneity, are topographically subordinate to all but the Khomas Schists and Salem granite group. On Okongava Ost 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 the diorite produces typical scenery of numerous small inselbergs composed of conical piles of exfoliated boulders rising from a level plain.

These medium- to coarse-grained rocks resemble norite, except that the hornblende is darker than the pyroxene. There is a generally very high proportion of mafic minerals, varying between 15 and 50%, 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. The diorite gneiss 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 only with difficulty, and, as previously mentioned, these two types have been grouped together where extensively developed.

The contacts between diorite types and members of the Khomas Schist and Marble Series are nearly always very sharply defined. Such contacts are readily observed on Gamikaub, Etusis and Goas. While the boundary between the metasediments and the diorite is

usually 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 being expelled from the molten diorite body. The textures of gneissic varieties vary from granitic to banded gneissose. At Etusis windmill near the Niekhoes boundary all gradations from schist to diorite can be found. The gneissose intermediate types have a distinctly metamorphic appearance, while the diorites have an igneous texture.

The relationships between Salem Gneiss and Granite and Quartz Diorite have already been discussed.

(iii) Petrography

Table 7 shows the volumetric mineralogical composition of eleven typical specimens of quartz diorites ranging from hornblende-rich, biotite-poor to biotite-rich, hornblende-poor types. Plotted on triangular diagrams Fig. 1 A, B, and C, they form a distinct group with a very wide variation in composition which, in part, overlaps that of the Salem Granites and Gneisses. The most distinctive feature of these rocks in thin section is the abundance of plagioclase (An_{30} to $_{60}$) and ferromagnesians as well as a total lack of or deficiency in potash felspar.

Their texture is variable, hypidiomorphic granular to lepidoblastic. The grain size is most commonly medium-coarse, though coarse or fine locally. Quartz is present as inter-locking anhedral granules and varies in amount from 8% to 35% of the rock. Microcline, absent in most specimens, occurs in subhedral grains in a few. Plagioclase is always abundant and is generally sub- 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 SM147 there are three variations:

1. a grain showing low An content in the core and outer zone, and a higher An component in the middle zone.

Specimen No.	SM 133	SM 147	SM 175	SM 148	SM 169	SM 170
Quartz	31.80	25.90	26.20	34.00	17.70	12.20
K-felspar	-	-	-	-	-	-
Plagioclase	41.80	54.10	47.30	46.50	45.20	63.30
Biotite	13.00	16.50	13.50	16.10	14.40	21.10
Hornblende	15.30	3.10	11.10	1.64	22.30	3.30
Accessories	0.20	0.40	1.80	1.99	0.60	0.20
TOTAL	101.40	100.00	99.90	100.73	98.90	100.10
Heavy Minerals	Apatite	Apatite	Zircon	Zircon	Zircon	Zircon
	Ore	Sphene	Apatite	Apatite	Apatite	Apatite
	Sphene		Sphene	Sphene	Sphene	Sphene
			Allanite	Allanite		
Plag. Comp.	An 60 ± 5	An 50 ± 5	-	An 60 ± 5	An 35 ± 5	An 62 ± 3

Table 7: Volumetric analyses of the Quartz Diorites

Specimen No.	SM 171	SM 124+	SM 181+	SM 129+	SM 115+
Quartz	3.72	19.65	23.20	8.03	9.95
K-felspar	-	13.08	1.98	21.32	1.49
Plagioclase	36.20	29.00	50.40	51.45	73.40
Biotite	10.40	27.70	20.22	12.46	11.25
Hornblende	47.65	10.05	4.20	6.27	3.14
Accessories	2.11	tr.	tr.	0.36	tr.
TOTAL	100.08	99.45	100.00	99.89	99.23
Heavy Minerals	Zircon	Zircon	Zircon	Apatite	Apatite
	Ore	Apatite	Apatite	Ore	
	Sphene	Sphene	Sphene	Sphene	
		Allanite	Allanite	Epidote	
		Ore			
		Calcite			
Plag. Comp.	An 56 ± 5	An 50 ± 5	An 40 ± 5	An 30 ± 7	An 35 ± 3

Table 7: Volumetric analyses of the Quartz Diorites

+ polished slice

All other analyses carried out on stained thin sections.

2. another grain showing a low An content in the outer portion and a high value in the inner zone.

3. a zoned crystal with a similar composition in every zone.

The relative An proportions were gauged from the maximum angle of extinction 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 phenomena lies beyond the scope of this work.

Biotite, in the diorites, is generally abundant, but often 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 the foliation.

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

The diorites are characterised by a variety of accessories of which apatite, ore, zircon, sphene and allanite are the most common. It seems significant that sphene is rare in other igneous rock types examined, and its presence in the diorites is suggestive of a lower temperature stability field. Apatite is usually subhedral to euhedral. Zircon is subround to euhedral and occurs mostly as inclusions in biotite. Sphene is present as abundant, extremely irregular grains of variable size and allanite as small- to medium- (less than 1 mm) sized grains some of which are twinned. Calcite, rutile and epidote are rarely present. Of the ore minerals examined ilmenite appears 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 haematite. The general minute size of the grains makes positive identification of some of the components uncertain.

(iv) Other Rocks Association with the Diorites

Hornblendites: On Etusis and Niekhoes there are spectacular ringform dyke-like outcrops of coarse-grained, hard, fairly homo-

geneous, black hornblende-rich rocks of doubtful origin. Similar small occurrences of these rocks were also found on Okongava Ost, near the Neu Schwaben-Otjimbingwe boundary, on Palmental close to the Donkerhuk road and on Stingbank. Macroscopically all these rocks are almost identical, being composed of hornblende and variable amounts of plagioclase and quartz. On Etusis and Niekhoes they are associated with a variety of diorites, granites and pegmatites, and definitely predate the pegmatites.

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

Thin section examination of the hornblendite from Stingbank and Otjimbingwe clearly indicates that these two outcrops are of uralitized olivine gabbro and consist of calcic plagioclase altered to a less calcic type, altered olivine, orthopyroxene altered to chlorite, and hornblende with fairly abundant laths of biotite and prismatic zoisite. The Stingbank rock is less highly uralitized than the other. The specimen from Etusis 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 glommeroporphyroblasts and does not occur disseminated in the matrix, as it does in the quartz diorites. There is no olivine in this specimen. In view of the uralitized nature of the rock examined, the writer prefers to think of the ringform horn blendites as uralitized gabbro intruded in early, possibly pre-fold and pre-metamorphic times. The quartz glommeroporphyroblasts may have been introduced during metamorphism and granite emplacement. In this case, the occurrence of at least three bodies of this rock type within the Khomas Schist horizon 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 horizon. The horizon was subsequently folded. The possibility that these rocks could have been formed at the same time as the diorites, to which they may be genetically related, also exists. Gevers (1931a) regards these rocks as being differentiates "from more deep-seated portions of the same dioritic magma and hence was intruded, after the differentiation in higher regions had already progressed somewhat further".

Anorthosites: The only anorthositic rocks found by the author occurred intercalated in a suite of metasediments described in the Lower Marble Series. Gevers (1931a), however, describes a dyke of white anorthosite studded with pyrite occurring in marbles on the northeastern slopes of the Potberg in the neighbourhood of Palmental.

Acid plagioclase is the only major constituent, with accessory quartz, sphene and idiomorphic garnet. This dyke is thought to be a derivative of the dioritic rocks ourcropping to the north.

Granites and Diorite Porphyrite: The granitic texture of the diorites and their close association with biotite granites of the Salem type on Niekhoes and Etusis has already been referred to. In addition to these rocks there is a complex suite of intrusives in the vicinity of the windmill on the Niekhoes-Etusis boundary. A traverse in the stream bed southward from the marble-granite contact towards the windmill crossed from banded blue marbles immediately into biotite schists 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 these hornblendites pre- or post date the Salem Granite emplacement. To the south of the Salem granite body the traverse crosses a belt of coarse quartzo-felspathic schist containing abundant lenticular bands of granitic rock. 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 granites, containing a little hornblende (thus close to the quartz diorites in appearance), which occupy the bulk of the Etusis-Niekhoes syncline.

At the windmill there occur over a very localised area in these granite-diorites two unusual rock types. The first of these is composed of odd-shaped quartz diorite orbicles in a matrix of Salem-type allotriomorphic granular rock, a specimen of which (SM 119) was composed of 35% quartz, 11% potash felspar, 43% plagioclase (An 30 $\pm$ 5) and 12% 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 euhedral, very abundant hornblende set in a matrix of anhedral quartz and altered subhedral plagioclase (An 60 $\pm$ 5). Quartz is also present in round aggregates. It seems clear that the quartz diorite was intruded by the granite.

The other rock-type, in close proximity to the one described above, consists of abundant coarse pegmatitic fragments, of variable size, contained in a matrix of pale buff-coloured porphyritic rock. A finer-grained specimen of the pegmatitic fragments (SM 117) contained 22% quartz, 53% microcline and 24% plagioclase ($An_{12} \pm 5$) some myrmekitic, in an allotriomorphic to hypidiomorphic, interstitially holohyaline texture. The host rock (SM 116) consists of euhedral, generally altered plagioclase ($An_{30} \pm 5$) set in a groundmass 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 Marble Series on the Habis A and B boundary, and where the Donkerhuk road crosses the Marble Series on Habis B. These rocks, though andesitic and intrusive, may not be true andesites since the composition of the plagioclase may not be ubiquitously andesine. Gevers (1931a) has termed rocks of similar appearance, diorite porphyrite, which is, perhaps, a better, though wider, term.

(v) Chemical Composition of the Diorites

A chemical analysis was made of specimen SM 181 which had a closest-to-mean composition of all the diorites volumetrically analysed in Table 7. The analysis, together with the derived cation proportions, is compared with those of Khomas Schist and Salem Granite in Table 5 A and B; and with that of the Red Gneiss is Granites in Table 9. It may be observed here that the chemical composition of the diorites 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) The Intrusive Granites and Pegmatitic Granites

(i) Distribution

The largest of such bodies occurs at the Geisterberg and Okatjeueberg, in and around the Otjimbingwe Reserve, on Ubib, Kubas, Gamikaub West and Dorst Rivier. There are numerous other bodies of lesser size scattered throughout the region in all stratigraphic horizons.

(ii) Macroscopic Character and Field Relations

This group consists entirely of homogeneous, non-foliated, reddish-to-buff or pale grey-coloured granite, or very coarse-grained pegmatitic granite. In general, the members are poor in ferric minerals, but on Ubib, Gamikaub West, Kubas and Dorst Rivier the greyish granites have a biotite content comparable with the Salem Granite and cannot be distinguished macroscopically from those mapped as Salem Granite on Neu Schwaben. The deciding factor for including the above granites in the intrusive group is their locally distinct transgressive nature with regard to the metasediments. On Ubib West there is a clearcut intrusive contact between this kind of granite and the steeply dipping Chuos quartzite. In the vicinity of the Naibberg the granite cross-cuts Khomas Schist foliation as well as the foliation of the Salem Gneisses. On Gamikaub West the granite is intricately associated with biotite schist remnants and quartz diorite bodies.

The granites in the east have a reddish-to-buff colour, and are characterised by low biotite, but significant muscovite, content. The Geisterberg is an outstanding example of this type of granite which is often topographically 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 granites are found to be paragenetically younger.

One of the most remarkable features of these granites is their relation to the metamorphosed carbonate rocks of the Marble 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 seen at Ubib and Kubas where two large bodies of granite are separated by only a narrow band of homogeneous crystalline marble. A few hundred yards away, on the Chuos east-facing scarp, the bedding of the quartzites is truncated by the granite which also intrudes the metasediment in veinlets. A similar relationship between granite and marble occurs on Meyersrust. These features show the remarkable stability of the carbonates in a magmatic environment, and not only indicate that the marbles 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 numerous instances of marbles capping large bodies of pegmatitic granite associated with the Red Gneissic Granites of the Quartzite Series. The gneiss domes bordering the Lower Khan Gorge area are excellent examples of this phenomena. Such concentrations of pegmatite below the marble point strongly to the fact that volatile constituents promoting the concentration of silica and alkalis, especially potash, were locally dammed up by the overlying marbles. This may be, as will be discussed later, an important factor in the localization of many of the late-stage mineralized pegmatites in the marble horizon.

