THE GEOLOGY OF A PORTION OF THE COUNTRY BETWEEN WITVLEI AND OMITARA, SOUTH WEST AFRICA

by

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A B S T R A C T

A brief account of the location and physical aspects of the region is followed by descriptions of mapping and laboratory techniques employed. Recent ideas on regional stratigraphical correlation in South West Africa are critically reviewed.

Strata lying southeast of the farm Losberg 105 have, on the basis of lithology and copper mineralisation, been correlated with the Tsumis Formation. The Nosib Formation, of predominantly marine character, has on structural grounds been excluded from the Damara System. The latter here has a greater thickness than elsewhere in South West Africa, unless isoclinal folding is much more prevalent than has been assumed.

The occurrence on Eintracht 118 of a pebble conglomerate, tentatively equated with the Chuos Tillite, makes possible a subdivision of the Damara strata into the various series established in the literature.

It has been found possible to differentiate between Kamtsas and Damara quartzites on petrological grounds. Further, it is concluded that the bulk of Hakos carbonate rocks originated as dolomites and have subsequently been dedolomitized to a greater or lesser extent.

The area contains both ortho- and para-amphibolites, as well as one occurrence of intrusive granite.

Evidence is given for at least three periods of deformation. It is considered that, if the Nosib Formation was involved in a pre-Damara orogenic episode, later folding must have been co-axial with this.

Sedimentation and metamorphism are treated in broad outline. There appears to have been a deepening

of the basin of deposition from Nosib to Damara times. Cyclicity in sedimentation is evidenced by lithological associations in the Damara strata. The entire area falls into the greenschist facies of regional metamorphism.

Superficial deposits include river gravel and silt, quartzite- and vein quartz-rubble, calcrete and Kalahari sand.

The economic geology is described with special reference to the widespread copper mineralisation.

I. INTRODUCTION

The country described in this account covers an area of some 900 square kilometres, and is situated astride the White Nossob River, with its centre lying approximately 140 km. east of Windhoek (see Map 1 at the end of this report). Stretching from 4 km. east of Omitara to 17 km. west of Witvlei, the area has the following approximate boundaries:

18^{o} 02' and 18^{o} 20' east longitude

22^{o} 15' and 22' 32' south latitude.

The gravelled main road from Windhoek to Gobabis crosses the area in an east-west direction, and follows the left bank of the Nossob, as does the railway line connecting these towns. At present a new tarmac road linking Gobabis and Windhoek is under construction, and the proposed route is indicated on Map 2. A secondary road, connecting Omitara with Nina and Leonardville further down the Nossob, crosses the southwestern portion of the area, access to the remainder of which is by means of farm tracks of variable quality. Drifts through the Nossob are generally sandy, and become impassable when the river comes down in flood every three to four years.

Owing to the aridity of the country the White Nossob River, with its then plentiful supply of underground water, attracted the attention of the early German settlers. Hence, it is from the period 1904-1914 that most of the "Nossob farms" may be said to date, having been acquired principally by former soldiers of the Schutztruppe. Land further removed from the river was developed somewhat later.

Farming is the sole occupation of the population, the emphasis being on cattle ranching. Crops such as maize and beans are grown on a limited scale in good rainy seasons to provide supplementary fodder. Witvlei and Omitara, both situated on the main road and railway, and lying respectively east and west of the area mapped, are the centres for the farming communities. Both centres have a European population numbering only a few dozen, but do offer essential services.

Until recently, the only evidence of prospecting to be found in the area consisted of several old trenches. These are concentrated especially on the farm Goldene Aue 106, and date from the period between the two world wars. They were dug in search of gold, to which end also at least one diamond drill hole was put down on Astra 205 during the same period. Activity ceased until 1968, when two South African mining houses took out large concessions with a view to prospecting for copper. These activities are still continuing at the present time, and it was while he was in charge of an exploration programme in the area, during the period 1969-1970, that the author was able to carry out the mapping which forms the subject of this report.

Climatically, the Nossob valley shows extremes. Day temperatures during the period October-February are normally in excess of 35°C, while the winter average lies around 28°C. During June-July the nights are generally well below freezing, a temperature of -16°C having been recorded in 1968. Precipitation is erratic and unreliable. The "small rains" in September usually yield negligible amounts. The main rainy season commences in November, and lasts until March, with January being a dry month. An annual average for the area is 300 millimetres.

II. PHYSICAL FEATURES

TOPOGRAPHY

Broadly, the region consists of a gently undulating surface, sloping eastwards and lying between the 1500 and 1550 metre altitude contours. Rising out of these plains are "inselberge" and isolated ranges that in places reach absolute altitudes of over 1700 metres. This portion of the country may thus be considered to represent part of a transition zone between the relatively broken country that slopes down from the Auas Mountains and the Neudammer Hochland, east of Windhoek, and the monotonous plains that stretch across into South West Africa from the Kalahari Basin of Botswana. The highest point in the area is the peak of Kuduberg on Joachimstal 107, at an altitude of 1748 metres, while the lowest point is in the bed of the White Nossob River where it leaves the area mapped at a height of 1470 metres. The total relief of 280 metres is thus not inconsiderable.

The alternation of bands of hard and soft rock has had a decisive influence on the topography of the area, rolling grasslands underlain by soft schists being interspersed with sharp quartzite ranges and isolated hills that rise steeply from the plains. A prominent feature of relief is the line of hills that traverses the centre of the mapped area in a NE-SW direction, forming the approximate southeastern boundary of the Damara System. The range, commencing at the southern boundary of Ottawa 150, gradually increases in height towards the southwest. It reaches 1609 metres in the Rotberg on Otjiwarumendu 119, and 1704 metres in the Otjiwarumenduberg, which rises some 200 metres above the plain on Losberg 105.

Plate 1. View from the Vierkuppenberg across the valley of the White Nossob River to the Otjiwarumenduberg. The Weissberg is in the central background.

Plate II. "Parkland" vegetation - Stipogrostis grass and Acacia giraffiae trees on Goldene Aue 106. The Kuduberg-Omatewaberg massif is seen in the background.

From there the range continues, at a height of some 100 metres above the surrounding country, as far as Locarno 211.

Some 3-4 kilometres north of the above range are two further bands of quartzite that manifest themselves in isolated hills. These peaks, such as the Okaheberg on Losberg 105 and the Loskop on Dorka 206, lie at an average elevation of 1650 metres. The dominant feature of the area, especially when viewed from the southwest, is the Kuduberg-Omatewaberg massif, an eroded anticline now bisected by the White Nossob River. North of the river a band of Hakos dolomite locally reaches prominence in the Vierkuppenberg range on Eintracht 118, while quartzite is again responsible for the peculiar cone of the Hutberg, immediately north of the main road on Diana 117. In the extreme north of the area mapped only the granitic cupolas of the Dachsberge rise above the edge of the sandveld on Sandflats 123.

DRAINAGE

Owing to the arid climate, there is no permanent open water anywhere in the region. The chief drainage feature is the wide shallow valley of the White Nossob River, which traverses the country in a direction just south of east. When the first settlers arrived at the turn of the century, the local water table was less than a metre below the surface of the river bed. Depletion by pumping has dropped this level by some 20-30 metres in most areas of the valley. Running parallel to and some 12 km. north of the White Nossob is a prominent vlei, or "omuramba", that eventually forms the river on Grünental 151, just west of Witvlei.

Away from these two features, local runoff usually ends in the numerous small pans and depressions that dot the plains.

The regional drainage is at right angles to the topographical and geological grain of the country. River erosion has kept pace with uplift, as evidenced by the valley cut by the Nossob right through the flat-lying resistant quartzite of the Omatewaberg-Kuduberg anticline. Neither this, nor any of the other resistant bands, has had any influence on the direction of the drainage, which must thus be regarded as superposed.

The pronounced meanders of the river indicate that an advanced stage of maturity was attained. A subsequent period of uplift, evidenced by the general rise in summit levels of the hills towards the southwest, caused renewed downcutting to take place. The desiccation of the climate resulted in decreased runoff and this, coupled with the reattained maturity of the river, led to the incised meanders being filled with sediment to their present level.

VEGETATION

The vegetation of the area is varied, and reflects to a large extent the underlying rock types.

In the southwest and extreme northeast of the region mapped, a fairly thick cover of Kalahari sand masks the geology, the surface consisting of gently rolling plains with a good grass cover. The genera *Stipogrostis* and *Eragrostis* predominate, the former being the chief source of cattle fodder. The "steekgras" (*Aristida congesta*) is developed locally. The "inselberge" dotted over the plains, usually consisting of quartzites or dolomites carry a dense growth of "hakiesbos", the _Acacia melifera_. On the dolomite ridges aloes are commonly found.

On approaching the Nossob valley, the sand cover decreases in thickness and outcrops become more frequent. The grasslands go over into parkland featuring the shrub _Acacia hebeclada_ and the trees _A. hereroensis_, _A. melifera_ and _A.giraffiae_, the camelthorn. This latter is common in areas of deep sand cover, and was observed to show a marked preference for bands of Hakos dolomite where these are obscured by the sand. This feature was used extensively in the photogeological mapping of the region.

On the fossil dunes developed on the northern slopes of the quartzite ridges, trees of the genera _Tarchonanthus_ and _Terminalia_ are found. The Kamtsas quartzite ranges are clothed in _Albizzia anthelmintica_ on their slopes, the crests being covered by _Combretum apiculatum_ and _Dichrostachus_. The lower bands of Damara quartzite, forming the Okaheberg on Losberg 105 and the Loskop on Dorka 206, carry a good growth of aloes, as do the overlying Hakos dolomites.

Areas of more plentiful ground water supply, such as fault zones and pans, usually carry thickets of "_haak en steek_", the _Ziziphus mucronata_. The shrub _Catophractes alexandrii_, the "gabbabos" of the farmers, shows a preference for areas underlain by calcrete or calcareous rocks, and was accordingly also used for mapping purposes.

Finally, the banks of the Nossob river are characterised by thick stands of the "soetdoring" tree, _Acacia karoo_.

III. PREVIOUS GEOLOGICAL WORK

There are no published maps or accounts of any geological investigations undertaken in the region under consideration.

Korn and Martin paid reconnaissance visits to the area in 1939, and worked intermittently in it from 1943 onwards, mainly in order to locate new ground water supplies for the farming sector. No mapping was carried out by them.

According to K. Seeger (personal communication), geologists of Bethlehem Exploration and Mining Company mapped the area between Witvlei and Omitara during the period 1952-53, with the object of locating economic deposits of iron ore. A reconnaissance map on a scale of 1:100,000 was prepared. This was, however, not available to the present author.

Systematic mapping of the region between Rehoboth and Dordabis, covering the areas underlain by rocks of the Marienhof and Tsumis Formations, and the Dordabis and Damara Systems, was undertaken for the South West African Geological Survey by Schalk in the period 1959-1964. His map, on a scale of 1:100,000, was followed by a detailed report written in 1966/67; to date neither work has been published.

This mapping was continued in a northeasterly direction from Dordabis as far as the farms Locarno 211 and Koko 212 by Seeger in the period 1966-68, and thus impinges on the area presently being considered. Again, the map has not been published, and there is as yet no report to accompany it.

In 1967 Seeger and Schalk compiled a reconnaissance map, also on a scale of 1:100,000, of the country between the farm Losberg 105 and the town of Witvlei. Distribution of this map was restricted to one mining company working in the area.

The only other map of the general area is one compiled by the above authors early in 1969, covering a narrow strip of country south of the White Nossob River between Seeis and Witvlei. This map, on a scale of 1:100,000, presents a broad outline of the regional geology, and was prepared as a result of investigations into the ground water supplies that could possibly be utilised in the construction of the new Windhoek-Gobabis road; it is again not available in published form.

Detailed mapping of the area around Losberg 105 on a scale of 1:20,000 was carried out for Anglovaal South West Africa (Pty) Limited by the present author in 1969-70. The adjacent territory to the east and north, held under concession by Fedswa Prospekteerders (Edms) Bpk, was mapped on the same scale by geologists of that firm during the period 1968-70.

IV. FIELD WORK AND COMPILATION OF MAPS

Regional mapping of the area held under concession by Anglovaal S.W.A. (Pty) Limited, consisting of the four farms Losberg 105, Goldene Aue 106, Astra 205 and Dorka 206, was started by the author in June 1969. Owing to the pressure of other prospecting work such as soil sampling, trenching and wagon-drilling, only three of these farms had been mapped on a scale of 1:20,000 by the end of the year. However, during this period, two areas showing copper mineralisation were geologically surveyed on a scale of 1:1,000. Map 3, covering one of these prospects, which is situated in the extreme eastern corner of Goldene Aue 106, is included in this work.

The remaining farm in the concession, Astra 205, was mapped in January 1970. It was by then appreciated that a fuller understanding of the geology and structure of the region would be obtained only if the mapping were continued beyond the boundaries of the concession, and this was done during the period February-April 1970.

Aerial photographs, taken in 1958 as part of Job 294, on a scale of approximately 1:36,000, were available for the concession area, and for the country extending northwards beyond Sandflats 123. For the farms Joachimstal 107, Büschow 108 and Omatewa 113, the farmer kindly supplied a mosaic compiled from photographs on a scale of 1:25,000. At the end of 1969, enlargements of the photographs covering the concession, on a scale of approximately 1:12,000 became available. These were not extensively used, since their size of approximately 70 x 70 cm. made them difficult to handle in the field, especially on windy days.

REGIONAL MAPPING

Generally, mapping was done by recording all data directly on the photographs by means of pencil or Rapidograph pen. The information was subsequently transferred to the working plan using proportional dividers and scale rulers. Until a working plan on a scale of 1:20,000 for the whole area had been compiled, a copy of Seeger's 1:100,000 Seeis-Witvlei map was used. The widespread cover of Kalahari sand hampered field mapping considerably and much use was made of a "Casella" pocket stereoscope in producing a photogeological compilation of such areas. As already mentioned in Chapter II, the Hakos Dolomite bands could be traced easily by means of the darker tone produced on the photographs by the belts of camelthorn trees commonly growing on these bands. Elsewhere, despite the poor quality of the photographs, stereoscopic examination often yielded information that would have been unobtainable in the field, and provided many clues to the structure. In short, it was a valuable aid to the mapping and allowed much ground to be covered in a short space of time. Traverses on foot and by vehicle were undertaken at intervals across the area to check on the validity of the photogeological interpretation.

Despite the fact that the cover of Kalahari sand severely limited the areas of outcrop, it was the author's intention to provide, where possible, an idea of the continuity of the strata. The techniques of photogeological interpretation allowed this to be done with a considerable measure of success, and in many cases helped to elucidate important aspects of the regional structure.

For the southeastern boundary of the Damara System, along the faulted contact with the Tsumis Formation, excellent colour photographs on a scale of 1:20,000, were made available to the author early in 1971. These photographs, taken by the Aircraft Operating Company of Johannesburg for Fedswa Prospekteerders (Edms) Bpk, were found to be far superior to the black and white photographs in that tonal changes were much more marked. An added advantage was that, owing to the correspondence of scales, the geology as interpreted from these photographs could be transferred directly to the transparent master copy of the geological map. The availability of a full stereo cover allowed the elimination of any distortion.