(iii) Petrography

Comparatively few specimens of these granites were studied in detail. The volumetric analyses of specimens from six different granite bodies (see Map 2) are shown on Table 8 and plotted on triangular diagrams in Fig. 3 A, B and C.

With the exception of the pegmatitic granite specimen from the Otjimbingwe Reserve, which has a very high potash felspar content, the remainder of the granites are of fairly similar composition and fall within the composition zones of the Red Gneissic Granites and Salem Granite as shown in Fig. 1 A, B and C. It is interesting that there is very little difference in composition of the granites occurring in the Khomas Schist on Kubas and in the Chuos Quartzite horizon on Ubib. Also the Geisterberg type, SM 162, has very similar characteristics to the granites underlying the marble horizon in the Okatjeueberg.

The texture of the granites is typically medium-to coarse-grained allotriomorphic, or very coarse-grained in the pegmatitic types. Quartz is present as anhedral interlocking grains. Microcline 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 139), though generally albite or oligoclase. In several cases it is more abundant that potash felspar. 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 amounts, and is associated particularly 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 granites. Insufficient specimens were studied in detail to establish whether or not marked differences occur in the mineralogy of intrusive granites situated in various stratigraphic horizons.

	Intrusive into Chuos Quartzites			Intrusive into Khomas Schists		
Specimen No.	SM 135	SM 139	SM 180	SM 150	SM 182	SM 162+
Quartz	36.08	27.25	31.85	30.78	18.45	31.75
K-felspar	22.99	30.65	29.41	35.50	71.46	29.16
Plagioclase	32.08	35.40	30.20	29.00	7.86	35.70
Biotite	8.92	6.35	8.57	4.98	-	0.51
Muscovite	-	-	-	-	-	1.91
Hornblende	-	-	-	-	2.42	-
Accessories	tr.	tr.	0.14	tr.	tr.	tr.
TOTAL	100.07	99.65	100.17	100.26	100.19	99.03
Heavy Minerals	-	-	-	-	Sphene	Ore
						Garnet
Plag. Comp.	An 30 ± 5	An 30 ± 5	-	-	-	An 5 ± 3

Table 8: Volumetric analyses of the Intrusive Granites.

	Intrusive into Upper Marble Series			Intrusive into Khomas Schists	
Specimen No.	SM 86	SM 69+	SM 197	SM 114	KR 10
Quartz	52.40	36.08	18.55	24.25	22.46
K-felspar	15.54	53.15	43.80	54.20	60.26
Plagioclase	27.62	10.61	37.65	21.10	14.89
Biotite	-	0.27	-	0.45	2.57
Biotite & Muscovite	4.38	-	-	-	-
Accessories	tr.	tr.	tr.	tr.	tr.
TOTAL	99.94	100.15	100.00	100.00	100.18
Heavy Minerals	Zircon	Ore	-	Ore	Ore
		Uranin-ite			Apatite
Comp. of Plagioclase	-	-	An 3	An 18 ± 3	-

Table 8 (contd.): Volumetric analyses of the Pegmatitic Granites

+ polished slice

All other analyses carried out on stained thin sections.

(e) Pegmatites and Quartz Veins

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

(i) Distribution

Although pegmatites are generally distributed throughout the area in all rock-types, certain formations are apparently particularly unfavourable for their localization. Such formations include the massive Chuos Quartzite strata in the Otjipatera and Chuos Mountains as well as the Khan Quartzites in the Rössing Mountain. Similarly, the homogeneous units of the Upper Marble Series are largely devoid of pegmatites. Although the Khomas Schist horizon is a favourable site for the emplacement of these bodies, it is noticeable that the coarsely crystalline variety contains fewer pegmatites than the well-bedded types, as can be seen to the south-east of the Karub Gorge and Khan River on Namibplaas. The effect of bedding on the abundance of pegmatites is also very well illustrated in the Khan Quartzites surrounding the Dome near the S.J. Claims. In many of the homogeneous quartz diorite bodies the pegmatites are relatively subordinate in amount.

(ii) Macroscopic Character and Field Relationships

In general, the pegmatites are all macroscopically similar, being composed of clear-to-milky quartz, flesh-coloured microcline (often graphically intergrown with quartz), subordinate white plagioclase, and accessory biotite or tourmaline. Certain differences are, however, locally apparent. In the Khomas Schists the pegmatites are often noticeably richer in biotite; in the marbles they are frequently found to be poor in potash felspar; in Salem Granite and Gneiss bodies, as well as in diorites, they are commonly tourmaline-rich. In all pegmatites the grain size is seldom uniform throughout, and there is often a zonal distribution of minerals, even in the more common concordant types.

An important feature of the pegmatites is that they are obviously of different 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 varies.

In the chapter on structure it is shown that one of the earliest fold movements in the tectonic history of the area 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 pegmatites are relatively undisturbed. Here it was found that the pegmatites, largely concordantly emplaced in the strata of this fold, are of pre-fold age and have been both boudinaged and folded in a parasitic manner together with other competent units involved in the folding of the mainly incompetent strata. These pegmatites, when in contact with homogeneous marble, contain calc-silicate minerals (diopside and scapolite) in narrow contact reaction zones which, together with the accessory zircon in the main body of the pegmatite, indicates that they were originally intruded. There are a vast number of highly folded pegmatites and quartz veins, including some which show fold interference patterns of two phases, localized 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 pegmatites having formed in the folded axial planes of the earliest identified set of folds. 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 Map 3). Many of these pegmatites are of the secretion type (Ramberg, 1952). Isolated pegmatite nodules found in some metasedimentary strata may also have formed at this time, as metamorphic products contemporaneous with the formation of early granite gneisses. 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 mineralized, usually discordant, bodies associated, in at least one instance, with pegmatites actually occupying a fault plane (Roering, 1961). The pegmatites of Karlsbrunn, Brockmann's, Rubicon and Helikon, as well as Brockmann's Beryl Pegmatite on Tsaobismund, are definitely late-stage, while those on Etusis, Habis, Dernberg and many other lesser ones are probably contemporaneous with these and the large non-mineralized dykes in the Abbabis System.

(iii) Petrography

Owing to the extremely coarse-grained nature of these rocks, they do not lend themselves to microscopic study. The petrography of the mineralized group has been studied by Frommurze and Gevers (1929), and by Cameron (1955). By far the most pegmatites are of simple mineralogy, being composed 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 Marble Series, and two from Khomas Schist horizons were examined. The volumetric analysis of these are shown on Table 8 and plotted on triangular diagrams, together with the Intrusive Granite group, in Fig. 3 A, B and C. Two of the specimens in the Marbles show high plagioclase : potash felspar ratios.

The pegmatites associated with uranium mineralization in the Lower Khan Gorge are conspicuously associated with biotite schist bands in the Lower Marble Series, though there are exceptions. Here the pegmatites consist of dark smokey quartz, deep pink 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. These pegmatites, as well as those containing copper, will be further discussed in the final economic chapter in this work.

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

(f) Aplites

Aplites occur in all the Damara rocks, but are far less in number than the pegmatites. They are essentially of identical mineralogical composition and structural situation as pegmatites. The aplites are, however, not usually associated with mineralized bodies.

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E. PETROGENESIS OF THE GNEISSES AND GRANITES

The macroscopic character, field relations, petrography and, in some cases, chemistry of the Red Gneissic Granites, Salem Granites and Gneisses, Quartz Diorites, homogeneous granites and pegmatites have been described.

In the region considered, about 70% of the area covered by igneous rock-types is occupied by gneissose varieties which include migmatites and metasediment remnants. These, as indicated by either their concordant foliation or their rare lineation and microfold structures, are paragneisses or intruded rocks which were subjected to subsequent tectonic stress. Their distribution, mineral and chemical compositions (potash-rich red gneisses in the lower strata; biotite-rich Salem gneisses and plagioclase-hornblende-rich diorite gneisses in the Khomas Schist horizon) suggest that they are either granitization or magmatic assimilation products.

It is unlikely that metamorphism and granite emplacement occurred at different times. The fact that recrystallization 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-, rather than, flow-structure. However, a certain amount of orientation may be due to slight compression.

If large bodies of granite were intruded into the sediments at any stage up to the final stage of fold movements, it would be expected that such bodies would transgress 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 horizon are underlain by marble. The marble limbs of the syncline on Mon Repos, for example, dip inwards at moderate angles toward the centre, and fold plunges do likewise. Any cross-sections through such a syncline, of which there are many, would demand, on a magmatic intrusion hypothesis, narrow pipe-like feeders penetrating the Marble Series at the bottom of the syncline. It is difficult to accept that all such pipes should be obscured from view. The writer has, therefore, concluded that the gneissic rocks are all autochthonous and have been produced by high-grade metamorphism.

The nonfoliated granitic rocks, which form the remaining 30% 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 gneisses. At the time of their crystallization there must have been a minimum of tectonic stress. In the Okatjueberg they may have transgressed the marble horizon since the

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granites below and above it are markedly similar. On Ubib, where the most spectacular intrusive contacts are exposed, the granite, although not occurring in the Khomas Schist horizon, has a very similar composition to the Salem granite. It is difficult to envisage intrusion of the latter downwards or sideways through the Marble Series as the contacts indicate an upward movement of the granite. It is suggested that they might have originated from the ultrametamorphism of biotite schists, similar to the Khomas Schists, extensively developed in the Abbabis System into which this granite is intrusive. The intrusive granites associated with the diorites on Etusis are apparently very late-stage mobilized portions, some of which 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 dispositions of these granitic types indicate that, for the most part, they have moved only short distances from their place of origin. For instance, they seldom transgress the Upper Marble Series. They are probably products of usually slight metamorphic differentiation of the autochthonous gneisses, as the difference in chemical composition of the Salem Granite and the Salem Gneiss in Table 9 indicates.

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

The following factors must be taken into consideration:

(i) the Khomas Schist pseudo-channel sample (SM 218) across 950 feet of schist, excluding pegmatite, was taken some 30 miles away from the diorite and granite specimens;

(ii) both the gneissic granites and the diorites 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 9, therefore, gives a broad comparison only of the different rock-types.

	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'''	0.62	1.31	2.67	0.56	1.44
Fe''	4.72	3.19	2.08	1.24	1.18
Ca	1.99	5.28	2.82	3.79	1.98
Mg	5.38	3.60	2.19	1.07	1.61
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
TOTAL	100.38	100.09	99.91	99.61	100.19

Table 9: Comparison of cation proportions of:

Pseudo channel-sample of Khomas Schist (SM 218)

Quartz Diorite of mean mineralogical composition (SM 181)

Salem Gneiss (SM 47)

Salem Granite (SM 153). Average of two analyses of specimen of mean mineralogical composition.

Red Gneissis Granite of mean mineralogical composition (SM 214A).

In Table 9 the compositions of the Khomas Schist, diorite and Salem granites are all comparable, except for Mg in the schist and Ca in the diorite which are both higher than in the others. This comparison points to the fact that the iso-chemical change from schist to granite or diorite seems possible only within the limits of $\pm$ 2.5% and with respect to Fe", Ca, Mg, Na and K. This figure is rather high, but considering the variable composition of both the diorites and the Salem Granites and Gneisses, it is not excessive. The points derived from the norm of the Khomas Schist analysis (SM 218) fall within the zone plots derived from volumetric analysis of Salem Granite (Fig. 4 A, B and C). This shows that an isochemical change from Khomas Schist to Salem Granite is possible, but that the dioritic rocks are of very different composition.

The reason for the difference in chemical and mineralogical composition of the Salem Gneisses and Quartz Diorites, 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 diorites, is indicative of a somewhat lower temperature of formation than the granites and Salem Gneisses. The diorite gneisses are also particularly inhomogeneous varying in combined hornblende plus biotite content from 18% to 57%. 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 diorites do not occur west of Kubas in the region mapped. This is a significant feature, but could be due to metamorphic grade and/or chemical variation in the Khomas Schist. On 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.

F. PETROGENESIS OF THE PEGMATITES

The differing ages and structural situations of the pegmatites have been described. Most of the earliest pegmatites were apparently concordantly emplaced in relatively unfolded strata. This first group is perhaps the largest. The macroscopic appearance of many of these is suggestive of an intrusive petrogenesis. They occur in marbles as well as in other sediments, those in marbles containing zircon and micas not generally associated with pure marble beds. The pegmatites also occur in bedding-planes as well as in cross-cutting dilation cracks, the latter phenomenon showing that they are not

volume-for-volume replacements. On the other hand, in the Khomas Schists, for example, they do not transgress from below the Marble Series. 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 competence of the host rocks on the degree to which these pegmatites are developed indicates that they were introduced in low pressure zones in the rocks.

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

The third group associated with faults and probably cooling tension cracks in granitic rocks, is almost exclusively of an intrusive character, though here, again, the quartzo-felspathic material may not necessarily have been derived from great distances. The abundance of pegmatites in the roof zones of Quartzite Series domes is suggestive of a concentration of volatiles promoting such accumulation and coarse crystallization. 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 mineralized group.

G. THE METAMORPHIC SEQUENCE

Early metamorphic events have been largely obliterated by those of later age and greater intensity. The first signs of metamorphism appear in the production of pegmatites followed by the first phase of deformation which, because of the development of similar-type folding, took place while the rocks were in a plastic condition. Metamorphism increased in intensity during the second fold phase producing, in addition to pegmatites, the crystallization of biotite in fold axial planes. At this stage, 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 crystallization of porphyroblasts of many kinds in the sediments, and in granization, differentiation and mobilization in the cores of synclines and anticlines. Low pressure centres must have been present in these cores where 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°C and 650°C probably existed during the peak of metamorphism, while in the mobilized magmatic portions temperatures up to 800°C may have occurred. Wyllie and Tuttle (1960) have established that melting of granite rocks may occur at 650°C at 20 kms. depth and at higher temperatures closer to the surface.

It seems unlikely that temperatures as high as 800°C were common, however, since the marble horizons show remarkable stability and, only in a few places, have melted to lose their bedding features. This can be seen in the 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 24 kms. depth. If CO_2 and water are present the melting temperature is raised so markedly that the rocks are unlikely to have melted at all (Wyllie and Tuttle, 1960). Few of the carbonate rocks 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 per km. to have been present in this orogen, a depth of burial of the rock must have been of the order of 18 to 24 km. 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 - 500°C, associated with earlier amphibolite-facies metamorphism and pegmatitization, were operative.

H. THE AGE OF THE DAMARA METAMORPHISM AND GRANITIZATION

Eight separate age measurements have been made by Nicolaysen (personal communication) on rocks associated with the metamorphism and granite emplacement in the Damara System. These are listed in Table 10.

Mineral	Host Rock	Locality	Age
davidite	pegmatite in L.M.S.	Panner's Gorge	510 ± 40 m.y.
davidite	pegmatite in KQS gn.	Louw's Claims	"
yttro-tantalite		Jakalswater (old station)	"
yttro-columbite	pegmatite	- do -	"
davidite	pegmatite	Cox's Claims	"
biotite	pegmatite in L.M.S.	S.J. Claims	"
biotite	pegmatite in U.M.S.	- do -	"
uraninite	pegmatite	Louw's Claims borehole	"
monazite	marble	Eureka	520 ± 20 m.y.

Table 10: Age determinations on metamorphic and granitization products in the Damara System.

The pegmatites at Panner's Gorge and S.J. Claims pre-date either the first or the second phase of folding, while those at Louw's Claims are of post-granitization age. The euhedral monazite in marble on Eureka is randomly oriented and is probably of post-fold age.

These determinations indicate that the metamorphic and fold events, as has also been deduced from the history of the pegmatite emplacements, occurred within a relatively limited interval of time which may be regarded as well established at 510 ± 40 million years.

The age of sedimentation of the Damara System must have been post 1,700 ± 60 m.y. (Clifford, et. al, in press) which is the age of formation of the pre-Damara granite near Franzfontein. Although there is no molasse-type deposit to show that sedimentation continued during tectonism, it is thought that the sedimentation cycle of the Damara preceded the folding and metamorphism by only a very short period.

STRUCTURE

A. INTRODUCTION

In addition to the regional mapping of the area under discussion, two sub-areas were selected for detailed structural investigation. These are located in the Khan Gorge area in the vicinity of the Khan Mine (see Map 2) and in the Karub Gorge (Map 4). These areas, together with that dealt with by Roering (1961) in the Koliombo-Albrechtshöhe locality, centred on Brockmann's Pegmatite are structurally typical of this portion of the Damara Geosyncline.

(a) Methods

The general geological features were mapped during the course of regional work. Enlarged aerial photographs (1:12,300 and 1:18,000) were used for the more detailed structural study which entailed the accurate plotting of foliation, lineation, cleavage and axial planes of minor folds. Most of this data was subsequently analysed and is presented on lower hemisphere stereographic and equal-area projections. Maximum values were obtained from contoured plots on an equal-area (Schmidt) net and, in some cases, transferred onto a Wulff net. Axial traces were plotted on aerial photographs as lines intersecting hinge zones of folds. In the case of the third set of folds on Map 2 the hinges are largely conjectural. No petrofabric analyses were made, but a careful note of the crystallization features in relation to structure in the rocks was kept during the course of petrographic examinations.

(b) Definitions

(i) Tectonic Axes (after Sander, 1930)

'a' denotes direction of transport, or movement, or maximum relief.

'b' is at right angles to 'a' and sometimes is parallel to the fold axis.

'c' is normal to the 'ab' plane which is parallel to the axial plane.

'c' is usually parallel to the maximum pressure direction (P max)

(ii) Folds

1. Concentric or Flexure Folds: folds in which the beds remain constant in thickness (De Sitter, 1956).

2. Similar Folds: folds in which the bent strata maintain a similar shape, and in which beds are thickened in the crests and troughs and thinned on the limbs; these folds are also known as shear folds, flow folds or cleavage folds.

B. THE REGIONAL STRUCTURAL SETTING

The directions of Cambrian fold trends in South West Africa are shown on Map 1. The area mapped falls fairly centrally within a 200 mile-wide lineament belt trending northeast. This fold belt is bounded on the north by the Otavi foreland (Map 1, areas 9 and 10) and on the south by the Nama foreland (Map 1, areas 5 and 6). To the west of each of these foreland areas the fold trends become progressively more parallel to the coast. In the Otavi zone they swing to the north-northwest and in the Nama region to the southwest and eventually, in southern South West Africa, to the south and southeast. Thus, the major trends in the Damara System in the territory may be said to be primarily northeast, and secondarily north-northwest.

The fold style on the foreland margin in the south is apparently similar to the upper-level Alpine-type, e.g. in the Naukluft (Korn and Martin, 1959), whereas that in the central Damara regions is associated with high-grade metamorphism and with the production of gneisses and granites in an environment typical of the deep-seated portions of a eugeosyncline.

C. THE STRUCTURE OF THE AREA INVESTIGATED

(a) Major Structures

The region exhibits the characteristic structural pattern of a series of elongate brachydomes and basins, with steeply inclined northwest and southeast limbs, arranged along a strongly developed northeast trend. Cross-fold interference patterns are apparent at several places in the form of curved or cross-oriented fold axes, good examples of which are found at Rössing Mountain, the "nose structure" in the Khan Mine area, the Karub Gorge area, around Nord Horebis and in the area extending from Karibib Townlands to Koliombo.

A feature of the northeast-trending folds throughout the area is that they plunge, in the majority of cases, to the northeast. There are many instances of the southwest limbs of anticlines and northeast limbs of synclines being overturned, though this is not by any means ubiquitous. The reason for this feature, well exhibited in the Kuduberg on Neu-Schwaben, Groot Aukas, and southwest of Vergenoeg, will be discussed later.

The northeast-trending major folds maintain a fairly constant wavelength of 6 to 8 miles across the area mapped. Their amplitude, which cannot be accurately measured, appears to be of the order of 4 to 5 miles (measured on a cross-section which is a profile normal to the regional plunge). Thus, in broad terms, and assuming flexure and concentric folding processes to have operated, the amount of crustal shortening necessary to produce these folds must have been between 40% and 50%. If this is the case, then the amount of strata contained in 50 miles northwest-to-southeast must have been contained in about 70 to 75 miles of unfolded strata.

The dip of the axial planes of these northeast-trending folds is always steep, seldom being less than 70° to the northwest or southeast. Thus, if the assumption that Pmax is normal to the axial plane of a fold is correct, these major folds must have been formed dominantly by nearly horizontal pressure directed from the southeast and northwest.

The fold pattern naturally controls the areal distribution of the metasediments, but, as mentioned previously, it also determines the distribution of most of the igneous rock types, e.g. Red Gneissic Granites in anticlines; Salem Gneisses, Quartz Diorite and Diorite Gneisses in synclines.

There are relatively few faults in the area and these (of small horizontal displacement) are largely confined to the Kuduberg and Karlsbrunn localities. The scarcity of faults is due to the fact that nearly all tectonism occurred while the rocks were in a plastic state.

(b) Minor Structures

The following types of minor structures were observed and measured in the field in the localities investigated in comparative detail:

(i) Planar Structures

1. Foliation or S-planes: The rocks within the area show several megascopic S-planes, the most dominant of which are bedding-planes separating bands of different composition. Schistosity and gneissosity are also very widespread and nearly always conform to the bedding-planes. The micas are oriented with the basal cleavage parallel to the bedding in the majority of cases. Prismatic crystals, commonly hornblende, usually have their long axes in the foliation plane.

2. Axial-Plane Cleavage: This feature is surprisingly rare in these rocks, the reason being that the metamorphism out-lasted the fold movements for the most part. Nevertheless, there are several areas where axial-plane cleavage can be observed, and where the basal parting of the micas is oriented parallel to the cleavage-plane which is, in turn, parallel to the axial-planes of major and minor folds.

3. Axial-Planes of Minor folds: Although not visible as an actual plane in the rocks this feature is readily measured in the field and especially valuable in recognising early folds or folded folds. The minor folds are particularly abundant in the hinge zones of major folds.

(ii) Axial Structures

1. Linear Structures: Lineations of different kinds are prominent throughout the area in the well-foliated rock-types. They are best developed on steeply inclined and overturned limbs, as well as in the hinge zones of folds. The following types were recognised:

   Minor Fold Axes:- The crests and troughs of minor folds commonly form impressive linear corrugations on bedding surfaces, and are readily measurable. These lineations are particularly well-developed in the marbles on overturned limbs. Though less spectacular in other rock types, in which they are often present on a microscale, they are the most common type of lineation found, and are nearly always related to the second, and dominant, northeast-trending fold axes.

Cleavage-Bedding Intersections:- As previously mentioned, cleavage is rarely developed, but where it does occur, it gives rise to fine linear stripes on bedding or foliation surfaces. These are generally found to be associated with the second fold axes.

Boudinage:- This is a common feature in the region where competent rock bands are frequently found intercalated with incompetent types. The most spectacular of the competent group are calc-silicate bands in marble and pegmatite in biotite schist or marble. Quartzite and amphibole bands are also abundant as boudins in schist hosts. The linear neck between the competent ruptured units is a readily measurable feature seldom formed parallel to the other lineations which are usually folded about the boudinage axis (Fig. 5).

Elongated Augen:- These are plentiful in the Abbabis Augen Gneiss and also present in the porphyroblastic Salem Gneiss. These rocks occur only in isolated places in the areas investigated in detail and have not been systematically measured. It is, however, apparent that the augen, or euhedral prismatic felspars, are, in some cases, oriented parallel to the regional fold axes, e.g. in Salem Gneiss at Gamikaubmund.

Pebble Elongation:- Both in the Damara basal conglomerate and in the tillite, pebbles and boulders have been flattened and elongated in certain localities (mostly in hinge zones of folds). The rock fragments in the tillite in the Lower Khan Gorge are drawn out to a remarkable degree in several places. The

orientation of pebble elongation defines the direction of tectonic transport, or the "a" tectonic axis. Despite the pebble lineation in this area being parallel, or nearly so, to the fold axis, it will be shown that it does indeed define the "a" direction.

2. Major Fold Axes: The axial traces of the major fold axes are plotted on the maps (Maps 3 and 4). The plunges of these axes were determined by the position of the pole to a great circle containing the S-plane poles on a stereogram for each sub-area. The position of the traces, as mentioned, was determined by the hinge zones of folds. Two distinct sets of fold axes have been distinguished, as well as a possible third set. These have been termed Fold 1, 2 and 3.