All the field data were plotted, on a scale of 1:20,000 onto two sheets of transparent plastic film on which the regional cadastral grid for the area had been erected. Farm boundary co-ordinates for all the farms concerned were obtained from the office of the Surveyor-General in Windhoek, and were plotted as accurately as possible on the scale used. As already mentioned, transfer of data from photograph to map was by means of scale rulers, proportional dividers, or by straight tracing from the photographs of corresponding scales. The two master sheets thus produced were then photographically reduced to a scale of 1:50,000, and the final map redrawn from this reduction. All the draughting, except for the final master plan made from the photographic reduction, was done by the author, including the large-scale map of the extreme eastern portion of the farm Goldene Aue 106.

DETAILED MAPPING

Mention must be made of the method employed in the production of the detailed map (Map 3) mentioned above.

This is on a scale of 1:1000, representing an area in which copper mineralisation had been found. The region is immediately adjacent to the White Nossob River and consists of slightly dissected country with a total relief of perhaps 15 metres. The vegetation consists of a thin belt of corridor forest along the river, the rest of the area being rather open, covered only by grass and Acacia melifera. The latter here seldom attains heights of more than 1 metre.

The mapping procedure is one successfully used by the Messina (Transvaal) Development Company in the region around Messina, modified but slightly to fit local conditions. A baseline was cut parallel to the strike of the strata and staked at 50-metre intervals along its length. From these stakes lines were led off at right angles, both to the north and south of the baseline, by means of a Brunton compass mounted on a tripod. These lines were not cut open, but were also staked at 50-metre intervals and extended as far as was necessary for mapping. This was done on centimetre graph paper, 1 cm. corresponding to 10 metres on the ground i.e. a scale of 1:1000.

Commencing from the baseline and working outwards along a particular staked line, a tape was stretched along the ground between adjacent stakes. In practice a 100m steel tape was used. All outcrops adjacent to the tape were drawn in on the graph paper as accurately as possible with regard to shape and size. The tape distance between stakes was noted by an assistant reading from the tape; an Ovambo native was successfully used for this task. Distances to either side of the tape were estimated visually. In this way a strip of country 50m wide, i.e. 25m either side of the tape, was mapped with a high degree of accuracy. At the end of the traverse, the mapping was stepped over 50m to the next line of stakes perpendicular to the baseline, and proceeded in the reverse direction back towards the baseline.

The method is as accurate as plane tabling, and much quicker once the stakes have been positioned. The latter step required half a day for the Goldene Aue 106 map. Four-foot steel droppers, bearing metal tags having the distance from the baseline stamped on them, were used to stake the lines; at Messina stone cairns were used. The area covered by Map 3 and measuring approximately 700 x 450 metres was mapped in detail in less than a week; around Messina in the N. Transvaal, where thicker bush and greater differences of relief hampered operations, an area measuring 400 x 1000 feet could be mapped comfortably in a morning.

Each day's mapping was traced directly onto the transparent master plan on which the baseline had been plotted. Correlation and geological interpretation were done once the entire area had been mapped. On prints made from the master copy, the outcrops of any particular rock type were coloured boldly, whilst intervening areas thought to be underlain by the same rocks were coloured in the same tint, only lighter. The end result was a highly factual and extremely accurate "outcrop" map, the corner co-ordinates of which could easily be tied in to the regional grid.

Geological specimens collected in the field were labelled on the spot; back at camp each sample was numbered, and the number and sampling locality were recorded in a book for later reference.

V. LABORATORY METHODS

A total of 138 thin sections were studied under the microscope. Mineralogical compositions were intially estimated visually. Then, for rocks that warranted more detailed study, modal analyses were obtained micrometrically by means of a "Swift" Point Counter, manufactured by Cooke, Troughton and Simms Limited. The lengths of the traverses were at least 200 times greater than the maximum dimension of the largest crystal occurring in the slide. According to Walker and Poldervaart (1949, p. 629) the error inherent in this method is probably not more than 1-2%.

Only specimens 91 and 94 were considered suitable for detailed work on the felspars. By means of a Leitz 4-axis universal stage, compositions of the plagioclases were determined according to the Rittmann zonal method (Chudoba and Kennedy 1933, p. 41). Some amphiboles, as well as a pyroxene of the basic rocks occurring in the area, were investigated. Data obtained from the universal stage were plotted and evaluated on stereograms, using the equal-angle Wulff net. The 2V angle thus obtained, together with the refractive index, allowed the pyroxene composition to be estimated by reference to charts given by Hess (1949, pp 621-666).

Data from several amphiboles are presented. In view of the statements by Deer et al (1963, Vol. 2, p. 295) concerning the poor correlation of optical properties with chemical composition, the interpretation of these results is in broad terms only. For most refractive index determinations, no attempt was made to extract the mineral from the specimen. A crush of a small portion of the rock was normally found to be adequate. Standard immersion methods, using sodium light, were employed. The indices of the oils were checked after each determination on a Leitz-Jelley microrefractometer. The accuracy of the method is considered to be approximately .002.

In view of the difficulty of differentiating between calcite and dolomite under the microscope, most thin sections of the carbonate rocks investigated were subjected to a staining technique described by Toens (1966). In the present investigation a dye, originally described by Mitchell in 1956, was used very successfully. Toens (p. 6) states:

> "The solution lasts indefinitely and within reasonable limits can be used over and over again. It consists of a solution containing 0.1% of sodium alizarin sulphonate in N/15 HCI. The procedure is as follows: An uncovered slice or hand-specimen is immersed in the solution at a temperature of 40°C for 30 seconds. After this time those portions consisting of calcite are stained a deep red. Immediately on removal from the solution the specimen, or slice, should be washed gently in distilled water and after allowing to dry for a day or two the thin section can be covered in the normal way. Better preservation of the stained portion is, however, obtained by using liquid paraffin to keep the cover-glass in place."

One mineral in each of specimens 4 and 117 could not be identified by thin-section methods alone. Since the host rocks were limestone and dolomite respectively, fragments of these were dissolved in HCI; the insoluble residues contained, besides quartz and a few other impurities, the unknown minerals. Refractive-index determinations were carried out on these and then, since there was still doubt about their identity, the minerals were subjected to X-ray diffraction.

For this, each mineral was ground as finely as possible in a small agate mortar, then spread in a thin film over a glass slide that had been lightly smeared with grease. The slide was then mounted on the diffractometer.

The unit used was a G.E.C. XRD 3 diffractometer. A copper target was employed, the applied voltage being 30 kvp at 20 milliampères. Scan speed was 2° per minute, resulting in an accuracy of approximately 0.1° on the diffractogram. As the instrument has only recently been acquired by the Department of Geology, it was not possible to refine the data by applying appropriate corrections. The data obtained are quoted in the relevant parts of this text.

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VI. GENERAL DISCUSSION OF STRATIGRAPHY AND REGIONAL CORRELATION IN SOUTH WEST AFRICA

ABSTRACT

The Marienhof Formation is considered to represent the oldest rocks known in South West Africa. It stretches from west of Rehoboth to Dordabis, where it is overlain by the Dordabis System, now subdivided into the basal, volcanic Opdam, and the essentially sedimentary Doornpoort Formation. Schalk considers the Skumok rocks to represent a locally developed acid phase, not warranting the term "Formation". The Late Precambrian Damara System covers most of the northern portion of South West Africa, and has been divided into the miogeosynclinal Outjo Facies, and the eugeosynclinal Swakop Facies. The latter, with its further subdivisions, forms the main subject of this work. Comparisons are drawn between the basal member of the Damara System, namely the Nosib Formation, and the Tsumis Formation of Central South West Africa, initially described in detail by Handley. Copper mineralisation is found in both these formations. The Buschmannsklippe Formation, equated with the Lower Nama beds, conformably overlies the Tsumis rocks, and locally begins with a tillite horizon. The presence of this glacial horizon has been used as a basis for tentatively correlating the Buschmannsklippe Formation with that portion of the Damara System occurring above the Chuos Tillite. Should this correlation be upheld, the Nama System would represent a southern shelf facies of the Damara System.

In order to put in perspective the complex geology of the central portion of the country, it will be necessary to digress somewhat from the discussion of the area mapped, and to present in as concise a form as possible the relevant background.

Throughout this work an attempt has been made, where possible, to base the stratigraphic nomenclature on lithostratigraphic units since correlations between the exposures in one part of the country and another are fraught with difficulties, while age determinations are almost entirely lacking. The term "System" has of necessity been used in certain cases e.g. Damara System, but it is not implied that this latter is one chronostratigraphic unit. It is appreciated that the terminology used is inconsistent with the recommendations of the International Subcommission on Stratigraphic Terminology. However, until such time as a system of terminology is universally adopted, the present writer has, of necessity, had to make use of terms firmly established in the literature.

Throughout the following discussion reference should be made to Map 1.

Amongst the oldest known rocks of South West Africa, are those of the Marienhof Formation, tentatively dated at 1700 million years (Martin 1965, p.1), forming a belt of extensively granitised metamorphic rocks some 50km. wide, trending eastnortheast through Rehoboth to the vicinity of Dordabis. Here, the plunging nose of this geanticline, formed during Damara time, is capped by rocks of the Dordabis Series, so named by Gevers (1934, p.243), who subdivided the widespread sequence of sediments and volcanics into Upper and Lower Dordabis Beds. It is of note that Gevers tentatively suggested a correlation of these rocks with those of the Nama System. On remapping this area Schalk (1960) found the Upper Dordabis Beds to correspond to the Nosib Formation at the base of the Damara System, and to be separated from the Lower Dordabis Beds by a major unconformity.

Schalk divided the Lower Dordabis Beds, which he termed the Dordabis System, into the Opdam, Skumok and Doornpoort Formations, so named after the farms of the region where the various lithological sequences have their type areas. Details of this subdivision ~~are given~~ in Table 1.

In this connection Martin stated in 1965:

"It is proposed to use the name Dordabis System

TABLE 1

THE STRATIGRAPHY OF THE DORDABIS SYSTEM ACCORDING TO SCHALK (1961)

(Modified afer Martin (1965, p.16))

Formation	Lithology	Max. Thickness
Doornpoort	Thick clay pellet conglomerate. Quartzite with interbedded calcareous quartzite and sandy limestone. Hard well-bedded quartzites with ripple marks, clay pellets and mud cracks, alternating with layers of hard red slate. Coarse sedimentary breccia or conglomerate, with local interbedded rhyolite flows near base.	3,700 m
	Discordance	
Skumok	Local granite intrusions. Rhyolite, felsite, ignimbrite and thick quartz-porphyry sills. Quartzite with rhyolite flows. Sedimentary breccia.	1,500 m
	Unconformity	
Opdam	Quartzite with interbedded flows of mafic amygdaloidal lava. Amygdaloidal, epidotised basaltic lava, with interbedded sediments. Sericite quartzite with lenses of pebble conglomerate. Phyllite. Basal conglomerate with phyllitic matrix.	1,300 m
	Major Unconformity	

> for the combined Opdam, Skumok and Doornpoort Formations, if age determinations show them to be fairly closely related in time. The name Dordabis System is therefore regarded as provisional."

Later, more detailed mapping in the vicinity of Dordabis (Schalk, 1966) showed the Skumok rocks to represent a locally developed acid phase of the Opdam Formation; the term "Formation" is therefore no longer warranted for the Skumok rocks. The two members of the Dordabis System as defined at present by Schalk (op. cit.), namely the Opdam and Doornpoort Formations, have a combined maximum thickness in excess of 5,000m and were, according to Martin (1965, p. 20), folded before deposition of the Nosib and Tsumis Formations.

The Late Precambrian Damara System, entering South West Africa in the northwest from Angola, dominates the central and northern parts of the country. Two main facies developments are distinguished:

1. The strongly metamorphosed, eugeosynclinal Swakop Facies.
2. The almost unaltered, miogeosynclinal Outjo Facies.

These are separated from each other to a certain extent by older formations, forming a chain of inliers. The Swakop Facies, rocks of which form the main subject of this report has, on the basis of work by Smith (1961) and Schalk (1961 - 66), to name but two, been subdivided further into two series viz.

Khomas Series
Hakos Series

The Nosib Formation, a discontinuous succession of coarse clastic sediments, underlies the Outjo Facies of the Damara System in the Otavi Mountains of the Tsumeb-Grootfontein area. Comparable lithology and a similar mode of deposition in more or less disconnected basins are found in Gevers' Upper Dordabis Beds. This term has been abandoned, the lithologic unit being now termed the Kamtsas Quartzite Member of the Nosib Formation, after the type area of the Kamtsas Mountains on the farms Ibenstein 55, Opdam 284 and Hatsamas West 281 in the Dordabis district. Here, slaty and calcareous rocks overlie the Kamtsas quartzite conformably, forming the Witkoei Hill. To the west, between Dordabis and Rehoboth, a facies change occurs, and these rocks interfinger with the phyllitic Duruchaus Series of De Kock (1934). For this whole sequence overlying the Kamtsas quartzites the term Duruchaus Member has been proposed by Martin (1965) and Schalk (1966). Schalk describes a further quartzitic sequence lying above the Duruchaus Member and includes this in the Kamtsas Member.

The Lower Hakos Stage directly overlies the Nosib Formation, often unconformably. Of extremely varied lithology, it consists of dolomites, quartzites, schists, subordinate itabirites and amphibolites, and reflects the unstable and rapidly changing conditions of deposition usually associated with the early stages of geosynclinal subsidence.

The Upper Hakos Stage begins with the Tillite Substage, which follows on the Lower Stage with a discordance or an unconformity. This tillite horizon, named the Chuos Tillite by Gevers (1931), is of variable lithology and thickness, and is overlain by marbles, quartzites and schists.

The Khomas Series follows conformably on the Hakos Series, and is composed chiefly of biotite-garnet schists and local marble bands. North of Windhoek an ortho-amphibolite horizon may be followed on strike for a considerable distance, while the Auas Mountains south of this town represent a quartzitic horizon intercalated with the schists. The exact placing of the boundary between Hakos and Khomas Series is subject to dispute; the matter is treated in some detail by Martin (op. cit. pp 40, 42-43).

The Tsumis Formation, initially mapped as part of the Basal Beds of the Nama System by Rimann (1915) and De Kock (1934), covers a large area to the south of Rehoboth. It fringes the southern rim of the anticlinorium of Mariënhof and Dordabis System rocks, and overlies these with a pronounced unconformity. Locally, as on the farm Girib Ost 60 in the Rehoboth district, an angular difference of 90° is apparent between it and the underlying Doornpoort Formation. Northeast of Dordabis the Tsumis and Damara beds approach one another very closely, but are always separated by a large fault which precludes any direct age comparison on stratigraphic considerations. However, the Tsumis Formation and the Kamtsas Member of the Nosib Formation are lithologically similar, both being felspathic quartzites showing prominent cross-bedding, heavy-mineral banding and, locally, conglomerate lenses. Moreover, as stated by Martin (op. cit. p.49):

> "...... the Tsumis beds have been folded along axes parallel to those of the Nosib and the Damara sediments, and there is no indication that the Damara rocks were involved in younger movements after they were metamorphosed. The Tsumis Formation must therefore be older than 500 m.y."