(c) The Structure of the Karub Gorge Sub-Area

This area of 10 square miles (see Map 4) is located immediately north of the Khan River on the farms Vergenoeg and Namibfontein. It was selected for investigation by reason of the good outcrop and the presence of an apparent inter-section of three synclinal fold axes which were thought to show critical age relationships.

Attention was confined to the synclines only. Some 97 lineation, 45 minor fold axial-plane, 7 axial-plane cleavage, and 46 foliation measurements were made. These proved sufficient to distinguish two sets of folds in the field, i.e. the Blauer Berg synform fold axis about which the Zeta syncline had been folded. The relation of the Karub syncline to these two remained uncertain.

(i) The Zeta and Blauer Berg Synclines

The structural elements of the Zeta and Blauer Berg Synslines are analysed in Fig. 6. Here a girdle of foliation (pi) poles contains two maxima which are related to the normal and overturned limbs on the west and east sides respectively of the folded Zeta (1st. fold) axial-plane.

These limbs intersect at a point L1 which defines a position of the first fold axis. The girdle containing the poles to the axial-planes of minor first folds has a rotation axis A2 which is nearly coincident with the lineation maxima L2(a) and L2(b) which are associated with the second fold axial-plane of the Blauer Berg Syncline. The second fold axis orientation was controlled by the position of the first fold limbs, as can be seen by the position of L2(a) on the normal limb plunging at 43° in a direction N 32° E, and L2(b) on the overturned limb plunging at 33°, N 43° E. These phenomena, in addition to the fact that the lineations lie on the axial-plane of the second fold and close to the axis of folding of the first axial-plane are clear proof of the lineations being associated with the second fold movement. The orientation of the axial-plane and axis of the first fold cannot be determined for certain in this area as they have been considerably twisted.

Thus, from an analysis of these measurements the conclusions arrived at in the field can be substantiated and there is no doubt that early isoclinal folds were refolded by a set of second folds the axial-planes of which strike at an angle to the first fold axial-plane.

(ii) The Karub Syncline

The Karub Syncline (see Map 4) is an isoclinal overturned (to the southwest) fold trending southeasterly. It is slightly bent in the middle about a line parallel to a cross-cutting dolerite dyke. The relation of this fold to the Zeta and Blauer Berg Synclines could not be positively determined in the field owing to the scarcity of minor structures at the southeast end of the syncline.

An analysis of the minor structures measured in the syncline is shown in Figs. 7 and 8. In Fig. 8 the pi pole maxima, found on an equal area net, fall into two distinct sets. An (a) set, corresponding to the northwest sector which contains two maxima related to a north overturned limb and a southern normal limb, and a (b) set with similar maxima corresponding to the southeast sector. The foliation planes normal to these maxima all intersect at a single point which defines both the axis of rotation of the (a) and (b) sections (fold axis 2) as well as the fold axis of the Karub Syncline (fold axis 1). The centres (a) and (b) lie 16° apart and correspond to the bend in the syncline. By rotating the centres of the (a) and (b) pi maxima 8° toward each other the "bend" is unfolded and the orientation of the straight axial plane of the syncline is found to strike at 122°, dip 46° to the northeast and plunge 45° to the northeast. Thus, it is apparent that this overturned isoclinal fold was slightly bent about an axis coaxial with the major axis of the Karub Syncline.

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Lineations associated with the fold plot on a great circle nearly coincident with the unfolded (Karub) axial-plane and form two largely distinct groups on either side of the co-axis (fold axis 1 and 2). One group is associated with the southeast (b) sector and the other with the (a) sector. This spread of lineations on a great circle is indicative of a folding of early lineations by a later similar fold process (Ramsay, 1960). Thus, the bend in the syncline, as well as the folding of the lineations, is indicative of a later fold movement being present. An axial trace drawn through the bend in the syncline (Map 4) is approximately parallel to the Blauer Berg second fold to the southeast.

In Fig. 8 the major elements of the Zeta and Blauer Berg folds are plotted together with those of the Karub Syncline. The first fold axial-planes are nearly coincident. The lineation maxima marking the direction and plunge of the Blauer Berg fold axis is very close to the co-axis of the Karub Syncline confirming that fold (2) in this structure has the same orientation as the Blauer Berg structure. The girdle containing the lineations measured in the Karub Syncline intersects the fold (2) axial-plane at a point very close to the co-axis. This point of intersection of the plane containing the lineations and the fold (2) axial-plane defines the 'a' tectonic axis of the second fold which bent an earlier set of lineations associated with the Karub Syncline (Ramsay, 1960). This then proves to be an unusual case of the 'a' tectonic axis being almost coincident with the fold axis. The 'a', 'b' and 'c' tectonic axes of the second set of folds have orientations of N 35° E plunging at 45°, S 68° W plunging at 45° and S 38° E plunging at 16° respectively. The Karub Syncline is only very slightly folded by fold (2) owing to the fact that its isoclinal limbs were contained in almost the same plane as the 'a' axis, whereas the Zeta fold to the south must have had a slightly different attitude enabling the Blauer Berg fold to bend it to a fair degree.

The attitude of the Karub Syncline to the axial-plane and tectonic axes of the second fold is shown diagramatically in Fig. 9. ('a' and 'b' lie in the axial-plane of fold 2).

(d) The Structure of the Khan Mine Sub-Area

This area, covering some 70 square miles, is located along the Lower Khan River. It was selected for investigation for the following reasons:

(i) excellent outcrop,

(ii) the presence of folded axial-planes and a

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remarkably symmetrical dome structure,

(iii) accessibility, and

(iv) complete aerial photo cover.

Map 3 was compiled from an uncontrolled aerial mosaic (1:24,600) using 1:12,300 enlargements for more accurate plotting, the structural detail being largely transferred to it from the 1:12,300 aerial photographs.

(i) The Major Structures

The major structures in this area consist mainly of three recognisable early "bent" folds: the Nose Structure anticline, the Welwitsch syncline and the Paviaan syncline; and a number of relatively linear, later folds the most striking of which are the Blauer Heinrich and Khan Synclines, the Camp anticline, and the Dome. This latter group is slightly bent by a third fold. The Dome is partly surrounded by a synclinorium largely defined by the outcrop of highly folded Lower Marble Series.

The largest folds in this sub-area are readily recognised by the well-defined stratigraphy in which the Upper Marble Series is a superb marker horizon. The lesser folds can be delineated, often with difficulty, from the trace of the hinge zones in the bedding.

The axial-plane traces marked on Map 2 define the intersections of major fold axial-planes with the plane of projection on the map. A study of these traces reveals the three sets of folds referred to. Though distinct in some places, these folds are obscured in others, a particularly complex area occurring in a "vortex" in zone c4 (Map 3).

The axial-planes of the earliest set of major folds dip at low angles in various directions largely to the north-west and south-east. The axes of the earlier set, apparent only in the Nose Structure (b2) and in the hinge zone of the Welwitsch syncline, south of Map 3, plunge at low (30 - 40^{o}) angles to the northeast.

From an inspection of the major structures the original orientation of the first set of folds cannot be determined. It is fairly obvious, however, that the second set, only slightly disturbed, trends northeast, and on the assumption that the direction normal to the axial plane ('c') defines the maximum pressure (Pmax) direction,

they were formed by horizontally (or nearly so) directed compression from the southeast and northwest. The third set of folds is not well-defined but appears to have a Pmax direction east and west.

(ii) Faults and Joints

Only a few, minor, post-Damara lefthand wrench faults are present in this sub-area. The most prominent of these occurs on the northwest limb of the dome and is associated with local linear drainage trends following joints and/or faults of very small displacement. These are probably all post-Karroo in age since they affect dolerite dykes. No study was made of fault and joint plane orientation. Joints are, however, conspicuous throughout the region.

(iii) Minor Structures

The structural pattern of the central Damara region has been likened by some to "bubbles in porridge" and by others (Brock, 1961) to "whorls in a boiling pot". Such analogies imply that minor structures are unlikely to have any relation to major structures, or to convey any structural "message" at all. It has already been shown by Roering (1961), in the Karlsbrunn-Koliombo area, and by the analysis of the Karub Gorge area, that this is not the case. Similarly, in the Khan Mine area, minor structures show well-defined relationships to major structures.

Apart from foliation, minor structures are not developed everywhere. Lineations, minor fold axes and axial-planes are usually readily measurable in both Lower and Upper Marble Series, but are often difficult to find in the more massive quartzites as well as in the schists. Metasediment remnants in the Red Gneissic Granite only rarely contain minor structures other than foliation. Certain areas on Map 3 are almost devoid of measurements for this reason. Some 300 foliations, 380 lineations, 35 minor fold axes, 70 minor fold axial-planes and 5 axial-plane cleavage measurements were made. The bulk of these, apart from foliation, is shown on Map 3 and is concentrated in zones c3 and 4.

(iv) The Blauer Heinrich and Welwitsch Synclines and the Nose Structure Anticline

On Map 3, as previously noted, the Blauer Heinrich Syncline can be seen crossing the Nose Structure Anticline and also, possibly, the Welwitsch Syncline. In the field an inspection of the minor fold structures confirms the presence of superimposed folding. At a few places close to the Khan River in the c4 zone well-defined minor fold interference patterns are found. These indicate in many cases that the earlier and later folds have axes only slightly inclined to one another. The following analysis proves the existence of the early set of isoclinal folds which were refolded by the Blauer Heinrich and Khan folds:

Analysis: In Fig. 10 the poles normal to the foliation (pi poles) of the normal southwestern and overturned northeastern limbs of the Welwitsch Syncline plot on two corresponding great circles. The planes at right angles to these great circles define two foliation planes associated with the normal and overturned limbs respectively of the isoclinal overturned fold. A plot of the lineations measured on these limbs forms two maxima (determined on an equal area net) which lie on a great circle, defining the Blauer Heinrich axial plane, where it is intersected by the two foliation planes (Points L2). This proves that the plunge of the lineations formed by the second fold has been controlled by the attitude of the first fold limbs and that the lineations are directly related to the second fold major structure.

It is interesting to note that the lineations formed by pebble elongation in the tillite on the normal limb in the hinge zone of the Blauer Heinrich Syncline, and on the overturned limb of the Marmor Synform, plot on their corresponding maxima in the same way as the other lineations.

A comparison in Fig. 11 of the orientations of the first and second folds in this sub-area with those of the Karub Gorge area shows that they are nearly co-incident. In both areas the folds are co-axial. This coincidence points to the 'a' tectonic axis having the same orientation in the Khan Mine area as in the Karub Gorge area, suggesting that the pebble elongation does indeed define the 'a' tectonic axis despite its parallelism to the fold axes.

Discussion: Co-axial folding poses some problems. Fig. 12 is a simplified diagram showing the parallel axes of the earlier and later folds. Here the first fold axes must have been fairly steep (45°) prior to the onset of the second fold movements. This plunge can only have been brought about by an unrecognised movement earlier than fold 2 or by a steepening effect created by considerable vertical relief during fold 2 compression.

A second problem is that the 'a' axis of fold 2 appears to lie very close to the fold axis and is virtually parallel to the axial-plane of the first fold. It has been shown that the Karub

Syncline was only slightly bent by the second fold in which the direction of tectonic transport was nearly parallel to the axial-plane. Why, then, have the Nose Structure and Welwitsch folds been considerably bent? Either the 'a' axis makes a bigger angle to the first fold axial-plane than supposed, and is not parallel to pebble elongation or, in this case, horizontal lateral relief was possible, and the isoclinal folds were bent into an 'S' shape with maximum relief directed upwards as well as downwards at about 45° to vertical.

(v) The Dome and the Synclinorium

The occurrence of such a remarkably symmetrical dome in an area where isoclinal fold interference patterns exist seems extraordinary. The Dome, containing a core of gneissic granite with abundant metasediment remnants, has a steep northwest and a slightly overturned southeast limb. The northeast and southwest limbs are inclined at about 40°. The strata in the lowermost Khan Quartzite Series contain abundant concordant pre-fold pegmatites which might have increased the competence of this horizon since the structure is almost entirely a flexural one. There is no sign of appreciable thickening in the crest of the anticlines at either end of the Dome which is elongated along its northeast axis. There are few measurable minor structures in the immediate vicinity of the Dome which makes its formational history difficult to unravel.

The synclinorium which partly surrounds the Dome, and which is largely formed by highly folded Lower Marble Series, is characterised by both "canoe"-shaped synclines and "overturned canoe"-shaped anticlines, as well as by more complex folds. The axial-planes of these folds are largely vertical and their axes plunge northeast and southwest at 0° to 40°. Fig. 13 shows a mean girdle containing the spread of these fold axes. The pole of this girdle is horizontal and trends N 47° W coinciding with the strike of the first fold axial-planes of the Welwitsch, Nose Structure and Karub folds. This indicates that the plunge of the folds in the synclinorium was determined by the attitude of the first fold limbs which must have been relatively gently inclined in the vicinity of the Dome. It seems, therefore, that the Dome was formed by the refolding of an initially gentle anticline, the limbs of which dipped at less than 45° to the southwest and northeast by a strong movement directed from southeast and northwest. This type of structure could also be formed by one movement in which the pressure applied at opposite points in the centre of the northwest and southeast sides is greater than at the edges. Here there is no sign of variation in amount of applied force. Had this been the case one would expect to find concave long sides to the Dome. Such concave sides are, however, apparent in several brachydomes in the area (e.g.

on the Swakop River and southeast of Rössing) which might well have been formed, in part, by differential stress.

The reason for the development of excessive folding in the Lower Marble Series in the synclinorium is that it forms a zone of parasitic folding. This is apparent from the fact that this Series is much thinner along the steeply inclined limbs of the Khan Syncline and thickens considerably in the trough of the Blauer Heinrich Syncline. Many of the minor folds in the synclinorium also show 'similar' folding features. Thus, in the Dome which is relatively gently folded, the competent rocks have suffered flexural deformation (in the Nose Structure 'similar' deformation), and the incompetent marbles surrounding it have suffered 'similar' deformation.

(e) Synthesis

The following table shows the orientation of axial-planes in three different areas subjected to detailed investigations:

	Albrechtshöhe-Koliombo Area*		Karub Gorge Area		Khan Mine Area	
	Strike	Dip	Strike	Dip	Strike	Dip
Fold 1	105°	60°S	124°	45°NE	131°	50°NE
Fold 2	10°	52°ESE	52°	74°NW	58°	76°NW
Fold 3	18°	80°ESE	-		170°	?
∠ between poles to ax. pls. of 1 & 2	68°		67°		68°	
	* Roering (1961)					

Table 11: Orientation of Axial-Planes of Three Sets of Folds.

Although the first and second fold axial-plane orientations in the Albrechtshöhe-Koliombo area are not the same as in the other two areas, the angular relationships between the poles to the first and second fold axial-planes are the same. This suggests that these two fold movements originally had constant orientations and that a subsequent event is responsible for the disorientation of the folds in the northeastern areas. In the Albrechtshöhe-Koliombo area Roering (1961)

found that the first folds were formed about an axis trending west-north-west giving rise to an almost isoclinal fold. On unfolding this structure he found that the foliation planes became practically vertical with a tilt of 16° to the east-south-east. This tilting of the fold axis was thought to be due to later folding. The second phase of folding gave rise to northerly-trending structures which plunge at 40° to the south. The attitude of these folds was governed by the original attitude of the beds. The third set is less clear, but the ideal force required to produce it is essentially similar to that of the second set, i.e. Pmax WNW. and ESE. directed upwards or downwards at 38° in fold 2 and 10° in fold 3 (Roering, 1961). Here the 'a' axis of fold 2 is oriented 325° plunging at 50°, whereas in the Lower Khan Gorge areas it is 35° plunging at 45°.

There is little doubt that the first and second fold movements in the areas discussed are the same in each case. The third set is poorly defined in both areas and does not tie in. It must be emphasised, however, that the Albrechtshöhe-Koliombo area does not show fold orientations typical of the region. These trends have, for some reason, been locally disturbed. The Khan area shows the type trends as does the area of anticlinal structures along the Swakop River in the southeast of the region mapped. At the dome containing Brockmann's Beryl Pegmatite on Tsaobismund for example, the second fold axial-plane is near vertical and the axis plunges at 40° to the northeast (Roering, 1961). This is an almost identical trend to the second fold axis in the Khan area.

D. THE FOLD PATTERN IN RELATION TO THE REGIONAL TRENDS IN SOUTH WEST AFRICA

It has already been mentioned that the regional trends of Cambrian folds in South West Africa are dominantly northeast and north-north-west, though distinctly curvilinear in the north in the Kaokoveld and in the south in the Nama foreland regions. This swing in fold trends could be indicative of a single phase of folding.

In the area studied the northwest-trending folds are older than the northeast ones. This raises the question of whether the regional trends are related to the relatively local ones and, if so, whether the north-north-east trends are earlier throughout the whole region. In the central Damara the northeast trends are very widespread and the northwest group, though not readily recognised, seems fairly consistently developed and point to this trend being earlier throughout.

E. THE ORIGIN OF THE FOLDING

As mentioned earlier, the amplitude and wave-lengths of the folds, measured across the regional map (not reproduced here), indicate crustal shortening of between 40% and 50%. This amount is further substantiated by measurements of minor folds occurring in the Upper Marble Series on Groot Aukas. Here the folds contain 'similar' components in the marble bands and flexure components in the competent silicate bands. Measurements made show shortening of 45% and a compressional component of between 70% and 85%, indicating upwards of 60% actual shortening. Such crustal shortening is indicative of a compressional origin of folding.

The characteristics of minor and major folds also indicate a compressional origin. Flexure folds and similar folds contain both zones of boudinage and parasitic folding in more competent beds or bands. Both these types are common throughout the region mapped.

Carey (1958), Beloussov (1961a and b) and others have stressed the importance of vertical, and relative unimportance of horizontal movement, in geosynclinal tectonics. They have, however, failed to account, by purely vertical movement, for folds of flexural type having near vertical axial-planes. Carey (1958) explains folding in terms of flow folds (or rheid folds) which are akin to similar folds produced in marbles, for example, but which do not contain zones of boudinage and parasitic folding or flexural components in competent bands intercalated with incompetent layers. Beloussov (1961a) described fold features such as box folds, flow folds, injection folds and gravity folds, none of which, as he describes them, is prominent in the area under discussion. The dome structures are not dominant over synclinal structures, a feature which would indicate upward flow of low density regions (perhaps those undergoing granitization in the presence of abundant volatiles). In the experiments (Beloussov, 1961b) the flexure folds, produced by slumping after vertical uplift and stretching, all have axial-planes of low inclination. No explanation of vertical tectonics known to the author can account for the fold geometry found in the Damara or similar regions.

The Damara Fold Belt, excluding the marginal zones where gravity folding occurred, is over 200 miles wide and probably contains folded strata once occupying a flat area 60 - 100 miles wider than the present limits of the fold belt.

In the area considered, the Basement Abbabis System reacted homogeneously, together with the Damara, and could not have acted as rigid blocks or 'pistons' required to produce vertical uplift. The evidence for this lies in the fact that the Abbabis rocks

in the core of the major brachyanticline in the area of the main outcrop and in the core of the Nose Structure (Map 3) are folded homogeneously with the Damara sediments. It is also highly probable that Abbabis rocks are included in the granite gneiss cores of a number of domes in the area. Here they were contemporaneously granitized with the Damara rocks and could not possibly have been rigid.

F. SUMMARY OF FOLD TECTONICS

In the above investigations only a very small part of the 3,000 square-mile region has been dealt with. The area contains a large number of well-exposed structures from which a wealth of information could be gleaned by detailed investigation. Such structures as found in the Kuduberg on New Schwaben and the domes in the neighbourhood of the Potberg would be well worth investigating in detail. It is likely, however, that the areas just described are fairly representative of the whole region.

The relation between metamorphism and granitization and folding has been dealt with in a previous section and is only briefly summarized here.

The first events taking place after deep burial of the sediments appear to have been an early metamorphism of amphibolite facies grade associated with considerable generation of simple, largely concordant, pegmatites. The first phase of folding, probably beginning in conjunction with the metamorphism, then produced well-defined folds, locally isoclinal or overturned to the southwest and trending northwest. Metamorphism probably continued throughout this and the following phase which was of considerable intensity. The second fold phase directed by compression from the southeast and northwest almost obliterated the first folds, altering their shape substantially and leaving only local areas relatively unaffected.

Pegmatite formation continued during this second deformation, as is evident from their emplacement parallel to the axial-planes of a number of these folds. In a few places mica orientation in the axial-planes of minor folds associated with this movement shows that metamorphism was active but progressive. The formation of vast bodies of gneiss, the foliation of which conforms to this fold movement, must have begun during this phase, as is shown by porphyroblast orientation in many of the gneisses.

Metamorphism and granitization, resulting in the production of magma locally, continued after the second fold phase died out. This is evident from the abundant development of porphyroblasts in all rock types which show little to no orientation caused by crystallization under conditions of no directed stress. This feature is conspicuous in the granites.

The third fold phase which bent fold 2 axial-planes in the Khan Mine Sub-Area is extremely weak and may have occurred during the final and strongest phase of metamorphism.

Towards the close of the magmatic phase, cooling resulted in the onset of brittle conditions, as is evident from the development of faults and joints in metasediments, gneisses and granites. Some of these were filled by pegmatite, aplite, and quartz associated with the escape of volatiles and mobile constituents from the ultra-metamorphosed rocks.

Roering (1961) has investigated the relation of mineralized pegmatite emplacement to structure, and relates faults and tension zones to post-fold stress.

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 of little economic value. The most important mines at the present time are Rubicon, Helikon and Karlsbrunn which produce beryllium-lithium minerals with subordinate quantities of associated pegmatitic minerals.

The region has been thoroughly prospected for the more obvious metals (copper, lead, zinc, 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 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 occurrence of asbestos in the Marble Series at Pforte (south of the map), a few miles southwest of the Geiseb Spitz, was recorded by Wagner (1916) to be of no economic importance.

Chrysotile was occasionally seen, associated with serpentenized forsterite and dolomite within marbles. 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 exists. Almost all of these are associated with pyroxene-bearing pegmatites situated in a stratigraphic horizon in the Quartzite Series, a short distance below the Lower Marble Series, or, where this is absent, below the Upper Marble Series. Exceptions to this stratigraphic positioning occur at the Pot and Gamikaubmund Mines situated within the Upper Marble Series and the Lower Khomas Schist Series respectively. Also excepted are a number of very small prospects including the Ubib Mine situated in Abbabis rocks on Tsawisis and Naob.

The mineralogy of the copper occurrences is generally very similar.

(a) Khan Mine

The Khan Mine is situated some 35 miles east-north-east of Swakopmund and 4½ miles due south of Arandis (see Map 2). 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), Burg (1942) 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-Kupfergrubbe-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% Cu. Concentrates contained, in addition to 60 - 70% copper, 5.10 ozs. per ton of silver, 0.6 dwts. of gold per ton and 0.146% selenium and tellurium (Se 95% Te 5%).

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 Johannesburg Consolidated Investment Co.

The mineralized pegmatite has a width of 3 - 5 feet, a strike length of some 1,000 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 portion of the Khan Quartzite Series which dips at variable angles (45° - 70°) to the northwest in the vicinity of the mine.

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 (Söhnge, 1939) is suggestive of at least a partial 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.

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

The ore reserves are generally considered to be small. An estimate in 1927 indicated 5,080 tons of metallic copper in ore of a grade between 5% and 6% Cu. A consistent and substantial increase in the price of copper would be required to make this mine payable.

(b) Kainkachas Mine

The Kainkachas Mine is located in the marginal 'badlands' on the south side of the Khan River on Namibplaas.

The mineralized zone, some 12 - 40 feet wide and 1,500 feet long, occurs in amphibolite schist and marble beds associated with the lowest horizons of the Lower Marble Series. The ore, bornite, chalcocite, and subordinate chalcopyrite, occurs both within calc-silicate bands and hornblende-quartz-microcline rocks.

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Prospecting operations have been carried out along a strike length of about 1,500 feet. A number of trenches and pits have been excavated together with one 50 - 100 foot shaft (now sand filled) which is situated on the north bank of a dry river bed transgressing the outcrop. Grab samples assayed 1.5% Cu. on the average.

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

(c) Ebony Mine

Located some 4½ miles east-south-east of Ebony on the farm Namibfontein, the Ebony 'Mine' consists of one vertical sand-filled shaft and a few prospect trenches. The only sulphide mineralization visible on the surface consists of a few specks of chalcopyrite and bornite contained in a 5 - 10 inch-wide cross-cutting pegmatite.