In the Klein Aub area Handley (1965) showed that the Tsumis Formation attains a maximum thickness of 5,700m, but thins out rapidly towards the sides of the basin of deposition. This feature, together with the occurrence of copper mineralisation in both formations, is another point supporting correlation with the Nosib Formation. Handley (op. cit. p.213) subdivided the rocks of the Klein Aub area into four stages; remapping by Schalk showed a major structural and sedimentological unconformity to lie between the Doornpoort and the three overlying formations (see Table 2). The Kamtsas Formation here is believed by Schalk to correspond to the Nosib Formation of northern South West Africa; his broad correlation may be extended to cover the Witvlei region.

It is of interest that as early as 1950 Martin, mentioned in Boocock and Van Straten (1962, p.138), thought the Ghanzi Beds of Botswana to represent the northeastern continuation of the Tsumis Formation. Work by geologists of Anglovaal South West Africa (Pty) Limited in the period 1968-1970 has strengthened the possibility of such a correlation.

In the area mapped by the author between Witvlei and Omitara, rocks correlated by the Geological Survey of South West Africa with the Opdam Formation occur on the farms Ottawa 150, Sandflats 123, and Eintracht 118. However, these have now been included by the present writer in the Damara System, for reasons fully discussed in the appropriate chapter below.

Rocks correlated by geologists of Fedswa Prospekteerders (Edms) Bpk with Schalk's Klein Aub Formation, and possibly including a portion of the Doornpoort Formation, are present on the farm Christiadore 104. They occur on the southeastern side of the thrust fault separating the "Tsumis" rocks from the Damara System.

TABLE 2

REGIONAL CORRELATION OF THE TSUMIS FORMATION
(Modified after Toens, 1969)

Klein Aub Area		Dordabis District	Witvlei Region	W. Botswana
(Handley)	(Schalk)	(Schalk)	(Anglovaal S.W.A.)	(Geological Survey)
Nama System	Nama System Buschmannsklippe Form.	Damara System	Buschmannsklippe Formation	Damara System
- Unconformity -	- Unconformity -	- Unconformity -	- Unconformity -	- Unconformity -
Tsumis Formation: Upper Quartzite & Conglomerate Stage	Kamtsas Formation (of the Tsumis)	Kamtsas Member (of the Nosib Form.)	Tsumis "C" (Kamtsas of Fedswa)	Upper Ghanzi Beds
	- Unconformity -	- Unconformity -	- Unconformity -	- Unconformity -
Tsumis Formation: Calcareous Quartzite Stage; Calcareous Shale Stage	Klein Aub Form. (copper mineralisation)	Not developed	Tsumis "B" (copper mineralisation)	Middle Ghanzi Beds (copper mineralisation)
	- Unconformity -	-	- Unconformity -	- Unconformity -
Tsumis Formation: Lower Quartzite & Conglomerate Stage	Dordabis System: Doornpoort Formation including Skumok Porphyry)	Dordabis System: Doornpoort Formation with local porphyry	Tsumis "A", including basal conglomerate	Lower Ghanzi Beds (copper mineralisation)
- Unconformity -	- Unconformity -	- Unconformity -	- Unconformity -	- Unconformity -
Skumok Formation	Dordabis System: Opdam Formation	Dordabis System: Opdam Formation (copper mineralisation)	Opdam Formation	Kgwebe Porphyry Series

The Nosib Formation is well developed on the northwest side of this fault, where the sequence consists of phyllites interbedded with subordinate limestones and contains two prominent quartzite beds. Owing to the presence of the fault, a basal conglomerate is absent here. The top of the sequence is marked by the lowermost band of Damara quartzite, which is in turn overlain conformably by the lowest Hakos dolomite horizon.

The Buschmannsklippe Formation generally exhibits a near-conformable relationship with the underlying Tsumis rocks, with which it has been folded, and usually consists of shallow-water dolomitic limestones, shales, white ripple-marked quartzites and red sandstone. It covers the extreme southeastern portion of the area under consideration.

On Orochevley 216, immediately south of the southern margin of the area mapped, rocks of the Tsumis Formation are exposed in the anticlinal core of a large fold in Buschmannsklippe rocks. The fact that "Tsumis" rocks, more correctly assigned to the Klein Aub and Doornpoort Formations (see above) also apparently overlie the Buschmannsklippe Formation to the northwest on Christiadore 104, may be explained by the presence of a strike fault. This feature, trending roughly parallel to the previously mentioned fault which separates the "Tsumis" rocks from those of the Nosib Formation, has upfaulted southeasterly dipping strata of the former group against Buschmannsklippe sediments having a northwesterly dip.

Seeger recently mapped a tillite at the base of the Buschmannsklippe Formation south of Gobabis. In 1969 drilling by Anglovaal S.W.A. (Pty) Limited in the

Uhlenhorst district of central South West Africa revealing s similar tillite, apparently filling topographical lows in the Tsumis surface, and showing an angular unconformity of 10-15^{o} with the Tsumis rocks. The tillite is overlain by poorly-bedded pink to purple quartzites not easily distinguishable from the Tsumis quartzite of the area.

The discovery of this tillite horizon has important implications regarding the correlation between the Nama and Damara Systems of South West Africa. Martin (1965, pp. 22, 114-116) discusses the relationship between the Hakos Series of the Damara System and the underlying Nosib Formation, and that of the Nama System and the underlying Tsumis Formation. The possible equivalence of Nosib and Tsumis Formations has already been alluded to and, if this interpretation is correct, the overlying sediments of the Damara and Nama Systems should be comparable. The Lower Hakos Stage presents a contact with the Nosib Formation that is not everywhere conformable; in certain areas, the Stage is not present, the Chuos Tillite of the Upper Hakos Stage transgressing directly onto the older basement. If this tillite is correlated with the Buschmannsklippe tillite, the upper portion of the Damara System could well correspond to the Nama System, the latter possibly representing a southern shelf facies of the former. The Buschmannsklippe Formation would thus form the base of the Nama System. Schalk (1961) has already correlated it with the Kuibis and Schwarzkalk beds of the Lower Nama.

A further possible correlation, again strengthened by the presence of the tillite, might be made between the Buschmannsklippe Formation and the Numees Formation of southern South West Africa. The latter formation could then, as has already been done by Rogers in 1915, be included in the base of the Nama System.

VII. OUTLINE OF THE GEOLOGY OF THE COUNTRY BETWEEN WITVLEI AND OMITARA

ABSTRACT

The area mapped comprises a slightly larger northwestern portion, underlain by rocks of the Nosib Formation and Damara System, and a southeastern part, containing the Tsumis and Buschmannsklippe Formations. The relatively narrow strip of Tsumis rocks is fault-bounded both to the northwest and southeast. An unconformity exists between Nosib Formation and Damara System. Owing to the great thickness of sediments present, all members of the Damara System are considered to be represented in the area. Recent deposits include river gravel and silt, pediments of scree flanking the hills, as well as a widespread cover of Kalahari sand. The system of grid references used throughout the remainder of this work is explained.

The area covered by Map 2 may be roughly divided into two sections. The slightly larger northwestern portion is made up of rocks assigned to the Nosib Formation and the Damara System, while the southeastern portion comprises the Tsumis and Buschmannsklippe rocks.

The Tsumis Formation covers a strip of country some 3km. wide trending northeastwards through the farms Owinieikiro 213, Gemsbockvley 214 and Christiadore 104, broadening to a width of approximately 7.5km. on the farms Otjiwarumendu 119, Okasewa NW 120 and Okasewa North 121. It forms an area of low relief, best described as an undulating plain. Outcrops are fairly abundant, the beds generally dipping steeply to the southeast. The more calcareous members are overlain by surface limestone.

On the northwestern side, the Tsumis rocks are separated from the Nosib Formation by a thrust fault, which dips to the northwest at a relatively shallow angle. The Nosib Formation consists of the phyllitic Duruchaus Member, forming a belt of low relief, and the Kamtsas Member which here consists of two parallel bands of quartzite, generally forming prominent ranges.

Rocks tentatively assigned to the Kamtsas Member of the Nosib Formation occur in the extreme southwest of the area mapped, on the farms Owinieikiro 213 and Locarno 211. Consisting chiefly of purple quartzites, they dip northwestwards at moderate angles, forming hills which rapidly gain height towards the southwest.

The Nosib Formation is separated from the overlying Hakos Series of the Damara System by an unconformity. Major strike faulting is present along the contact between Nosib Formation and Hakos Series, and is reponsible for the apparent overlap of the latter onto the former. This is very evident from the map, which shows the Nosib Formation to decrease in outcrop width from some 9km. in the southwest to less than 2km. in the northeast of the area mapped. The Lower Hakos Stage begins with a quartzite, overlain by a dolomite band. The lithological assemblage that follows above this consists of quartzites, dolomitic limestones, phyllites and schists with subordinate amphibolites and dolerites. It is characterised by repetition of these rock types, and by facies changes and wedging out of whole units. Major quartz-filled shear zones parallel to the regional strike are common. The relief is varied, the phyllites and schists forming low ground while the quartzites and dolomites give rise to prominent ridges and hills.

Although the presence of an horizon corresponding to the Tillite Substage of the Upper Hakos Stage could not be established with certainty, the large thickness of sediments overlying the Nosib Formation suggests that the greater portion, if not the whole of the Hakos Series, is represented in the area. Accordingly, the possibility that certain horizons belonging to the Khomas Series occur in the extreme west of the region, towards Omitara, cannot be ruled out.

The Buschmannsklippe Formation occupies the remainder of the area mapped, and covers that portion of the country lying to the southeast of the strip of Tsumis Formation rocks. The contact between these two formations is a fault. The larger portion of the area is underlain by shales, which give rise to flat or gently undulating ground similar to that of the Tsumis Formation. In the extreme south of the map, on Orochevley 216, sheared quartzites form the prominent anticlinal nose of the Weissberg, which plunges northeastwards.

Strike faults are characteristic of the whole region. Folding is isoclinal in the Tsumis rocks, but of a more open character in the Buschmannsklippe, Nosib and Damara sediments.

Among the more recent deposits to be found covering the area are thick accumulations of silt and gravel in the valley of the White Nossob River, as well as pediments of scree from the hills of the Kamtsas Member. The most widespread of all is a cover of red to grey Kalahari sand which obliterates most outcrops in the areas underlain by phyllites and schists.

Throughout the remainder of this work, the positions of sampling stations and other places of interest, whose precise location cannot be easily defined by purely descriptive terms, will be quoted by means of their grid references. For this purpose, a metric grid has been marked around the edges of Map 2. Thus, the grid reference for the homestead on Losberg 105 would be given by the figures -23540/40860. The Y co-ordinate is quoted first, followed by the X co-ordinate. In the example above, these would be:

Y	-	23540
X		40860

VIII. DETAILED GEOLOGY OF THE COUNTRY BETWEEN WITVLEI AND OMITARA

1. THE TSUMIS FORMATION

ABSTRACT

Techniques employed in the mapping of the Tsumis rocks between Witvlei and Omitara are discussed. With the exception of the striking purple colour, which is peculiar to Tsumis and Doornpoort rocks, there are strong similarities, chiefly on lithological grounds, between these formations and the Nosib Formation. However, differences in the style of folding of Tsumis and Nosib rocks show up well on aerial photographs. Broad similarities in lithology, together with the occurrence of strata-bound copper mineralisation, make possible a correlation of the Tsumis rocks of the Witvlei region with those of Handley's Klein Aub type area. Current stratigraphical nomenclature is critically reviewed, and a theory seeking to explain the lenticular nature and irregular distribution of copper-bearing strata is put forward.

The general distribution of this formation in South West Africa has been covered in Chapter VI.

In the region under consideration, rocks tentatively assigned to the Tsumis Formation lie on the southeastern side of the thrust fault that forms the southeastern boundary of the Nosib and Damara rocks. This tract of country, falling under the prospecting grant held by Fedswa Prospekteerders (Edms) Bpk could not, for obvious reasons, be investigated as thoroughly as the rest of the region. Mapping, coupled with a few short traverses across the area, was done largely on aerial photographs on a scale of 1:36,000 (part of Job 294 of 1958), and on the recent colour photographs on a scale of 1:20,000. Many data were kindly furnished by geologists of Fedswa, the adoption of whose detailed subdivision of the Tsumis rocks was not considered justified for the purposes of the present investigation.

Generally, the rocks consist of fine- to medium-grained felspathic quartzites, often cross-bedded and usually showing concentrations of heavy-minerals along their bedding planes. Lithologically, they exhibit striking similarities with rocks of the Kamtsas Quartzite Member of the Nosib Formation with regard to felspar content, cross-bedding and heavy-mineral banding. A point of difference is that these Tsumis rocks weather to a characteristic and conspicuous purple colour. This, according to Martin (1965, p. 51) has been shown, from boreholes put down in the Gobabis district, to be a secondary near-surface feature only, the colour fading at a depth of approximately 100m. Nevertheless, the colour is characteristic of all areas of Tsumis rocks visited by the present author.

Conglomerate lenses are well developed locally, as are limestones, marls and shales, ranging from maroon to green in colour. Folding is isoclinal, the general dir-direction of dip being towards the southeast. Strike faulting is common. The linear pattern produced by these structures shows up distinctly on aerial photographs, and is in marked contrast to the bold open folding exhibited by the quartzitic members of the Nosib Formation.

The presence of extensive conglomerate lenses may be used in a tentative correlation with the rocks of the Klein Aub area, described by Handley in 1965. On the farm Christiadore 104 copper mineralisation occurs locally within these conglomerates, while on Okasewa NW 120 it is found in the shales and limestones above the conglomerates. A broad correlation with the Klein Aub type area of the Tsumis Formation (see Table 2) would place the conglomerates and associated quartzites in Handley's Lower Quartzite & Conglomerate Stage. This corresponds to Schalk's Doornpoort Formation, and to the Tsumis "A" of Anglovaal South West Africa (Pty) Limited. These rocks bear a strong resemblance to Doornpoort sediments observed by the author on the farm Renown 235 in the Dordabis district. The overlying calcareous shales on Okasewa NW 120 would then correspond to Handley's Calcareous Shale Stage which, together with the Calcareous Quartzite Stage, makes up Schalk's Klein Aub Formation. The corresponding mineralised strata north of Witvlei have been termed Tsumis "B" by Anglovaal workers. Quartzites lying above these two formations may be correlated with Handley's Upper Quartzite & Conglomerate Stage, and are termed Tsumis "C" in the Witvlei area. Fedswa geologists follow Schalk's nomenclature and assign these strata to the Kamtsas Formation. The present author feels that this leads to confusion in the Losberg area, where the term Kamtsas should be retained for the quartzitic members of the Nosib Formation until such time as definite proof of the equivalence of Nosib and Tsumis Formations is at hand.

For the Klein Aub area, Handley (1965, p. 213) mentions the presence of a sinuous northern contact of the Tsumis rocks with the underlying older formations. This, together with the restricted strike development of the lower members, suggests that deposition occurred on an uneven floor in isolated basins, beyond the limits of which only the higher members were able to transgress. These observations may serve to explain the fact that copper mineralisation, apparently confined as it is to the lower members of the Tsumis Formation, is found only in isolated localities. Furthermore, a reason would be provided for the lateral thinning out of strata and rapid facies changes that characterise these sediments on Okasewa NW 120.