The shaft is located in calc-granulites of the Khan Quartzites and was sunk prior to 1914.

(d) Henderson's and Ehler's Mines

These prospects are located on Naob some 8 miles south-southwest of Usakos.

They were developed in 1914 by the Otavi Minen und Eisenbahn Gesellschaft (O.M.E.G.) in search of pyrite for fluxing purposes. A shaft was sunk to the 4th level (depth unknown).

Mineralization occurs within sahlite-bearing pegmatites (aplite at Ehler's Mine) situated in hornblende schist and calc-silicate rocks at the top of the Quartzite Series. 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. A description of the mine is given by Brinkmann (1924). It has also been referred to by Rimann (1914) and Berg (1942).

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(e) Ubib Mine and Associated Prospects in Abbabis Rocks

At Ubib Mine on Naob, and immediately north of the Klein Chuos Berge, copper mineralization occurs in both biotite schists and quartzo-felspathic gneisses belonging to the Abbabis System.

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.

(f) 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.

(g) Gamikaubmund Prospect

This occurrence is located immediately to the northeast of the Gamikaub-Swakop confluence on Ukuib. The mineralized zone is associated with felspathic quartzite beds intercalated in highly folded biotite schists of the Khomas Schist 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.

(h) 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 pegmatites and, like those described above, are of little economic importance for this reason.

The pegmatites containing mineralization 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 mineralization was encountered both in the marbles and in the intercalated schists.

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 Quartzite Series. In view of this,particular attention should be paid to this, as well as to the Lower Marble horizon,when prospecting for copper in the Damara System.

D. GOLD

Gold prospects occur at several places in the Chuos Mountains. The most important of these is the Sphinx Mine which is located on the crest of the ridge close to the Nordenburg-Bergrus farm boundary. Small amounts of gold were recovered from a mineralized quartz vein. No record of the amount recovered 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 farm.

E. GRAPHITE

Graphite is of little economic importance. No known prospects of this mineral occur in the region considered. Graphite is, however, present in quantity in some of the marbles. Some specimens contain up to 10% of this mineral, but large zones containing consistent values have not been observed.

F. GYPSUM

Gypsum occurs in many areas near the coast where it is intercalated with superficial calcrete deposits. The concentrations are likely to contain other salts. To date none of these occurrences has been worked.

G. 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 two miles to the southeast of Usakos. Mineralization occurs in a distinct stratigraphic zone in the Upper Marble Series a short distance above the contact with the amphibolite facies of the Quartzite Series. The outcrop is high up on the slope of the prominent dark hills overlooking Usakos.

The prospect has been extensively explored and has in the post produced some 22,500 tons of ore from which 116 tons of Pb, and 227 tons Zn were concentrated at a plant located on the outskirts of Usakos. The mining venture, however, ended in failure due to lack of ore tonnage.

The Namib Lead Mine, located a few miles to the northwest of Rössing Mountain, is not included in the region mapped. It is situated in the Upper Marble Series and is apparently a hydrothermal type deposit containing galena, cerrusite, vanadinite, descloisite and numbers of other associated minerals. Several more weakly mineralized zones in the same general stratigraphic horizon occur in the vicinity.

Disseminated galena also occurs in the Upper Marble Series on Navachab close to the contact with the Abbabis Gneiss. The extent of the mineralization is apparently small. It has not been prospected.

H. LIMESTONE

The bulk of the Marble Series, widely developed, throughout the region, is composed of dolomitic marble. Calcite zones do, however, occur and have been prospected. One prospect near Karibib and another on the Swakop River, just outside Swakopmund, have been proved to be exploitable.

I. MARBLE

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

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Present day production, largely from quarries located immediately to the north of Karibib, is small. Production in 1960 amounted to 170 tons.

J. 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 amphibolite schists situated within and beneath the Lower and Upper Marble Series. Books of mica up to 18 inches across are sometimes developed in moderate quantities.

K. MONAZITE

Monazite containing a high thorium content (as determined by high radiometric assay and low U_3O_8 value), occurs in pegmatites at Louw's Claims. Mineralized zones are extremely patchy and of little economic interest.

An interesting monazite deposit was discovered on the farm Eureka in 1959. The deposit occurs in the Upper Marble Series which is covered to a large extent by surface limestone. Monazite occurs as euhedral crystals, up to 4 inches across, disseminated in a marble host. Grab samples, weighing between 3 and 10 lbs., contain up to 75% by volume of monazite. The occurrence, where opened up in an open pit about 20 feet wide and 5 feet deep, is extremely rich.

A specimen analysed as follows (Von Knorring and Clifford, 1961):

SiO_2	0.13%
ThO_2	0.70%
Ce_2O_3	33.65%
La_2O_3	23.00%
Nd_2O_3	10.00%
R_2O_3	2.18%
P_2O_5	30.10%
TOTAL	99.76%

L. PEGMATITES

(a) Distribution

The major lithium-beryllium mineralized pegmatites occur in the eastern areas of the regional map. The most important bodies are listed in Table 12 which shows that the majority are contained in the Upper Marble Series. There is no distinct zonal distribution of these pegmatites, they occur both in metasediments and in igneous types.

(b) 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).

(c) Origin

The fact that the mineralized 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). They are related to a period of granitization resulting in the production of granitic and dioritic magmas which occur extensively in the environment in which the pegmatites are found. The fact that the majority of the lithium-beryllium pegmatites occur in the Upper Marble Series is probably due to the damming effect of this group on volatiles. The rocks of the Upper Marble Series also created structural traps for pegmatitic melts in tension zones.

(d) Mines and Production

The most important mines, both past and present, are listed in Table 12. Of these the Helikon and Rubicon are by far the most important and account for the bulk of the South West African lithium, beryllium and bismuth production.

Name of Pegmatite	Locality	Stratigraphic Position	Minerals Exploited
Dernberg o	Navachab	Chuos Quartzite	amb, lep, be, ta
Macdonald's +	Etusis	Up. Marble Series	amb, pet, lep, be, bi
Fricker's +	Okatjimukuju	Up. Marble Series	ta, be, pet
Karlsbrunn +	Koliombo	Up. Marble Series	lep, amb, pet, be, co
Brockmann's o	Koliombo	Up. Marble Series	lep, amb, co, be
Berger's +	Koliombo	Up. Marble Series	lep, amb, co, be
Helikon I and II *	Okongava Ost	Up. Marble Series	lep, amb, pet, be, co
Rubicon *	Okongava Ost	Khomas Schist	lep, amb, pet, bi, be co
Becker's +	Otjua	Up. Marble Series	lep, to, be
Brockmann's *	Gamikaubmund	Chuos Quartzite	be, co, ta

Table 12: The major lithium-beryllium pegmatites of the Karibib District.

amb	=	amblygonite	ta	=	tantalite
pet	=	petalite	co	=	columbite
lep	=	lepidolite	to	=	tourmaline
be	=	beryl	bi	=	bismuth

* large producer + small producer o production ceased

Production statistics for individual mining ventures for 1957 - 1959 are given in Table 13. The approximate monthly tonnages of ores produced in 1956 from Helikon and Rubicon are as follows:

Lepidolite	(3 - 3.6% Li)	100 tons
Amblygonite	(6 - 8% Li)	60 - 100 tons
Petalite	(3 - 4% Li)	400 - 500 tons
Beryl		20 - 25 tons
Columbite		½ ton

These figures vary considerably depending on both production and marketing. Mineral production figures for the territory of South West Africa from January to December 1960 showed the following:

Amblygonite	161 tons
Lepidolite	972 tons
Petalite	3,909 tons
Beryl	413 tons
Bismuth	1,048 lbs.

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

Producer	Petalite tons	Lepido-lite tons	Tanta-lite lbs.	Colum-bite lbs.	Beryl Tons	Ambly-gonite tons	Tourma-line gm	Bismuth lbs.
Helikon I and II, Rubicon, Karlsbrunn	3,966	1,317		1,107	74	93		1,223
Brockmann's : Koliombo, Gamikaubmund, Donkerhuk.	15	5	169	417	19	3		
Berger's : Koliombo, Neu Schwaben.	80		33	83	2		2,333	
Durnburg			53		12	12	2,663	
Becker's : Otjua		8					266	

Table 13: Mineral production averages for 1957 - 59

(e) Reserves

There are 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. Other large pegmatites, containing fairly evenly disseminated beryl have been reported, but not investigated.

M. SALT

With the vast salt deposits occurring along the coast northwest of Swakopmund, the rock salt occurrences within the lime-cemented Tertiary sediments near Goanikontes are of no economic interest.

N. SEMI-PRECIOUS STONES

A small trade in semi-precious 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 produced green beryl, aquamarine and heliodore (Wagner, 1916) 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 (Herring's Claims) and on Becker's Claims at Otjua, as well as at several other places of lesser importance.

Aquamarine of gem quality is also occasionally found.

O. TIN

Very little tin is produced from this region. Various tin claims exist, largely on pegmatites situated in the Khomas Schist 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) in the late 1920's and 30'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) to be of hydrothermal origin. The mine is located some 20 miles north of Arandis in highly

folded Upper Marble Series and has been described by Gevers (1929) and Ramdohr (1935). An unusual mineral, arandisite (tin silicate) is present (Partridge, 1929).

P. URANIUM

The discovery of davidite in the 1920's on Louw's Claims near Rössing eventually led to the prospecting for radioactive minerals in 1955 - 1958. The search revealed a large number of uraniferous zones, most of which are associated with pegmatites situated in the Lower Marble Series.

The largest concentration is located on the S.J. Claims which were prospected by diamond drilling, trenching and 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 schists and biotite quartzites intercalated in highly folded Lower Marble Series in the Dome Synclinorium. The 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 lbs. per ton were obtained at the S. J. and Louw's Claims but zones containing such high values are extremely patchy. Large volumes (several million tons) of low grade (1 lb. per ton) ore were proved at the S.J. Claims, but were deemed to be unpayable.

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

The mineralization in the region mapped, as already mentioned, 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 recrystallized 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 Schist Series is only preserved in the deeper synclines and large areas of Marble Series and underlying rocks are exposed. In regions to the north and south the lower stratigraphic levels are often poorly exposed and granites are 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 pegmatites occur in the Upper Marble Series it is felt that the material from which they are composed is not derived from the nearly pure carbonate marbles, but was introduced into structural traps within them, as well as within other strata, from underlying granitized and mobilised metasediments. Roering (1961) has suggested that lithium and beryllium are likely to have been derived from rocks which were originally marine shales, i.e. the Khomas Schists. This seems unlikely, however, since so many of the lithium- and beryl-bearing pegmatites occur both structurally and stratigraphically below this horizon (see Table 12), where there are only minor biotite schist intercalations.

Tin (cassiterite) pegmatites are almost exclusively restricted to the Khomas Schist horizon. This is indicative of an originally high trace content of this element in the schists (possibly contained in biotite), and of subsequent concentration by granitization processes into pegmatites within this horizon.

Tantalite and/or columbite occur in pegmatites in all horizons. No distinct preference for any one horizon is apparent.

Copper occurrences are widespread within the Damara-Otavi-Nama System. In the region mapped they are mainly limited to the upper zones of the Quartzite Series. Those occurring south of Windhoek are apparently confined to similar stratigraphic horizons. No documentation of the position of all these deposits has been made, however. The stratigraphic control on copper mineralization suggests that it was introduced during the sedimentation of the Upper Quartzite Series in the Damara, and of the Otavi Dolomites in the Otavi. There are some 290 copper showings mainly in dolomites in the Otavi Mountainland (Söhnge, 1958).

The contention of original sedimentary control of copper mineralization, in the region mapped, is strongly supported by the distribution of uranium mineralization in dominantly metasomatic-type pegmatites, confined almost exclusively to the Lower Marble Series in a highly folded region in the Lower Khan Gorge. The Khan Mine pegmatite mineral assemblage, as well as of many other copper-bearing pegmatites, is also indicative of a partly metasomatic origin (Söhnge, 1939)

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Lead and zinc are found only in the Upper Marble Series in this region. At the Usakos Lead Mine, these metals are restricted to a definite stratigraphic horizon within the Marbles. The hydrothermal type deposit at Namib Lead Mines may be a reconcentration of original sedimentary material.

The relation between stratigraphy and mineralization in the Damara-Otavi-Nama 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 lithology to the Damara System.

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EXPLANATION OF FIGURES

Fig. 1 : (a) quartz - K-felspar - plagioclase plot of volumetric analysis of igneous rocks of autochthonous character.

(b) quartz - total felspar - biotite and hornblende plot of volumetric analysis of igneous rocks of autochthonous character.

(c) quartz - albite - anorthite plot of volumetric analysis of igneous rocks of autochthonous character.

Fig. 2 : quartz - K-felspar - plagioclase plot of volumetric analysis of gneisses underlying the Marble Series in the eastern and western portions of the area.

Fig. 3 : (a) quartz - K-felspar - plagioclase plot of volumetric analysis of granites and pegmatites showing intrusive relationships.

(b) quartz - total felspar - biotite and hornblende plot of volumetric analysis of granites and pegmatites showing intrusive relationships.

(c) quartz - albite - anorthite plot of volumetric analysis of granites and pegmatites showing intrusive relationships.

Fig. 4 : (a) quartz - K-felspar - plagioclase plot of volumetric analysis of igneous rocks of autochthonous character with norm of Khomas Schist.

(b) quartz - total felspar - biotite and hornblende plot of volumetric analysis of igneous rocks of autochthonous character with norm of Khomas Schist.

(c) quartz - albite - anorthite plot of volumetric analysis of igneous rocks of autochthonous character with norm of Khomas Schist.

Fig. 5 : Lineations formed by boudinage structure.

Fig. 6 : Lower hemisphere equal-area plot of the structural elements of the Zeta and Blauer Berg (fold 2) folds:

A_2 = axis about which the axial-plane of the first fold was folded

L_1 = a position of the first fold axis

L_2 (a) = lineation maxima on normal limb of Zeta fold

L_2 (b) = lineation maxima on overturned limb of Zeta fold

Fig. 7 : Lower hemisphere stereogram showing a plot of the major elements of the Karub Syncline

(x) = pole to axial plane of fold 1 after unfolding.

Fig. 8 : Lower hemisphere stereogram showing the elements of the Zeta and Blauer Berg folds plotted together with those of the Karub Syncline. The co-axial axis of the Karub Syncline lies very close to the axis of the Blauer Berg fold. The Zeta and Karub axial-planes are nearly parallel.

Fig. 9 : Diagrammatic representation of attitude of Karub Syncline to axial-plane and tectonic axis of second fold.

Fig. 10 : Lower hemisphere stereogram showing plots of the major elements of the Welwitsch Syncline (fold 1) and the Blauer Heinrich Syncline (fold 2)

x = pi poles of overturned limb • = pi poles of normal limb.

Fig. 11 : Lower hemisphere stereogram showing the coincidence of the major axial-plane orientations of the Karub Gorge and Khan Mine sub-areas.

Fig. 12 : Simplified diagram illustrating the co-axial nature of the refolding of the Welwitsch and Nose Structure folds, and the orientation of the tectonic axes of the second folds.

Fig. 13 : Lower hemisphere equal-area plot showing the major orientation of minor fold axes in the synclinorium (contours at 2 point intervals).

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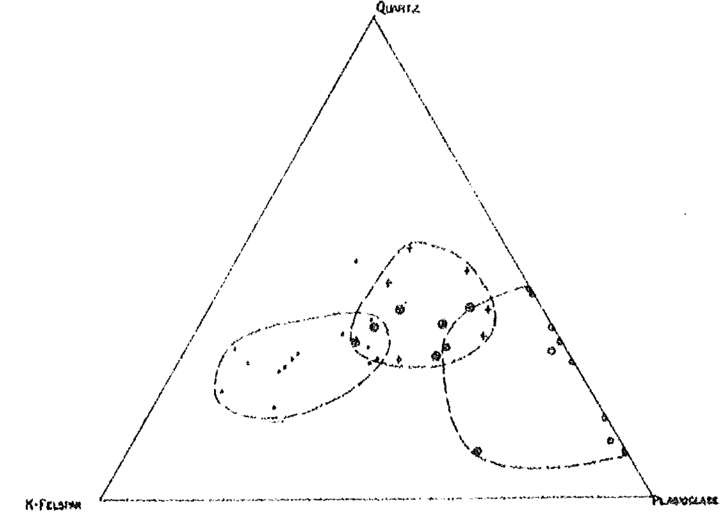


Fig. 1 A

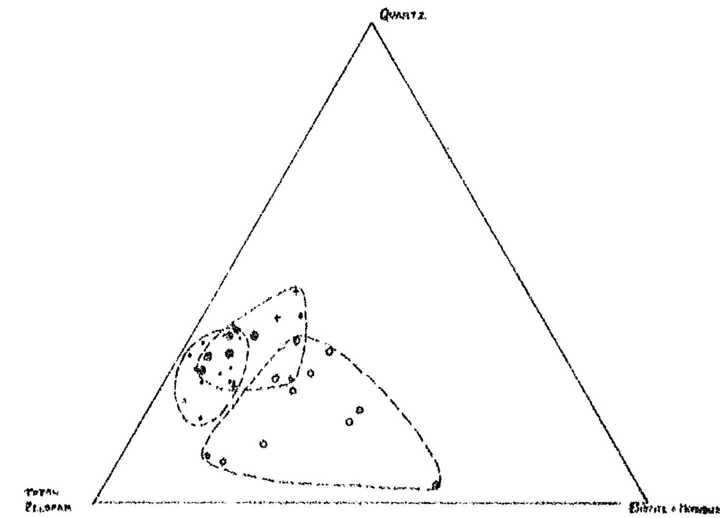
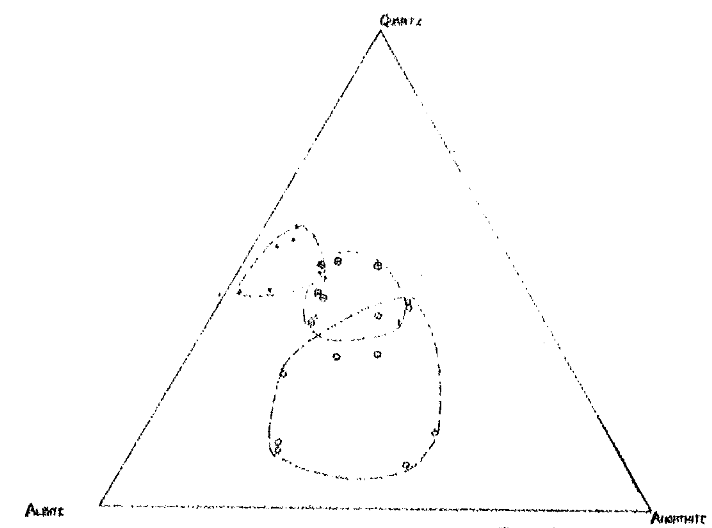


Fig. 1 B



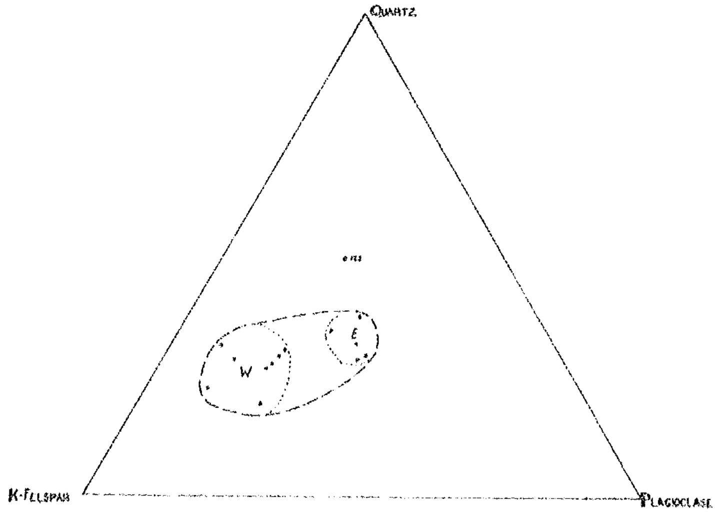


Fig. 2

KEY TO SYMBOLS USED IN FIGS 1-4

- ∘ red gneissic granites underlying Marble Series (in Quartzite Series horizon)
- ⊕ Salem granite overlying Marble Series (in Khomas Schist horizon)
- + Salem gneiss overlying Marble Series (in Khomas Schist horizon)
- ⊙ quartz dioritic rocks overlying Marble Series (in Khomas Schist horizon)
- Salem-type granite in Chuos Quartzite
- pegmatitic granite in Khomas Schist
- pegmatite in Khomas Schist
- pegmatite in Marble Series
- derived from norm of Khomas Schist channel sample SM 218