It is felt that the detailed work at present being carried out by the mining companies engaged in prospecting activities in the area between Dordabis and Witvlei will eventually enable a clearer subdivision of the Tsumis Formation to be made. This, together with a more precisely defined interrelationship between Doornpoort, Klein Aub and Tsumis rocks may result in the discovery of further zones of mineralisation. Furthermore, correlation of these beds between Klein Aub and Witvlei would be a significant step towards placing the present tentative correlation between the Tsumis Formation of South West Africa and the Ghanzi Beds of Botswana on a firmer basis.

The Tsumis Formation may yet prove to be one of the more important and widespread sedimentary sequences of the subcontinent.

2. THE NOSIB FORMATION AND DAMARA SYSTEM

ABSTRACT

Trends in nomenclature during the period when a detailed stratigraphic column for the Damara System was being established, are discussed, as are events leading to the incorporation of the Otavi System within the Damara System as the miogeosynclinal portion of the latter. The basal arenaceous member of both the miogeosynclinal Outjo Facies, and of the eugeosynclinal Swakop Facies of the Damara System, is termed the Nosib Formation. Pertinent literature on this is reviewed. Owing to similarities in lithology between the Nosib rocks of the Losberg area and those of the Dordabis region, Schalk's subdivision of the latter into an arenaceous Kamtsas Member and an argillaceous Duruchaus Member has been adopted by the present author. In the vicinity of Losberg 105, differences in the conditions of deposition, when compared with the Dordabis type area, have caused the Duruchaus Member to be developed at the expense of the Kamtsas quartzite, which is represented by two narrow, lenticular horizons. A detailed treatment is given, covering all aspects of the Nosib Formation between Witvlei and Omitara. Finally, reference is made to a breccia occurring on the farm Locarno 211. This horizon shows certain similarities with the basal Bevet's Conglomerate of the Transvaal System.

Notes on Nomenclature

In 1928 Krenkel proposed the term "Damara System" for what was then considered to represent the oldest group of sedimentary rocks in the central part of South West Africa. It is of note that he thought the Khomas Series to belong to a younger group of metasediments. Gevers and Frommurze (1929), working in Northwestern Damaraland and broadly following the classification of Rimann (1915), divided this system into a basal "Quartzite Series" overlain by the "Marble Series", the "Mica-schist Series" forming the top of the succession. This subdivision was followed in the Western Rehoboth by De Kock (1934), who substituted the term "Khomas Series" for the uppermost member of the Damara System.

The limestones and dolomites of the Otavi Mountains and the eastern Kaokoveld, termed the Otavi System by

Hermann in 1908, were considered to form a separate geological entity by workers such as Stahl. However, later mapping in the period 1950 to 1960 by Rabie in the Kaokoveld, Clifford in the Fransfontein-Outjo area, and Söhnge and Smit in the Otavi Mountainland, led to the correlation of the Otavi System with the Damara System. According to Martin (1965), the rocks of the former Otavi System should now be termed the (miogeosynclinal) Outjo Facies of the Damara System, while the former Damara System per se makes up the (eugeosynclinal) Swakop Facies (of the Damara System).

The subdivision of the System led to some difficulty. Mapping in both the northern and central parts of South West Africa had shown that in certain areas a discordance, locally passing into an angular unconformity, separates the predominantly quartzitic basal formation from the higher members of the Damara System. In the southeastern Windhoek district Gevers (1934) unwittingly split this basal member into two; one portion he included in the Damara System as the "Quartzite Series", the other, around Dordabis, he correlated with the Nama System, and tentatively called it the "Upper Dordabis Beds". Both units have now been recognised as belonging to the Nosib Formation.

In 1908 Hermann termed the basal formation of his "Otavi System" the "Nosib Series" in the Otavi Mountains, while in 1926 Stahl labelled it the "Hundskopf Formation" in the Kaokoveld. Stahl subsequently (1940) recognised the equivalence of the two beds in the northern part of the country, and dropped the term "Hundskopf Formation". In 1954, this latter name was unfortunately revived by the Geological Survey of South Africa, which body separated the series from the overlying Damara System on account of the unconformity existing between them. However, as stated by Martin (1965, p.22) and Smith (1965, p.8), the term "Nosib" has priority over "Hundskopf", and should thus be used in future.

The term "Marble Series" has been dropped in favour of "Hakos Series", named after the Hakos Mountains of the Rehoboth District. The table below gives the old and new names:

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

(after Smith, 1965, p.9)

The Nosib Formation of Central South West Africa

This forms an essentially arenaceous series in both the northern and central parts of South West Africa, and its position at the base of the Damara System fits in with the classical concept that geosynclinal assemblages characteristically have arenaceous beds at their bases (Martin 1965, p.22). However, the formation exhibits considerable lithological variation from one locality to another, and is often separated, as in the area between Witvlei and Omitara, by an unconformity from the overlying Damara System. It is for this reason that the Nosib Formation will be considered separately here.

The earliest detailed map and accompanying description of rocks now included in the Nosib Formation stems from Rimann (1915), who made a geological survey of the Baster Gebiet for the Hanseatische Minen-Gesellschaft. In the period 1923-25 Reuning published a map of the central portion of South West Africa, as well as a description and map of the Natas Mine and surroundings, while in 1929 Gevers' and Frommurze's account of the geology of Northwestern Damaraland appeared. These authors included the "Quartzite Series" in the Damara System, since there was no intervening unconformity between it and the overlying beds.

Concerning the lithology of the series these authors state (p. 34):

> "Well-bedded phyllitic quartzites form the topmost portion of this group, and are succeeded down the scale by phyllitic and coarse conglomeratic arkoses. The latter are usually very massive, entirely unbedded and rendered markedly gneissose by regional metamorphism. They are, as a consequence, very easily mistaken for gneissose granites. Both quartzites and grits are usually highly felspathic and sericitic."

Deposition of the upper quartzites appears to have occurred irregularly over an uneven floor; pinching out and lateral facies changes into mica schists and greywackes underlying the "Marble Series" were commonly noted. To the south these quartzites increase in thickness from some 350m at the Great Rooiberg to many times this figure in the Chuos and Etusis Mountains between the Khan and Swakop Rivers.

The most comprehensive work of this early period was carried out by De Kock (1934) in the Western Rehoboth. Distinguishing two series of pre-Damara beds, namely the Marienhof and the Duruchaus Series, he divided the latter into:

(a) Mica schists containing impure limestone bands;

(b) Crystalline and talcose marbles;

(c) Micaceous quartzites and sandstones.

These rocks, covering an area of some 1500 sq. km. west of Rehoboth, are stated by De Kock to have a maximum thickness of 7,000 metres. They rest on and have in part been metamorphosed with rocks of the Marienhof Series, and are overlain, often unconformably, by the basal conglomerates of the Damara quartzites.

More recent work in this area has necessitated a partial revision of De Kock's interpretation. Martin (1965, p.11) states:

> "Mapping in progress has .... revealed that the conglomerate which was regarded by De Kock as the basal conglomerate of the Duruchaus Series is not a basal conglomerate but an intraformational conglomerate of the Marienhof Formation. A considerable portion of the terrain assigned by De Kock to the Duruchaus Series has therefore to be included in the Marienhof Formation."

Mapping by Gevers (1934) in the Windhoek district revealed an arenaceous sequence, similar to the one occurring in Northwestern Damaraland, to exist at the base of the Damara System. This "Quartzite Series", today termed the Nosib Formation, ranges in thickness from 500 metres to approximately 3,000 metres. It locally begins with a basal conglomerate, up to 40m thick, of Marienhof and Duruchaus pebblesfollowed by conglomeratic arkoses and reddish felspathic quartzites containing isolated pebbly layers. These sediments form the prominent relief of the Billstein (2,250 metres), Oamitesberg (2,144m), and Hoher Schein (2,258m) mountains, to name but a few. In the vicinity of the Oamitesberg Gevers (p. 230) found that:

> "........ the quartzite horizon includes thick (up to 1,000 metres) intercalations of highly garnetiferous quartz-muscovite-schists and sericitic quartz-phyllites."

This sequence may probably be correlated with the Witkoei Beds on the farm Ibenstein 55 in the Dordabis district.

With regard to the higher members of the "Quartzite Series" Gevers states (p. 231):

> "The upper portion of the Quartzite Series, which in this region has a total thickness of about 3,000 metres, exhibits very different features. It is platy and flaggy, in some layers almost laminated, of white colour, very fine-grained, less felspathic, but rich in sericite."

Schalk (1961), on remapping Gevers' Upper Dordabis Beds, was able to correlate these with the Nosib Formation. The essentially arenaceous series is now termed the Kamtsas Member. It begins with coarse felspathic quartzites characterised by scattered pebbles, talus breccias and conglomerates, whose pebbles are derived from all pre-Nosib rocks of the area, set in a soft phyllitic matrix.

These quartzites are, on the farm Ibenstein 55 of the Dordabis District, overlain on the Witkoei Hill by slates and calcareous rocks. An unconformity separates this Witkoei Formation from the overlying Lower Hakos Stage of the Damara System.

Mapping by Schalk of the intervening area between Dordabis and Rehoboth has shown that the Duruchaus Series and the Kamtsas Beds are merely different facies developments of the Nosib Formation. De Kock's Duruchaus Series is now termed the Duruchaus Member of the Nosib Formation. In the Dordabis area the underlying and overlying quartzites constitute the Kamtsas Member.

Working in the western part of South West Africa, around the Khan and Swakop rivers, Smith (1965) divided the Nosib Formation into a Lower and an Upper Stage; he stressed that in part these stages also represented lateral variations, or facies, of each other.

The Lower Stage begins locally with a conglomerate, of maximum thickness 80 metres, of poorly sorted, well rounded pebbles composed of underlying rock types found in the immediate vicinity, set in a granular to schistose matrix. This is followed by a thickness of 30 - 3,350 metres of felspathic quartzite, generally massively bedded at the base and becoming more thinly bedded at the top. There are numerous intercalated conglomeratic horizons, and cross-bedding is common. The variability in the thickness of this unit is attributable to deposition on an eroded Basement surface in local basins of variable depth. Granitisation of this stage is widespread.

The Upper Stage conformably overlies the Lower Stage and was divided by Smith (p. 18) into an "Amphibolite Facies", of a variable thickness judged to exceed 300 metres, and a "Calc-granulite Facies", again of variable thickness but estimated to reach 1200 metres. The rocks of this stage are thought to represent former calcareous argillites and calcareous felspathic sandstones respectively.

A similar two-fold subdivision of the Nosib Formation was also made by Guj (1970) in the Sesfontein area of the Kaokoveld. There, the base of the psammitic

Lower Stage is not exposed, the rocks consisting of more than 2,000 metres of thickly to thinly bedded arkosic quartzite containing local intraformational conglomerates up to 200 metres thick. Subordinate pelitic members and interbedded basic lavas are confined to the top of the stage. The concordant Upper Stage is essentially pelitic with but locally developed arenites; the thickness may exceed 1,500 metres.

The Nosib Formation between Witvlei and Omitara

In this area, lying some 90 km northeast of Dordabis, the present author found the Nosib Formation to be well represented. It consists of a pelitic assemblage, here correlated with the Duruchaus Member, and contains two prominent quartzite horizons equated with the Kamtsas Member. A basal conglomerate was not observed, since the formation is cut off against the Tsumis Formation to the southeast by a major fault. The sequence is overlain unconformably by the Hakos Series of the Damara System.

Table 3 shows the stratigraphy of the Nosib Formation in selected areas along the southern edge of the Damara geosyncline.

From this table it is evident that in the area between Witvlei and Omitara the phyllites, when compared with those of the Dordabis District, are developed at the expense of the quartzites, suggesting marine conditions to have prevailed for the greater part of the period of deposition. If allowance is made for the faulting out of a certain thickness of the basal member of the series, which in the Kleeberge range on

TABLE 3

COMPARATIVE STRATIGRAPHY OF THE NOSIB FORMATION ALONG THE SOUTHERN MARGIN OF THE DAMARA GEOSYNCLINE

Western Rehoboth (De Kock 1934)	Dordabis District (Schalk 1966)	Witvlei/Omitara Region (Fey 1970)
Damara System	Damara System	Damara System
- Unconformity -	- Unconformity -	- Unconformity -
Micaceous Quartzites (500 m)	Kamtsas Quartzite Member (600-1100 m)	Duruchaus Member (approx. 500m) Kamtsas Upper Member (250-980 m)
Crystalline & talcose marbles (approx. 90 m)	Witkoei (Duruchaus) Member (150-200 m)	Duruchaus Member (approx. 400 m)
Quartz-mica Schists (approx. 6500 m)	Kamtsas Quartzite Member (4000-6200 m)	Kamtsas Lower Member (300-400 m) Duruchaus Member (approx. 1000m)
Basal Conglomerate (locally developed)	Basal Conglomerate (locally developed)	Not exposed
- Unconformity -	- Unconformity -	Faulted Contact
Marienhof Series	Basement and Dordabis System	Tsumis Formation

farms Mountain View 107 and Kleeberg 292 some 50km to the southwest reaches 6,200 metres, it appears that the Nosib Formation between Witvlei and Omitara has thinned to between one third and two thirds of its maximum development elsewhere on the southern margin of the Damara geosyncline. The style and nature of the folding, as reflected especially in the psammitic members, together with the unconformable relationship exhibited by the overlying Hakos Series make it advisable to consider the Nosib Formation as a separate entity from the Damara System. The findings of the present author thus essentially confirm those of Schalk in the Dordabis region.

The Kamtsas Quartzite Member

(a) Lithology

Two quartzite members, designated Kql and Kq2 on the map, are present, both showing abundant evidence of deposition in shallow water, in all probability under fluviatile or lacustrine conditions. Cross-bedding, slumping and heavy-mineral banding are virtually ubiquitous. In contrast to the other regions where the Nosib Formation is developed, conglomerate lenses are not present in the area being considered. Only on Owinieikiro 213 were very isolated small pebbles of white vein quartz noted. Lithologically, both Upper and Lower Quartzite Members are very similar, both being composed of two main varieties of quartzite, occurring as alternating bands or irregular lenses of variable, but often considerable thickness:

i) A massive type, pink to grey, fine-grained and containing much finely disseminated magnetite,

Plate III. Kamtsas quartzite from the western portion of Losberg 105, showing overturned cross-bedding (topsets t, foresets f, bottomsets b).

the alteration of which imparts the pink colouration to the rock. Bedding is occasionally rendered faintly visible by the concentrations of heavy-minerals along the bedding planes. Slump structures, also shown up by the heavy-mineral banding, are very common. Owing to the resilicification of the outer skin to a depthof approximately 1 cm, this rock weathers into rounded boulders with a glassy appearance. The fracture is conchoidal.

ii) A second variety, less glassy than that above and weathering into fragments exhibiting a sugary texture to which the iron oxides impart a brown stain. Bedding is well defined by means of heavy-minerals along the planes of deposition; cross-bedding on a scale ranging from several centimetres to 1 - 2 metres is prominent. The rock is well jointed, breaking into angular fragments defined by the intersection of the bedding planes with one or more of the joint directions. The size of the fragments varies from approximately 10 cm to over 1 metre across.

Incipient limonitisation of the iron oxides may be seen in both varieties in the form of haloes, one to two millimetres across, surrounding the magnetite particles.

With regard to jointing in the quartzites, three main sets were noted:

i) A very flat, almost horizontal set which, on the flatter summits of the hills, leads to the formation of rock pavements. This subhorizontal set was often seen to carry a quartz filling several millimetres thick, which in turn frequently exhibited slickensiding, denoting some movement to have taken place along the joint surfaces.

ii) Two sets of almost vertical joints at approximately right angles to one another, and trending roughly northeast and northwest respectively.

(b) Distribution and Field Relations

The Lower Quartzite Member has a limited distribution, being found only in the extreme southwest of the area mapped on the farm Owinieikiro 213, and on the farms Losberg 105 and Otjiwarumendu 119 in the northeast. Here it forms the prominent Otjiwarumenduberg and its northeastern continuation, the Heliographenberg and the Rotberg.

On Owinieikiro 213 it forms a range of hills running parallel to and just southeast of the boundary between this farm and Dorka 206, here formed by the Upper Member. Like the latter, the Lower Member swings sharply southwards at the northwestern corner of Owinieikiro 213. It follows the western boundary of the farm before terminating against the thrust fault, south of which in this locality an uninvestigated sequence of undifferentiated quartzites occurs, striking roughly southwest with a northerly dip. This is tentatively included in the Kamtsas Quartzite Member of the Nosib Formation.

These latter rocks are felspathic quartzites, well bedded and exhibiting heavy-mineral concentrations along the bedding planes; their purple colour is similar to that of the Tsumis rocks. The formation manifests itself in a low rise, beginning just west of the Nina-Omitara road on Owinieikiro 213 and increasing rapidly in height towards the southwest. The nature of the relationship with rocks assigned to the Tsumis Formation could not be ascertained, since the intervening area between the two forms an extensive pan on Owinieikiro 213. In view of the opposing directions of dip a fault or unconformity could exist between the two. The obviously faulted contact in the north offers no information regarding the relationship with the Nosib Formation.

The base of the Lower Kamtsas Member was nowhere observed, but the unit is assumed to lie conformably on the Duruchaus phyllites, a thickness of some 400 metres of which also serves/to separate it from the Upper Member. Unlike this latter it does not form a continuous barrier, having been breached in several localities by water courses which have carved wide valleys in the quartzite. Nevertheless, it reaches impressive proportions near the western boundary of Owinieikiro 213, forming hills rising 75 - 100 metres above the plain. Here the quartzites are some 380 metres thick, and dip to the west at approximately 60°. East of the nose of the fold in the northwestern corner of the farm the dips steepen. At the point where the Nina-Omitara road crosses the Lower Member, 1.5 km south of the Owinieikiro 213- Dorka 206 boundary, dips of over 80° towards the northwest were measured, and the bed has thinned to approximately 240 metres. It can be followed eastwards for a further 2.5 km before dying out, presumably due to a facies change, Duruchaus phyllites taking its place on the farm Gemsbockvley 214.

The Lower Member reappears on the farm Losberg 105 to form the prominent Otjiwarumenduberg, which rises over 200 metres above the plain. This hill must be regarded as a tight anticline, overfolded to the south-east (see Section C-D of Map 2), and contains a core of Duruchaus phyllites. Owing to the fact that the steep slopes of the hill are covered by extensive deposits of scree, the contact between the quartzite and the over-lying phyllites is difficult to place with accuracy. This possibly leads to an exaggeration of the thickness of the Lower Member, which is in this vicinity estimated to reach 300 - 350 metres. The phyllitic core manifests itself in a valley running up the mountain from the north-east but, owing to the large amount of scree present, the soft, easily weathered phyllites were exposed only as a result of trenching operations near the summit.

The southern limb of the anticline appears to thin rapidly towards the northeast, and is assumed to swing sharply southwestwards on the boundary between Losberg 105 and Christiadore 104, possibly being cut off by the large thrust fault. A facies change to a phyllitic sequence separates it from its natural continuation on Gemsbockvley 214.

Immediately northeast of the Otjiwarumenduberg the northern limb of the anticline has been displaced approx-imately 100 metres by a sinistral fault that is very evident on aerial photographs. Beyond this fault it forms the low range running parallel to the Losberg 105/Christiadore 104 boundary. The Lower Member here thins out considerably, so that in the bed of the White Nossob River it consists of a few ribs of quartzite only, each 3 - 4 metres thick, in the phyllite. Northeast of the river it thickens again rapidly, to reach some 400 metres in the long Heliographenberg range on

Otjiwarumendu 119.

Structurally, a shallow syncline exists north of this range, straddling the White Nossob River and covering portions of the farms Losberg 105 and Otjiwarumendu 119. The low rise (grid reference -24500/41250) approximately 1 km eastsoutheast of the Losberg homestead forms the most prominent outcrop of this northern limb of the syncline, further evidence for which was observed in a gravel pit along the route of the new main road on Otjiwarumendu 119. Here a thin band of quartzite correlated with the Lower Member was found. Further, aerial photographs show a fold closure to exist immediately southeast of the Eintracht railway siding.

On the slight rise east of the Losberg homestead referred to above, the quartzite resembles that found in the Otjiwarumenduberg, with prominent heavy-mineral concentrations on the bedding planes. Cross-bedding, on a scale of several millimetres only, is occasionally visible. Slumping is prominent. The hill appears to be a zone of dislocation, as at least two zones of faulting with quartz veining and brecciation of the rock were noted, trending roughly parallel to each other, one on the northern and the other on the southern side of the hill respectively. A thin band of phyllite is exposed near the crest of the hill. The dips of the strata appear to be mainly to the south, but since several northerly dips were noted the presence of minor folds cannot be ruled out. As evidenced by overturned cross-bedding, some overfolding to the north is present.

A little distance to the northeast, on the banks of the White Nossob River, isolated outcrops of silicified quartzite occur. Between these and the hill described above quartz veins at least 1 metre wide crop out, continuing into the northerly zone of dislocation on the hill.

The Rotberg on Otjiwarumendu 119, just north of the railway line, forms the most northerly exposure of the Lower Quartzite Member in the area mapped. It consists of a saddle opening southwestwards, the railway line occupying the sie of what must have been an axis of uplift from which the Kamtsas sediments between Heliographenberg and Rotberg have now been eroded. The northeastern end of the Rotberg forms an anticlinorium, with folds plunging gently both to the northeast and southwest.

The Upper Member of the Kamtsas Quartzite is more continuous than the Lower Member, and forms a prominent ridge for most of its length. Its southwestern end being truncated by the thrust fault on Owinieikiro 213, it swings sharply northeastwards at the northwestern corner of the farm, to run just east of northeast in the form of a prominent range averaging 1,650 metres in height, or some 100 metres above the plains. This forms the boundary between the farms Costa 207, Dorka 206 and Losberg 105 in the northwest and Owinieikiro 213, Gemsbockvley 214 and Christiadore 104 in the southeast. The highest point of the range is reached immediately southwest of the southern corner beacon of Losberg 105; the hills decrease in height rapidly from here northeastwards. Where the range crosses the boundary between Losberg 105 and Christiadore 104 it is little more than a small rise, which dies out after a further kilometre. The thickness of the quartzite also decreases northeastwards, from some 980 metres on Owinieikiro 213 to 250 metres on Losberg 105. Dip measurement gave values of approximately 60°W on the eastern boundary of Locarno 211, steepening to 70 - 80°NW along the southeastern boundaries of Dorka 206 and Losberg 105. Four kilometres northeast of the point where the Nina-Omitara road crosses the range, a dextral fault with a lateral displacement of 500 metres was noted.

Immediately southeast of the Otjiwarumenduberg the sand cover masks the geology, but from aerial photographs the Upper Member is seen to form a tight synclinal closure, the beds now running back in a southwesterly direction. The quartzites immediately form more prominent relief once the Christiadore 104 - Losberg 105 boundary is recrossed. Initially overfolded to the northwest, the northern limb of the syncline soon resumes a normal attitude, although dips remain very steep. The quartzite forms a low ridge running as far as the boundary Losberg 105 - Dorka 206, where another prominent closure occurs in the form of a small anticlinal hill, from which the beds swing back to run northeastwards for a short distance. Further tight folding occurs in the southwestern corner of the farm Losberg 105 before the Upper Member, now manifesting itself in the otherwise flat, sandy terrain as a slight swell carrying occasional float, dies out in the centre of the farm just north of the Otjiwarumenduberg. In this area outcrop over a strike length of some 300 metres shows the beds to have thinned to less than 100 metres.

Most of the hills formed by both the Upper and Lower Members of the Kamtsas Quartzite fall away steeply to the northwest and southeast. The slopes are generally rubble-strewn, the rock breaking up chiefly due to the formation of angular blocks resulting from the intersection of bedding planes and joints. These blocks are often loosened by game e.g. kudu, which are still plentiful in the area, and by cattle which graze on the hills. Mechanical weathering probably plays an important part in the denudation of the hills, especially in winter when night temperatures of between -5°C and -10°C alternate with daytime averages of 27 - 33°C. Summer rainfall, usually in the form of heavy thunderstorms, leads to gully formation with the consequent removal of debris. On the southeastern flank of the Otjiwarumenduberg an excellent example of a depositional terrace at the lower end of such a gully was found, situated at an altitude of approximately 100 metres above the plain.

The extent to which the quartzite rubble derived from the hills covers the adjacent areas is discussed in Chapter XI.

Outcrop of the Kamtsas Member is confined to relatively isolated bands trending parallel to the long axes of the hills, and exposures are usually found only in the upper third of the ranges. Below this the scree masks all outcrop, and effectively conceals contacts with the Duruchaus phyllites.

Of interest is the band of brecciated, flesh-coloured quartzite found in a gravel pit (grid reference -10300/50220) on the western side of the Nina-Omitara road on Dorka 206, approximately 1.5 km north of the

Upper Quartzite Member. Similar rocks were found some 3.5 km to the northeast, along the camp fence running from the Dorka homestead to the boundary fence with Gemsbockvley 214. Here the outcrop consists of a low ridge, perhaps 200 metres long, showing several bands of brecciated quartzite which, with its heavy-mineral banding, resembles the Kamtsas quartzite. Dips in this locality appear to be both towards the northwest and the southeast. The quartzite beds are underlain by phyllites containing a band of brown- to buff-coloured limestone.

The two occurrences described above must be regarded as forming a small quartzitic interbed in the phyllites. They are seen to lie along the southwestward extension of the synclinal axis of the fold in the Upper Quartzite Member on Losberg 105, along which some dislocation and brecciation appears to have taken place. The rocks have been tentatively included in the Kamtsas Member.

(c) Petrography

Specimen 9 was collected from the hill in the Lower Quartzite Member immediately west of the Nina-Omitara road on Owinieikiro 213. It is a massive, glassy rock, pink in colour, rather felspathic, and contains much disseminated iron oxide. The thin section shows the grain size to vary between 0.3 and 0.8mm, the average being 0.5mm. Equidimensional quartz grains, somewhat recrystallised and showing undulose extinction, make up the bulk of the rock. Potassic felspar occurs chiefly as orthoclase, with subordinate microcline. Some micropegmatite was noted, as were perthitic intergrowths. The plagioclase was determined as albite. All the

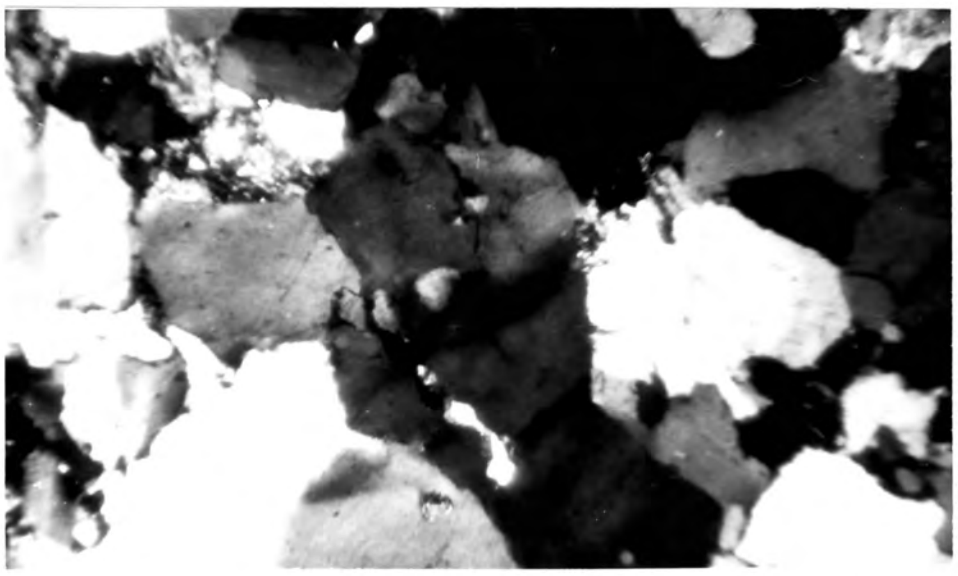


Plate IV. A specimen of the Lower Member of the Kamtsas Quartzite from Owinieikiro 213 in thin section. X 35, crossed nicols.

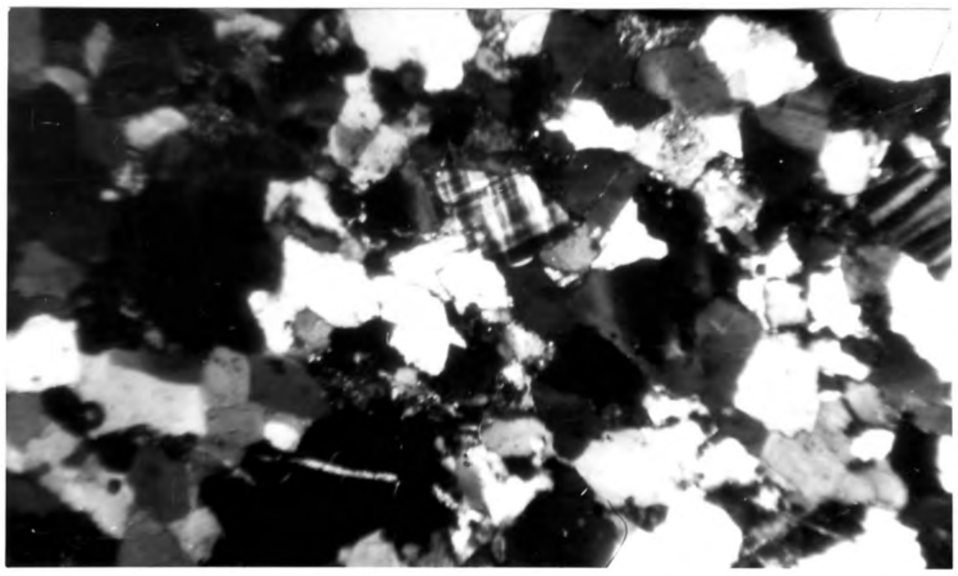


Plate V. Also from Owinieikiro 213, a specimen of the Kamtsas Upper Member in thin section. The difference in grain size between the two members of the Kamtsas is clearly brought out in the two photographs on this page. X 35, crossed nicols.

felspars are somewhat altered and cloudy. Iron oxides, probably chiefly magnetite, are common in the rock, occurring as cubes after pyrite, and as anhedral grains. Mica, both as biotite and muscovite, occurs in very minor amounts. A little zircon was also noted.