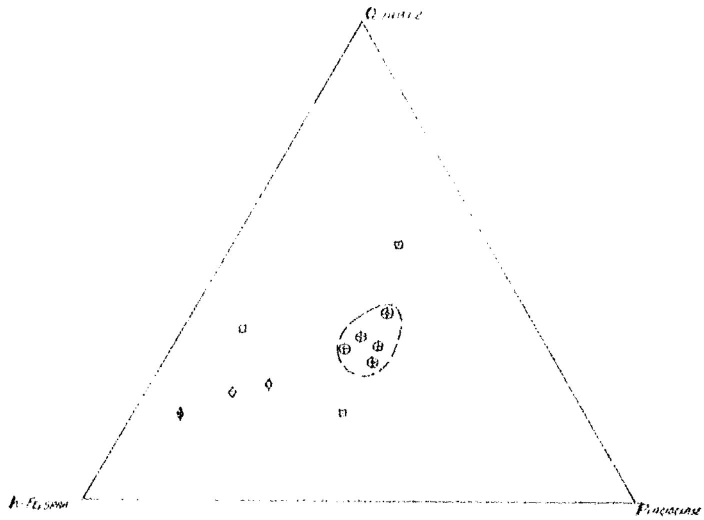


Fig. 3A

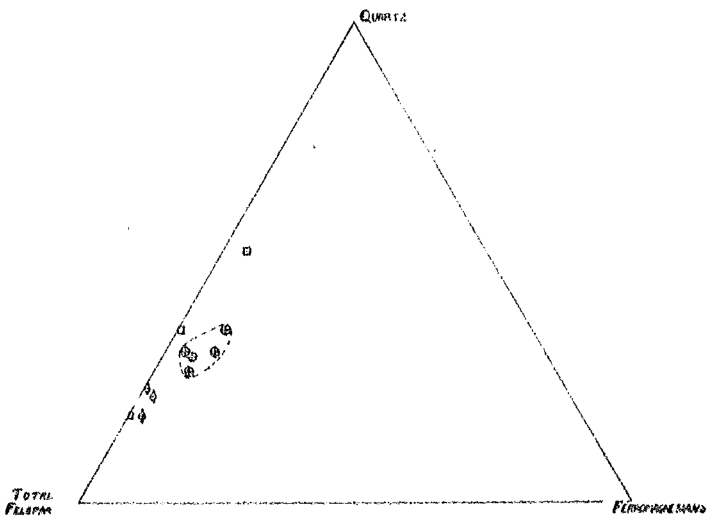
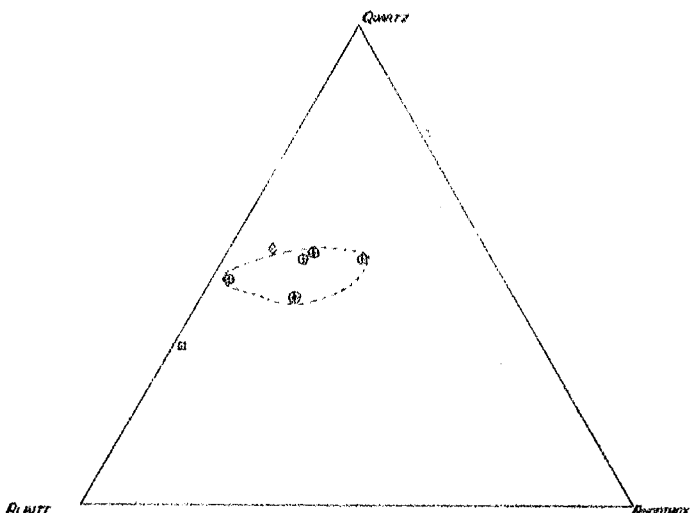
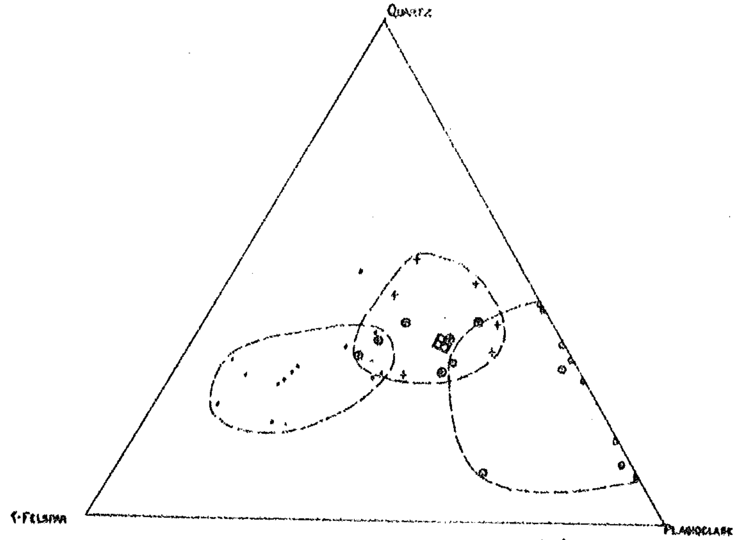
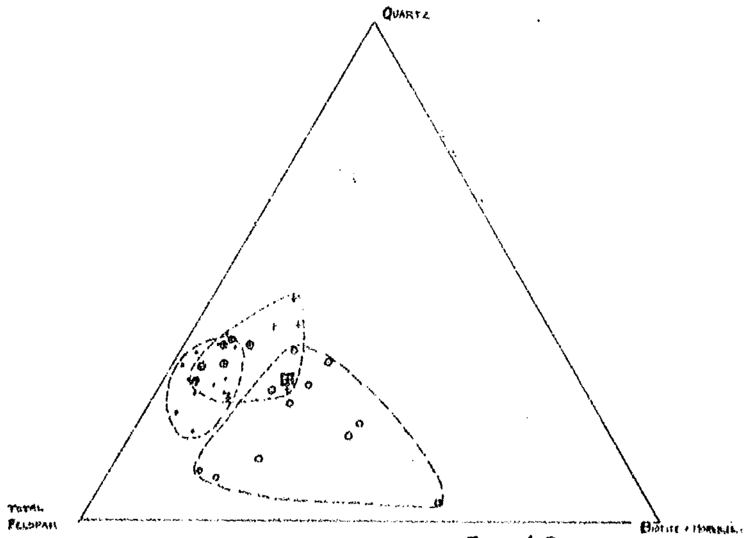
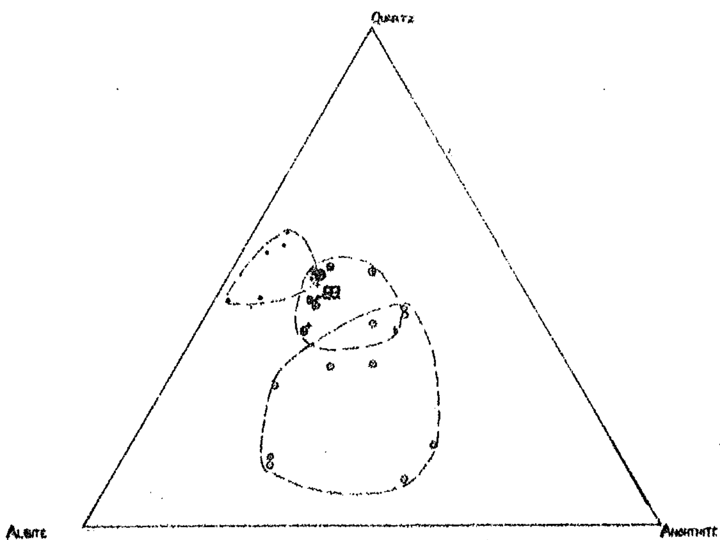


Fig. 3 B




Quartz
K-Felspar
Plagioclase
Fig. 4A


Quartz
Total Felspar
Fig. 4B


Quartz
Albite
Anorthite

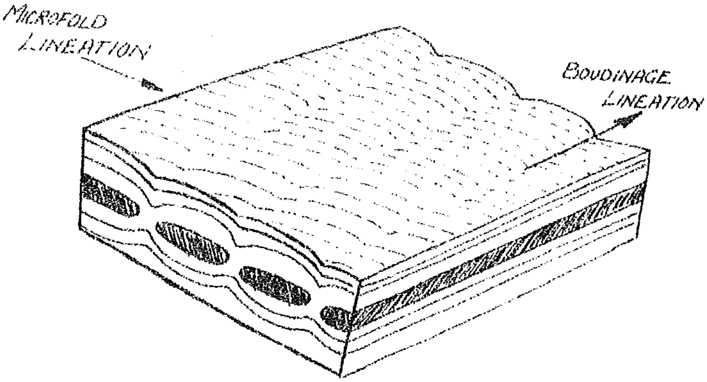


Fig.5

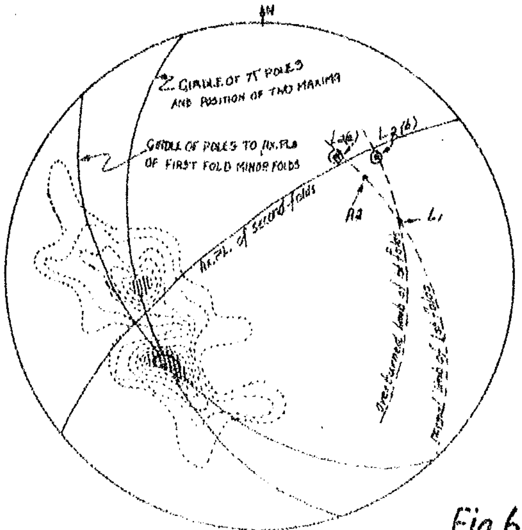


Fig.6

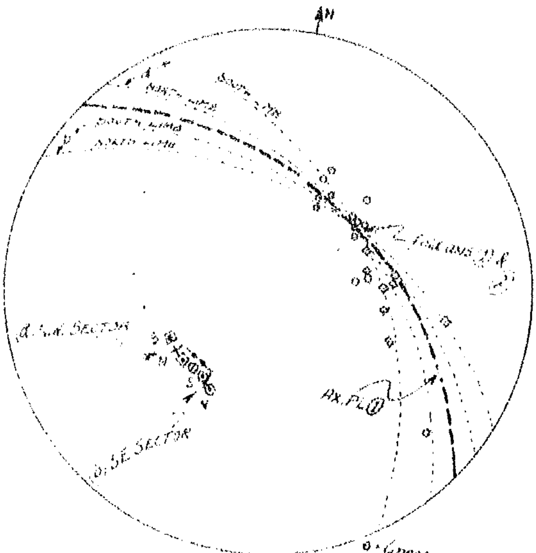


Fig.7

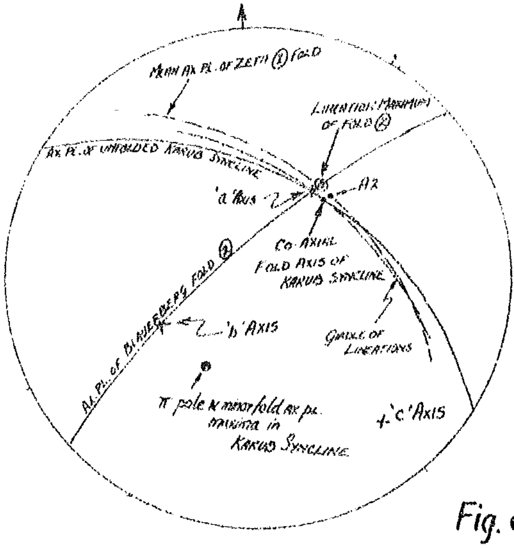


Fig. 8

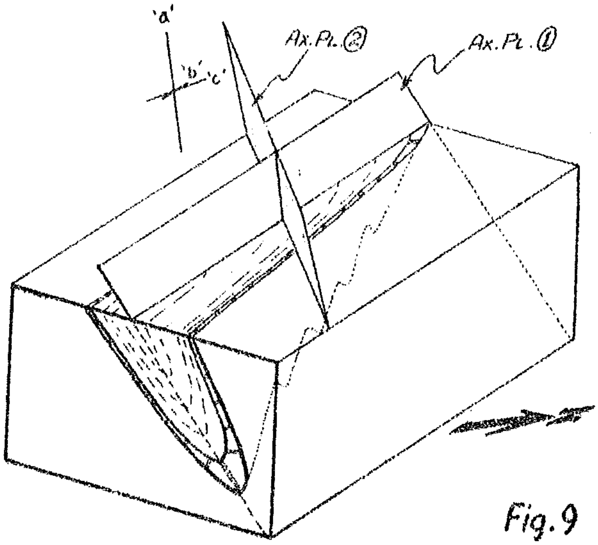


Fig. 9

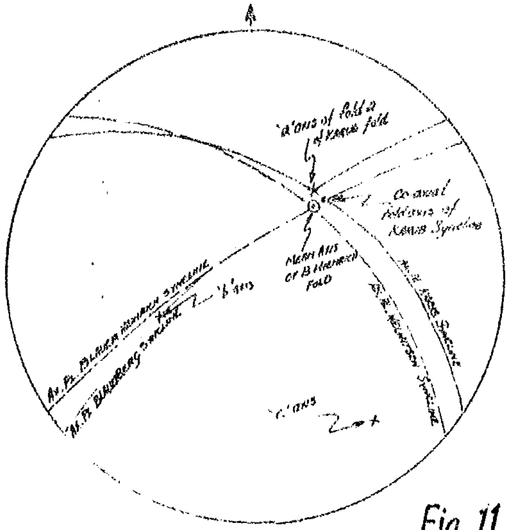


Fig. 11

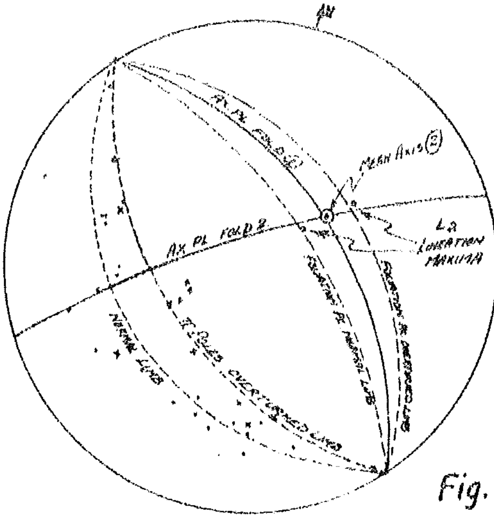


Fig. 10

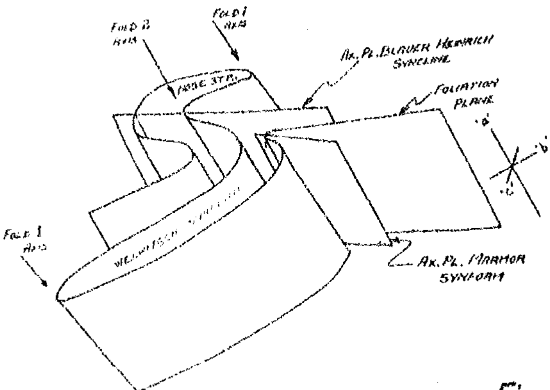


Fig. 12

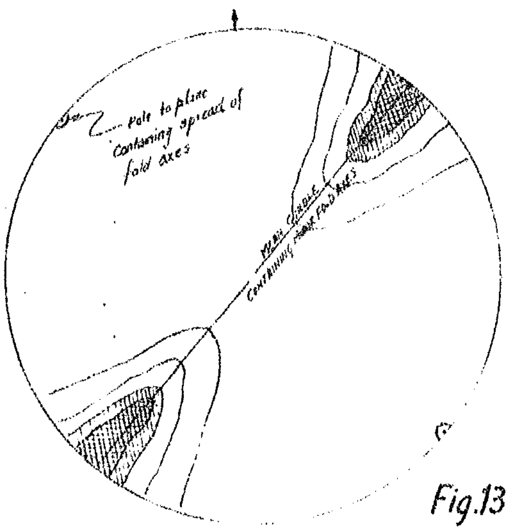


Fig. 13