A further specimen (No. 63) from the Lower Quartzite Member was collected on the northern slope of the Otjiwarumenduberg on Losberg 105, from a band of the massive quartzite (type (i) above) just below the summit. In hand specimen it resembles closely the rock described above, except for its grey colour. Under the microscope it was seen to be of finer and more uniform grain, the particle size varying between 0.1 and 0.3mm, with the average lying close to 0.25mm. The quartz grains, slightly elongated in the plane of the bedding, which is emphasized by the concentrations of magnetite particles, form a mosaic of recrystallised interlocking grains with mutual boundaries described by Spry (1969, p.19) as lobate sutures. Very subordinate anhedral calcite occurs between some of the grains. The felspar in the slide is only slightly cloudy. Orthoclase occurs as subhedral laths, as does microcline. Albite commonly shows anti-perthitic intergrowths with microcline. Of the micas, muscovite is the more prominent, occurring as laths 0.3mm long; some biotite was noted. Epidote, apatite and tourmaline are present in trace amounts.

Two specimens from the Upper Quartzite Member were investigated microscopically. A sample taken from the boundary between Owinieikiro 213 and Locarno 211 (specimen 10) is a fine-grained, pink, almost massive felspathic rock, and contains finely disseminated iron

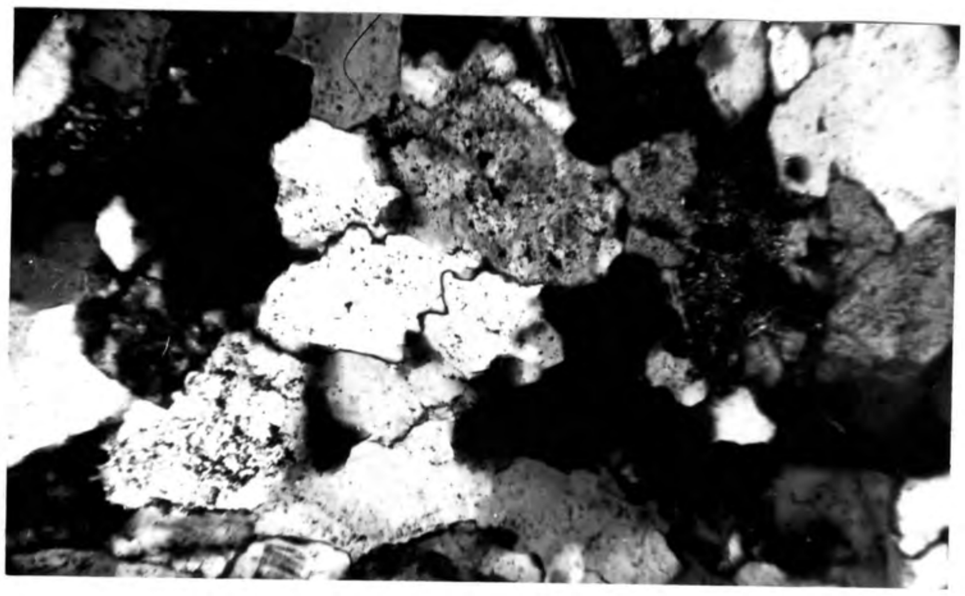


Plate VI. Micrograph of a specimen of quartzite from the Kamtsas Upper Member from the Otjiwarumenduberg, Losberg 105. The lobate sutures between certain of the quartz grains are clearly visible. X 100, crossed nicols.

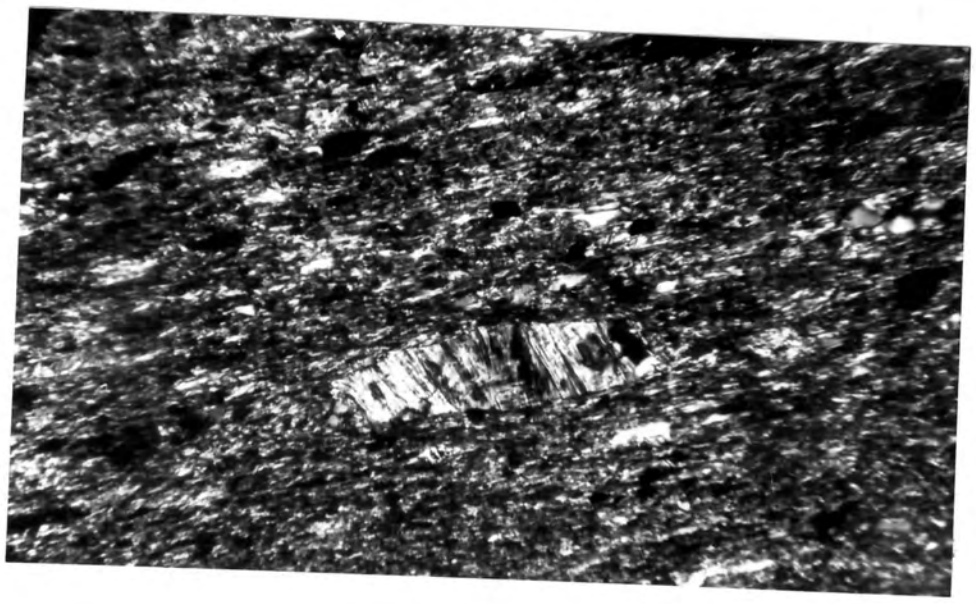


Plate VII. Duruchaus phyllite from Losberg 105, showing a porphyroblast of clinochlore in which the cleavage is at a high angle to the schistosity of the specimen. X 100, crossed nicols.

oxides which are occasionally concentrated along faintly visible bedding planes. Specimen 67 was collected from the small hill in the extreme southwest corner of Losberg 105 (grid reference -15670/46000). It is a fine-grained, grey, felspathic quartzite, in which the bedding is well defined by the heavy-mineral concentrations. The specimen is cut by a quartz-filled fault 1mm wide, with magnetite concentrations along its edges. This displaces the bedding on adjacent sides by approximately 2-3mm.

Texturally, the two specimens are again very similar, although there is a difference in grain size, as was also noted for the Lower Member specimens taken from broadly similar localities. Slide 10 shows the grain size to vary between 0.1 and 0.8mm, averaging 0.2 to 0.3mm, while in specimen 67 the limits range between 0.05 and 0.3mm, the average being 0.2mm. The bulk of each rock is again made up of recrystallised quartz grains, followed in terms of volume by potash felspar and plagioclase. It is noteworthy that the orthoclase in both specimens is rather sericitized whereas the plagioclase is still fresh. Specimen 67 contains more quartz and magnetite, and less felspar than specimen 10. Mica is subordinate in both rocks, while accessories are epidote, zircon and chlorite.

Table 4 shows the volumetric compositions of the four specimens described above; by way of comparison figures quoted by Schalk (1966) for a specimen of Kamtsas quartzite from the farm Wortel 54 in the Rehoboth district are also given. Specimens 9, 10 and 63 show an average felspar content of 19%, but even the range of 13-21% exhibited by the other two rocks given in the table still falls within the limits postulated by Pettijohn (1957, p.291) for subarkoses. According to

S4a

TABLE 4

VOLUMETRIC ANALYSES OF KAMTSAS QUARTZITES

Sample No.	9	63	10	67	X
Quartz	80.3	77.8	79.8	84.5	77
Orthoclase	13.2	13.0	12.6	10.0	21
Microcline	1.4	1.1	0.8	0.4	
Albite	4.5	4.9	5.5	3.0	2
Mica	Tr.	0.7	0.3	0.1	
Iron Oxides	0.5	1.3	1.0	2.0	
Carbonate	-	1.0	-	-	
Accessories	0.1	0.2	Tr.	Tr.	
Total %	100.0	100.0	100.0	100.0	100
Average grain size (mm)	0.5	0.25	0.25	0.2	0.13

Specimen 9 Owinicikiro 213) Kamtsas Quartzite, Lower Member
Specimen 63 Losberg 105)

Specimen 10 Locarno 211) Kamtsas Quartzite, Upper Member
Specimen 67 Losberg 105)

Specimen X Wortel 54, Rehoboth District. Kamtsas Quartzite (Schalk 1966)

Krumbein and Sloss (1963, p.168), citing data by Williams, Turner and Gilbert, the rocks would be classified as felspathic arenites.

For the sake of completeness, brief mention must be made of the breccia from the gravel pit on Dorka 206, already mentioned above. Specimen 33 is a very fine-grained, massive, flesh-coloured quartzite traversed by a quartz vein 4mm in width. Under the microscope quartz, as grains 0.1-0.2mm across, is seen to be the dominant constituent; incipient recrystallisation has led to clusters, each of several grains with sutured boundaries, cemented to adjacent similar clusters by anhedral carbonate. The felspar consists of roughly equal proportions of orthoclase and albite; magnetite occurs as irregular blebs, but also as isolated cubes after pyrite. Muscovite, biotite, apatite and epidote are accessories. A visual estimate gave the following figures:

Quartz	75%
Felspar	11%
Carbonate	12%
Magnetite	1%
Accessories	1%

It will be seen that this rock, apart from the carbonate content which must be attributed to the period of brecciation, also qualifies for the term felspathic quartzite.

The apparent uniformity of the Kamtsas quartzites, as demonstrated by the descriptions and figures quoted above, must lead to errors in mapping and interpretation. It is felt that a detailed sedimentological investigation of the area between Witvlei and Omitara, including grid sampling of both members of the Kamtsas, together with the plotting of cross-bedding directions, would probably yield valuable data concerning the source and direction of transport of the sediments. The lithological and mineralogical similarities between the quartzites, as set out above, suggest that the only possible method of distinguishing between Upper and Lower Members, and possibly between these latter and the numerous quartzite bands of the overlying Damara System, would be by means of a study of the heavy-mineral content of these rocks.

The Duruchaus Member

(a) Lithology

The dominant rock is generally a grey phyllite with prominent schistosity, which leads it to split readily into slabs 1 - 1.5cm thick. Weathered surfaces are grey to grey-green; in certain localities brown to blue-black skins on the schistosity planes denote a higher-than-average iron content. Bedding was not noted as such, but the phyllites contain numerous limestone bands dipping parallel to the schistosity, which thus seems to be approximately parallel to the bedding. These limestone bands range in thickness from 5 to approximately 30cm, the rock being fine-grained and finely bedded, often showing chlorite and quartz developed along the bedding planes. In composition these interbeds range from impure limestones to calcareous quartzites; colours vary from pink to buff, probably depending on the iron oxide content. Trenching at one locality exposed a band with a bright-yellow surface.

(b) Distribution and Field Relations

As distinct from the Dordabis area, where the phyllites of the Witkoei Hill form an interbed between the two quartzitic members of the Nosib Formation, the quartzites of the Losberg area must be regarded as lenticular. The bulk of the sediments is made up of phyllites which underlie, overlie and interfinger with the quartzite. The phyllites usually form featureless, gently rolling plains on which outcrop is masked by the Kalahari sand cover. However, examination of the spoil from the numerous "meerkat" burrows in the area usually reveals the nature of the underlying strata. The presence of phyllites containing interbedded limestone bands, as well as zones of calcareous phyllite, is normally indicated by the surface development of calcrete, together with a vegetation characterised by Catophractes alexandrii.

Where contacts with the overlying quartzites were exposed, as in trenching operations, these were usually gradational over thicknesses of 50-100m, the quartzitic interbeds becoming thicker and more frequent as one progresses upward in the succession. In the northern limb of the syncline, at the southern end of the farm Losberg 105, the Upper Member of the Kamtsas Quartzite is some 250m thick and becomes very phyllitic at the top. This zone of quartz-sericite schist contains cubes, 2-3mm across, of limonite after pyrite, as well as thin bands of brown limestone. On the southern side of the track (not marked on the map) that leads southeastwards from the windpump in the centre of the farm, this zone is seen to be overlain by a higher band of compact, pink, poorly bedded quartzite of unknown thickness.

Trenching on the southern limb of this syncline, immediately northwest of the boundary with Christiadore 104, showed the contact between quartzite and phyllite to be sharp, a further thin quartzitic interbed occurring in the phyllites some 200m higher up in the succession. A trench in the central portion of Losberg 105, situated approximately 1 km southsoutheast of the windpump (grid reference -19250/44400), showed the presence of several thin quartzite bands with heavy-mineral concentrations along the bedding planes in the otherwise phyllitic assemblage. A feature of the phyllites brought out by mapping and trenching is the presence of numerous bands of white quartz often associated with chlorite, and occasionally with massive carbonate. These veins appear to represent zones of dislocation, fracture fillings and secretion phenomena, and usually trend parallel to the regional strike.

Owing to the generally poor surface exposures, the thickness of the Duruchaus phyllites is difficult to estimate. Since trenching has revealed the occurrence of southeasterly as well as the more common northwesterly dip directions, fairly tight folding must be assumed to be present. The figures given in Table 3 above are thus in the nature of an estimate only, and should be treated with reserve.

(c) Petrography

Specimen 71, taken from Trench 005W(S) on Losberg 105, approximately 800 metres southwest of the White Nossob River and adjacent to the boundary with Christiadore 104, is a fragment of grey, fine-grained phyllite.

Approximately 2 cm. thick, it is bounded by the schistosity planes, to which the mica in the rock imparts a silky lustre.

In thin section, the rock is seen to consist of a matrix of very fine-grained sericite containing porphyroblasts of quartz 0.05mm thick and 0.1-0.2mm long in the plane of schistosity. Clinochlore forms subordinate bright-green, pleochroic laths elongated in the plane of schistosity, yet with a cleavage at a considerable angle to the latter. It appears to be an alteration product of biotite, occasional fragments of which it was seen to be replacing. Magnetite occurs as finely disseminated subhedral to anhedral grains of average size 0.05 to 0.1mm. Accessories are carbonate, felspar and tourmaline, the latter probably of the schorlite variety.

Specimen 76, from Trench 050W in the same locality as that above, closely resembles No. 71 in hand specimen. In thin section the very much finer grain size and the presence of appreciable amounts of ferruginous material precluded a detailed examination.

A grey quartz-sericite schist, Specimen 69, was collected from Trench 21(i) on the right bank of the White Nossob River approximately 400 metres downstream from the homestead on Losberg 105. The schistosity planes of the rock, apparently coinciding with the bedding, show two mutually perpendicular sets of crenulations, the one almost vertical, the other with a very gentle southwesterly plunge.

Under the microscope the rock is seen to consist of quartzitic layers, somewhat folded, set in a quartz-sericite matrix. The quartzitic bands are irregularly spaced, and average 1.5mm in width. They contain granoblastic elongate quartz crystals of average size 0.1mm, often with development of sericite along the grain boundaries. The bands locally interfinger with the matrix which, in the cores of the folds shown by the quartzitic layers, exhibits minor crenulations of wave length 0.25-0.3mm. Quartz porphyroblasts in the sericite are elongated in the plane of schistosity; an incipient cleavage axial planar to the minor crenulations is visible. Biotite and chlorite are locally developed; apatite occurs as rounded grains, and as crystals elongated parallel to the schistosity. Iron oxide, probably limonite, is present as yellow irregular masses. Prisms of brown, pleochroic schorlite are fairly common. Calcite, as anhedra up to 0.4mm across, is rare.

Specimen 74 is a phyllite from Trench 33 (grid reference -19910/47070) in the southeastern corner of the farm. A very fine-grained grey-green rock, it is seen under the microscope to consist of granoblastic elongate quartz grains set in a fine sericitic matrix; subordinate laths of muscovite are present. Apatite and tourmaline occur in minor amounts. The slide is murky owing to the presence of amorphous aggregates of iron oxide, probably limonite. This mineral is concentrated in the slide especially in one band approximately 1.25mm wide, as particles 0.05-0.15mm in diameter.

Table 5 shows the approximate modal compositions of Specimens 69, 71, 73 and 74, estimated visually. From these figures no general conclusions concerning the average composition of the phyllites can be reached

TABLE 5

APPROXIMATE MINERALOGICAL COMPOSITION OF

DURUCHAUS PHYLLITES

SPECIMEN	69	71	74	76
Quartz	30	22	45	73
Sericite	64	74	50	16
Plagioclase	-	Tr.	-	-
Mica	3	-	Tr.	Tr.
Chlorite		2	-	-
Iron Oxides	1	2	5	10
Accessories	2	Tr.	Tr.	1
	100%	100%	100%	100%

(Mica and Chlorite bracketed together for specimen 69: 3)

Specimen 69	Quartz-sericite	schist	Trench	21(i)	Losberg 105
" 71	" "	phyllite	"	005W(S)	
" 74	" "	"	"	33	
" 76	" "	"	"	050W	

as all components are seen to be extremely variable. The rocks are best termed quartz-sericite phyllites.

In addition to the rocks described above, limestones interbedded with the phyllites were also examined briefly. Specimen 72 was collected from Trench 005W(S), and in hand specimen is seen to be a fine-grained, finely bedded pink rock showing occasional quartz lenses on the bedding planes. There is local development of a brown carbonate assumed to be siderite or ankerite.

The thin section shows layers of quartz alternating with layers of calcite, the latter mineral being slightly more abundant and occurring as subhedral crystals approximately 0.2mm in diameter. Quartz is present as recrystallised grains 0.05-0.2mm across. Plagioclase in the form of albite constitutes a surprisingly large proportion of the rock. Accessories are iron oxides and mica. The slide is traversed by a quartz-calcite vein in which the crystal size is 0.5-1.0mm.

Specimen 73 comes from Trench 33 mentioned above, and was collected from just above the upper contact of the Upper Quartzite Member. It closely resembles No. 72 in hand specimen, except that occasional dendrites of manganese oxide are present on the bedding planes.

Specimen 75, from the same locality, is a calcareous quartzite. It is a fine-grained, grey-green rock consisting of bands 1-2mm thick of quartz-carbonate separated by thin micaceous layers. Iron carbonates are occasionally developed.

Under the microscope, the rock is seen to be composed essentially of granoblastic elongate quartz grains, approximately 0.1mm long in the plane of bedding, which

TABLE 6

APPROXIMATE MINERALOGICAL COMPOSITION OF
DURUCHAUS LIMESTONES

SPECIMEN	72	73	75
Calcite	55	74.9	20
Quartz	40	22.0	70
Albite	5	0.9	5
Mica	Tr.	0.8	4
Iron Oxides	Tr.	1.4	1
	100%	100.0%	100%

Specimen 72	Limestone	Trench	005W(S)	Losberg 105
" 73	"	"	33	
" 75	Calcareous quartzite	"	33	

N.B. Composition of Specimen 73 determined micrometrically by means of a Swift Point Counter.

is shown by a few bands 1mm wide of muscovite laths with very subordinate chlorite in a subparallel arrangement. Some albite occurs amongst the quartz grains, which in places have a cement of calcite. Magnetite is found as subhedral grains of size 0.05mm in the chlorite-rich layers; elsewhere it forms discrete cubes of size 0.2mm, probably after pyrite.

Table 6 gives the visually estimated compositions of Specimens 72 and 75, as well as the more reliable results of a micrometric analysis of Specimen 73. This latter was stained to determine the presence of dolomite, but with negative results. Specimens 72 and 73 are probably best described as quartzitic limestones, while Specimen 75 represents a calcareous quartzite.

The Breccia on Locarno 211

This occurrence lies in the Duruchaus phyllites immediately west of the western boundary of the area mapped, and does not feature on Map 2. It is centred on the windpump situated approximately in the middle of the farm Locarno 211 and forms, when approached from the southeast along the track from Owinieikiro 213, a low ridge rising 4-5 metres above the plain. The top of the ridge consists of a white to pink marble some 100 metres across in outcrop width, around which lies the breccia, forming a fold with a westerly plunging axis. The synclinal closure of this fold is situated approximately 300 metres northeast of the windpump. The marble overlying the breccia on the southeastern side of the syncline strikes approximately northeast and dips at 34° to the northwest. On the other limb of the syncline the dips are steep, e.g. 85° to the southeast; the strata may even be overturned locally.

The breccia, best exposed on the southeastern slope of the ridge, forms isolated boulders and low pavements between which occur blocks of quartzite and dolomite. Three types were recognised. Type (i) seems to be overlain in places by an only slightly brecciated quartzite resembling that of the Kamtsas Member. This is not found everywhere, but if present is overlain by type (ii), which may be overlain by type (iii). The succession is capped by the pink marble. Minor folding, with axes plunging steeply to the northeast, is present. On the track to the windpump the total outcrop width of the southeastern limb of the breccia is approximately 50 metres. Details of the three types are given below:

<u>Type (i)</u>

A small area, forming a low pavement, consists of a brown to pink rock containing angular to subrounded fragments of fine-grained cherty material, ranging in size from approximately 2mm to more than 15cm across. These fragments, constituting at least 50% of the rock, are set in a ferruginous and calcareous matrix. They occasionally show a very faint banding which may, in places, be traced across several inclusions. Portions of the rock show what appears to be relict folding.

A thin section of specimen 118, stained to differentiate between calcite and dolomite, shows a calcareous matrix containing subangular inclusions averaging 3-5mm in size. These latter consist of two types:

(a) Crytocrystalline mylonitic material, brown in plane-polarised light and appearing almost isotropic between crossed nicols.

(b) A very finely crystalline aggregate (grain size less than 0.05mm) of quartz and felspar in an essentially dolomitic matrix.

Of the two types only (a) shows any stratification. Where both types are present in one fragment, the contact between them is a sharp line parallel to the banding in the cryptocrystalline variety.

These fragments are cemented by material consisting of angular grains of quartz, dolomite and felspar, ranging in size from 0.05-1mm, set in a calcite-limonite matrix. The calcite locally shows flow-texture, denoting further brecciation and movement to have taken place in the rock after introduction of the carbonate. Calcite-filled veins are seen cutting across the inclusions described earlier. Quartz is present as anhedral grains, usually full of needle-like inclusions; it also forms veins in the brecciated fragments. Extinction is normally undulose. The felspar present is in most cases polysynthetically twinned, and was identified as albite. It occurs as veins cutting through the matrix of the rock, and as partial rims around the inclusions. Several dolomite grains were noted, poikiloblastically enclosing felspar and quartz. Locally, calcite actively replaces the dolomite. A mineral occurring as isolated, pale-brown, slightly pleochroic laths, often bent and resembling biotite, was identified as phlogopite.

It appears that brecciation of the rock was followed by the introduction of quartz and felspar, the latter rimming the breccia fragments. Dolomite was brought in almost simultaneously, and during crystallisation poikiloblastically enclosed felspar and quartz. Calcite-bearing solutions were the last to be introduced. A further period of brecciation led to the filling of cracks by calcite, and is responsible for the flow-structures that are developed locally in the calcite. Replacement of dolomite by calcite is now taking place.

Type (ii)

This type of breccia forms isolated boulders consisting of scattered, rounded fragments in the size range 0.5-3cm, set in a gritty pink matrix of quartz and occasional rhombohedra of carbonate. The rock is very calcareous, reacting strongly with dilute HCl. It is subject to replacement by surface limestone.

In thin section specimen 119 is seen to consist of quartz, dolomite and irregular fragments of brecciated quartz-felspar-calcite material in the size range 1.5-5mm, set in a very fine-grained quartz-carbonate-limonite matrix containing subordinate felspar. Matrix and inclusions of the latter type are not easily distinguished between crossed nicols. Biotite, phlogopite, tourmaline, glaucophane, and iron oxides are accessories. Some flow-banding, as was observed in slide 118, is again present.

The rock appears to have suffered cataclasis to a greater degree than type (i) above.

Type (iii)

Overlying the two types mentioned previously and occurring immediately below the marble, but of very limited distribution, is a slightly brecciated and folded quartzite. The rock is grey to buff in colour and finely bedded, with heavy-mineral concentrations along the bedding planes. It presents an irregular outer surface with many leached cavities. One outcrop of this rock type showed that the underlying Type (ii) had become squeezed upwards into a crack at the base of the quartzite, as though it had been injected in a plastic state. A fresh surface in specimen 120 shows quartzite bands 1-2mm thick alternating with layers of pink, coarse-grained carbonate. A green flaky mineral occurs in patches 2-3mm long, usually elongated parallel to the bedding. Some quartz-filled vugs were noted.

In thin section, specimen 120 is seen to consist of alternating bands 1-1.5mm wide, of fine-grained quartzite and coarser quartz-carbonate. The fine fraction consists of granoblastic elongate quartz grains, approximately 0.05mm long, with subordinate plagioclase and sub- to anhedral calcite grains. The coarser portion of the rock is made up of idioblastic dolomite, albite and granoblastic polygonal quartz grains in the 0.2-0.3mm size range, usually traversed by numerous cracks.

The green mineral noted in hand specimen was seen to occur in minor amounts in the fine-grained quartzite bands, but to be concentrated especially in the coarser parts of the rock. It is present as light-brown to light-green, slightly pleochroic laths up to 2mm wide, commonly showing sieve texture with inclusions of quartz and calcite. Longitudinal sections show one prominent cleavage; cross-sections are typical of pyroxenes, with two cleavages nearly at right angles to each other. In the laths the extinction angle measured from the cleavage is 3-12°, the mineral having a negative elongation. It was further found to be optically negative, with a $2V_x$ angle of approximately 85^o. From the foregoing it was identified as the soda pyroxene acmite.

Biotite, as deep-brown, strongly pleochroic grains, is concentrated in isolated bands. Apatite and microcline form accessories.

As already mentioned, both dolomite and calcite are present in the rock. The former tends to occur as idioblastic grains up to 2mm across; staining of the slide shows these to be in process of replacement by calcite. The latter also forms smaller fragments scattered throughout the rock, inclusions in the pyroxene, and gives rise to later veins cutting the rock.

A visual estimate of the mineralogical composition is given in Table 7. The rock must thus be regarded as a quartzite that has been subjected to partial replacement by carbonate, and seems to have received some soda from an outside source.

Types (i) and (ii) of the breccia appear to rest on and to be interbedded with a massive white dolomite, occurring as low pavements below and between the breccia. A thin section of specimen 117 shows this white dolomite to be composed essentially of dolomite grains varying in size from 0.05 to over 2mm. Subordinate calcite occurs in layers assumed to be parallel to the bedding. Quartz, muscovite and iron oxides are present in small amounts only.

Of interest is a colourless mineral occurring as pointed laths 1-2.5mm long, and sometimes showing one cleavage running diagonally across the needles. The

TABLE 7

APPROXIMATE MODES OF SPECIMENS FROM LOCARNO 211

SPECIMEN NO.	116	117	120
Dolomite	94	83.8	3
Calcite	4	-	6
Quartz	2	Tr.	70
Plagioclase	Tr.	-	2
Microcline	-	3.9	Tr.
Mica	Tr.	11.9	2
Acmite	-	-	15
Iron Oxides	Tr.	0.4	2
	100%	100.0%	100%

Specimen 116 - Pink marble overlying breccia.

Specimen 117 - White dolomite underlying breccia.

Specimen 120 - Breccia, type (iii).

N.B. Composition of Specimen 117 determined by means of a Swift Point Counter.

extinction is parallel to this cleavage. Twinning in two directions, approximately at right angles to each other, is present. The mineral apparently alters to sericite. It was found to be optically positive, with a 2V angle of at least 85°.

In an attempt to identify this mineral, a small portion of the rock was dissolved in warm dilute HCl The residue contained quartz, carbonate, and the unknown mineral on which refractive index determinations were then carried out. The following values for the optical constants were obtained:

N_z 1.529 N_x 1.523

These results, coupled with the occurrence of the poorly developed "grid-iron" twinning mentioned above, suggested the mineral to be microcline.

In order to verify this, an X-ray diffraction was undertaken. However, owing to the contaminated nature of the sample, results were inconclusive. Hence, no X-ray data are quoted. Approximately 20 peaks on the diffractogram could be matched with values for microcline given in the ASTM cards. Intensities were markedly lower than those quoted in the cards - this is possibly due to masking of the reflections by the contaminants present in the sample.

The pink marble (specimen 116) occupying the centre of the syncline is a rather pure dolomite. A visual estimate gave the mineralogical composition quoted in Table 7.

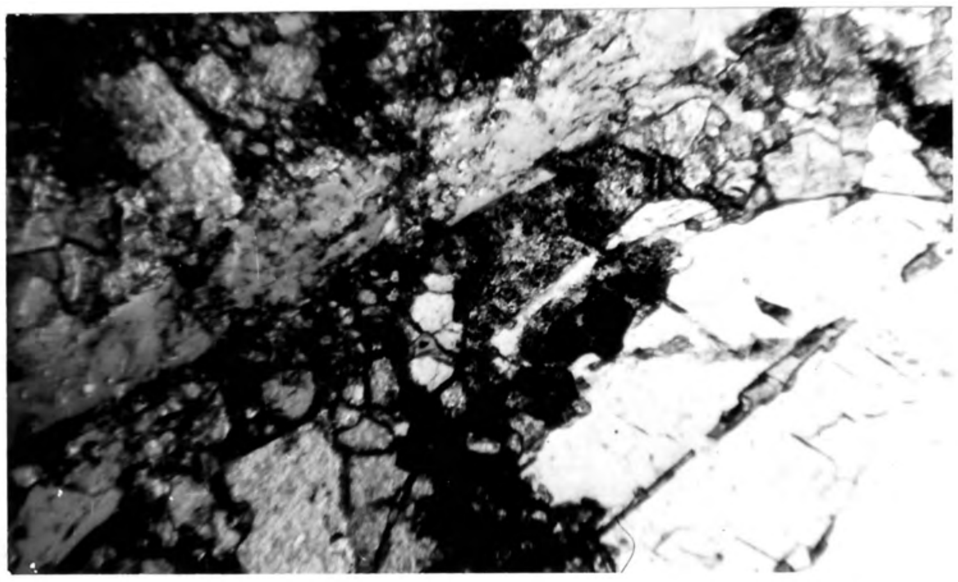


Plate VIII. Thin section of dolomite from the breccia on Locarno 211, showing laths of the mineral tentatively identified as microcline. X 35, crossed nicols.

Origin of the Breccia

Many of the features mentioned above are similar to those described by Du Toit (1954, pp 138-140), Toens (1966, pp 56-58) and Handley (undated) for the Basal (Bevet's) Conglomerate of the Pretoria Series in the Transvaal System. The principal points of similarity between this conglomerate and the occurrence on Locarno 211 are:

(i) The angular nature of the fragments, suggesting limited transport to have taken place.

(ii) The presence of bedding in the breccia fragments. These may often be fitted together, so that the original bedding may be traced for some distance through the rock.

Du Toit (pp 138-139) suggests that the Basal Conglomerate of the Pretoria Series represents a beach deposit, formed during a temporary period of emergence of the newly deposited Transvaal Dolomite. This, with its cherty upper portion, would have provided the bulk of the material for the conglomerate. Locally, quartzite pebbles from the Black Reef Series underlying the Dolomite are present.

Toens (p 57) remarks on the fact that the chert fragments of the conglomerate may often be fitted together and suggests an in situ origin.

Handley provides photographic evidence of brecciation in situ and postulates the following mode of formation for the Basal Conglomerate. The sequence dolomite-banded chert- sandstone/shale of the Transvaal System was deposited without a major break in sedimentation. With compaction resulting from the increasing load, connate water was expelled upwards through the thick sedimentary pile. However, the impervious shales above the chert horizon at the top of the Dolomite impeded egress of this water into the overlying basin. Accordingly, the water travelled outwards from the centre of the basin of deposition, moving upwards along the initial dip of the chert. The considerable pressure of this column of water led to solution and removal of gelatinous silica from this zone, eventually causing brecciation of the chert. Locally, anomalous conditions led to the preservation of some of the original banded cherts, which may be observed to grade laterally into the brecciated varieties.

For conglomerates formed in this manner, Handley proposes the term "infraformation conglomerate".

In the occurrence on Locarno 211, the breccia horizon is overlain by a dolomite. This rock type, although often a good aquifer, is here of a massive, compact nature, and could thus well have fulfilled the role assigned by Handley to the basal shales of the Pretoria Series. This particular dolomite horizon has not been observed elsewhere in the region mapped, and thus probably accounts for the very localised development of the conglomerate. A feature of infraformation conglomerates mentioned by Handley is the introduction of minerals, possibly of economic importance, into this zone of percolation. On Locarno 211 the considerable acmite content of type (iii) of the breccia may no doubt be attributed to the introduction of soda in this manner.

In view of the general similarity between Bevet's Conglomerate and the breccia on Locarno 211, it appears that the latter has also been formed in situ. The present author therefore concurs with Handley, and would like to see the term "infraformation conglomerate" applied to this occurrence.

3. THE DAMARA SYSTEM

ABSTRACT

In order to present the background for a discussion of the Damara System between Witvlei and Omitara, literature covering the eugeosynclinal portions of this System in other parts of central South West Africa is reviewed. Then follows a detailed treatment of similar rocks in the vicinity of the farm Losberg 105, where the main lithological types are quartzites and associated carbonate rocks, schists, and amphibolites. Problems connected with classification and origin of carbonate rocks are discussed, followed by an investigation into the processes of dolomite formation and dedolomitisation. It is concluded that the Hakos dolomites are true dolomites, possibly in part of organic origin. The pebble conglomerate found between Eintracht 118 and Spandau 149 is described with special reference to its stratigraphic implications. Reasons are given for including this horizon in the Damara System rather than in the Opdam Formation, as has been the case hitherto. The possible equivalence of the conglomerate with the Chuos Tillite is mentioned. Localised occurrences of melanocratic rocks of doubtful origin are considered to represent both ortho- and para-amphibolites. Igneous rocks related in age to the Damara orogeny are represented by the Dachsberg granodiorite on Sandflats 123, and by mafic intrusions on Goldene Aue 106 and Joachimstal 107.

Introductory Remarks

Following on the early, broad classification of the rocks of South West Africa into a "Fundamental Complex" overlain by the Nama System, the work of Rimann (1915) in the Bastardland around Rehoboth laid the foundations for the detailed stratigraphic subdivisions that were to be made in the former group.

Rimann found rocks of the Marienhof and Duruchaus Series to be overlain by his "Primärformation", his geological subdivision of which was modified and extended by Gevers and Frommurze (1929) to cover the rocks of Northwestern Damaraland, and by De Kock (1934) in the Western Rehoboth. The changes in nomenclature since this classification was set up have already been discussed.

General Stratigraphy and Lithology of the Swakop Facies of the Damara System in South West Africa

Before embarking on a discussion of the stratigraphy between Witvlei and Omitara, it is of interest to examine the eugeosynclinal portions of the Damara System in other parts of South West Africa in order that similarities and differences may be brought out later in this text.

In the Western Rehoboth, De Kock (op. cit.) found his "Quartzite Series" to lie unconformably on rocks of the Duruchaus Series, and to show locally developed basal conglomerates. These latter vary in thickness from 20 - 750 metres, and contain pebbles of Duruchaus and Marienhof Series rocks; the size of the pebbles varies from one locality to another, but normally lies between 5 and 50cm. The quartzites overlying the conglomerates are variable in colour, usually medium-grained and occasionally ripple-marked. Bedding planes are seldom visible. Usually forming prominent relief, this unit varies greatly in thickness; a maximum development of 3,000 metres is attained in the Hakos Mountains.

Judging from De Kock's description of these rocks, the present author feels that they should probably be correlated with the Kamtsas Member of the Nosib Formation.

The "Quartzite Series" is followed by the "Marble Series", of which De Kock (p. 41) says:

"This consists of crystalline marbles in bands of varying thickness usually containing bands and lenses of schists, phyllites, graphitic schists and graphitic phyllites,,and not uncommonly fairly thick lenses of quartzites. The marbles are more or less completely recrystallised, but the degree of crystallisation varies from place to place. They may be compact and fine-grained or massive; in places, however, they are coarsely crystalline, and weather into rhombohedrons up to a cm. and more across. Layers of chert in the fine-grained types are not uncommon, and may be locally extremely abundant."

A maximum development of 700 - 1000 metres is given by De Kock for this sequence.

Concerning the stratigraphic position of the tillite horizon in the Western Rehoboth, De Kock (p. 44) states:

"The horizon in which the glacial beds occur alters from place to place, sometimes the glacial beds are intimately mixed up with the Marble Series, sometimes they are just below the Marble Series, and sometimes just above."

Lithologically, the tillite varies from angular blocks and pebbles, set in a siliceous matrix, to pebbly limestones and grits with facetted pebbles; the size of the larger inclusions ranges from 2 - 30cm. The thickness of the tillite horizon varies from 30 to approximately 1000 metres.

The tillite is followed by the Khomas Series, consisting essentially of schists, with subordinate marbles and quartzites.

The "Quartzite Series" of Northwestern Damaraland, mapped by Gevers and Frommurze (1929) has been found to correspond to the Nosib Formation. This Series is overlain by a marble horizon consisting of one main band, 300 - 450 metres thick, over- and underlain by several thinner beds. The marbles vary in colour from blue to white, are occasionally banded and brecciated, and locally contain amphibolites derived by the metamorphism of impure argillaceous limestones (Gevers, p. 35). No tillite horizon was found in this area.

The "Marble Series" just described is conformably overlain by the great thickness of schistose rocks that constitutes the "Mica-Schist Series", now termed the Khomas Series. These rocks, ranging from mica-schists through arenaceous schists to micaceous quartzites, contain (Gevers, p. 36):

"......... numerous narrow bands of altered, usually ferruginous limestone, as well as bands of "marble" - granulite, garnet-granulite and, less commonly, amphibolite. Ortho-amphibolites derived from ancient basic intrusions, while generally common in the Fundamental Complex, are rather rare in the area under discussion."

In the region south of Windhoek Gevers (1934) found that (p. 231):

"Where there are continuous exposures from the Quartzite to the overlying Marble Series, as in the Billstein-Oamites area, there is generally a transition zone, in which fine-grained sericitic quartzites alternate with in part very quartzose biotite- and amphibole schists. In this region lenses of fine-grained sericitic quartzites are to be found right through the Marble Series as high up as the basal schists of the Khomas Series."

The "Marble Series", now termed the Hakos Series, in this area varies greatly in thickness and in lithology, the marbles grading laterally into schists. The amphibolites, talc rocks and itabirites on the farm Hohewarte 76, termed the "Hohewarte Series" and equated with the Duruchaus Series by Gevers, have been shown by Schalk (1961) to grade along strike into the Lower Hakos Series.

Concerning the Tillite Horizon, Gevers (p. 234) has this to say:

"In Western Damaraland, along the northwestern margin of the great Khomas syncline, the Chuos Tillite occupies a definite horizon between the Quartzite Series and the overlying Marble Series, but the occurrence of a great thickness of varved rocks at the Langer Heinrich, right through the very attenuated

Marble Horizon into the lower portion of the Khomas Schists, shows that glacial conditions in other regions continued for a considerable period. The tillite-horizon in Western Damaraland, moreover, is marked by well-developed rocks of morainic nature of very variable thickness and, in a number of places, by varved rocks overlying them.

In the Windhoek and Rehoboth districts, on the other hand, the tillite-horizon is indicated in the main by pebbly phyllites, limestones and altered marls forming part of the Marble Series, and also by banded pebbly biotite-schists immediately overlying the latter and belonging to the lowest horizon of the Khomas Series."

The maximum thickness of the Hakos Series, together with the tillite horizon, is given by Gevers as approximately 2,000 metres. These rocks are overlain conformably by those of the Khomas Series.

In contrast, Martin (1965, p. 37) states that in the Dordabis area the Damara System overlies the Nosib Formation unconformably, beginning with a white, locally conglomeratic quartzite.

In the area round the Khan River, Smith (1965, p. 21) found no conglomerate to occur at the base of the Damara System, which here follows the Nosib Formation conformably. The stratigraphy and lithology of the Lower Hakos Stage is extremely varied, facies changes from "sugary" quartzites to dolomitic marbles being common. The latter rocks make up the bulk of the stage. Several pebble bands are mentioned, as are quartz-biotite and biotite-amphibole schists. A maximum thickness of 180 metres is quoted for this Stage. It is noteworthy that the tillitic Chuos Stage, with a thickness varying from nothing to 600 metres, here lies between the Lower and Upper Hakos Stages.

The Upper Hakos Stage consists of a number of marble bands with intercalated biotite-schists and some quartz schists. For this unit a maximum thickness of approximately 650 metres is quoted by Smith (p. 27).

Working in the Huab-Welwitschia area, Frets (1969) found the Nosib Formation to be absent from the southern side of the Basement ridge that separates the Outjo Facies from the Swakop Facies. Accordingly, the Damara System rests directly on quartzitic and granitic gneiss, and begins with a basal conglomerate, or a tilloid which Frets interprets as corresponding to the Chuos Tillite. This would indicate that the Lower Hakos Stage is largely absent in this part of the Damara System; only in the immediate vicinity of Welwitschia is it represented by a thin sequence of phyllites, shales and argillaceous limestones. The tilloid may laterally grade into phyllites and pebbly shales. Of maximum thickness 100 metres, it is overlain by 40 - 800 metres of limestone followed by arenites and argillites correlated with the Khomas Series.

In the area west of Sesfontein, Guj (1970) found the Hakos Series to overlie the Nosib Formation paraconformably over most of the area mapped, but does mention two local angular unconformities. Generally, the Lower Hakos Stage in that area begins with a discontinuous band, up to 10 metres thick, of dark, polygenetic conglomerate or grit, composed of unsorted, poorly rounded pebbles in a calcareous or pelitic and ferruginous matrix. This is followed by 60 - 100 metres of dark ferruginous phyllites, and by a variable thickness of grey phyllitic or sandy schists, which may be graphitic. Itabirites and siliceous carbonates are found throughout the sequence; infrequent carbonate bands accompany the increasingly coarser-grained schists higher in the succession. Several concordant and discordant amphibolite bodies, regarded as sills and stocks, are present throughout the stage.

The base of the overlying Upper Hakos Stage is marked by the Tillite Substage (Chuos Tillite).

THE DAMARA SYSTEM BETWEEN WITVLEI AND OMITARA

Outline of Stratigraphy and Structure

The Hakos Series in the area under consideration consists of the following broad lithological groups:

i) Quartzites, together with a conglomerate horizon;

ii) Dolomites and limestones;

iii) Schists of various types;

iv) Igneous rocks.

The sequence is characterised by repetition of types (i) to (iii) above, reflecting the unstable conditions and essentially shallow-water environment that must have accompanied the early formative stages of the Damara trough. Amphibolite intercalations in the assemblage are not uncommon, and the present author considers these to represent, at least in part, metamorphosed mafic volcanics. Similar findings were made by Rabie (Martin 1965, p. 35) in the extreme northwest of South West Africa.

As mentioned in Chapter VII, a tillite horizon as such has not been recognised between Witvlei and Omitara. However, the great thickness of sediments overlying the Nosib Formation makes it probable that the whole of the Hakos Series, and possibly even the lower portion of the Khomas Series, is present in this region. If the Eintracht 118 conglomerate horizon can be equated with the Chuos Tillite, it would serve as a useful marker for the subdivision of the Hakos Series in the area into a Lower and an Upper Stage.

Only one occurrence of granite was noted in the area mapped. It lies in the southern portion of the farm Sandflats 123 and appears, from field relationships, to represent a low-temperature, late-syntectonic body.

Structurally, the sediments of the Hakos Series form a prominent anticline which dominates the northern portion of the region. The railway line roughly bisects this feature between Diana 117 and Omatewa 113. To the south of the White Nossob River there occurs a large syncline, whose folds die out rapidly towards the west. The schists interbedded with the more competent quartzites and dolomites are in part folded isoclinally.

In the following sections it is proposed to discuss at some length the lithology, distribution, field relationships and petrography of the various rocks that make up the Hakos Series, and the lower part of the Khomas Series, between Witvlei and Omitara. Details are given of attempts to detect variations in mineralogical composition of the many quartzite horizons in the succession. These are usually not easily distinguishable from one another, and often closely resemble the Kamtsas quartzites. Furthermore, mineralogical studies were undertaken on some of the many carbonate units in this area, as well as on the amphibolites and the Dachsberg granite.

The Contact with the Nosib Formation

In the area under discussion, the Hakos Series lies on the Nosib Formation with an unconformable contact, the exact nature of which could not be determined owing to:

(1) The widespread sand cover which blankets most outcrops, especially with increasing distance from the White Nossob River;

(2) The presence of a shear zone, marked by outcrops of massive white vein quartz, running along the contact. Brecciation and local mylonitisation suggest that some movement has occurred along this zone.

The practice followed by the Geological Survey of South West Africa is to place the base of the Damara System in this area at the base of the lowermost Hakos dolomite horizon (K. Seeger, personal communication). However, a study of field relationships by the author has shown that the basal dolomite horizon lies conformably on a quartzite which, on Losberg 105, forms the Okaheberg. The essentially linear nature of this quartzite-dolomite unit is in marked contrast to the fairly tight folding found in the sediments of the underlying Nosib Formation. Accordingly, in this work the Okaheberg quartzite has been taken to represent the basal unit of the Damara System in the area between Witvlei and Omitara.

An angular unconformity should be present between the Damara System and the Nosib Formation, since the latter was obviously involved in orogenic movements before the Damara sediments were deposited. However, a short distance upstream from the Losberg homestead, where the arbitrarily placed contact described above is exposed, no such unconformity was noted. The Okaheberg quartzite has here thinned to less than 5 metres and is extremely brecciated. The overlying dolomite has lensed out completely. Approximately 500 metres southwest of the White Nossob River, mylonite was found along this contact. The presence of such shear zones, which are especially prominent on Eintracht 118, makes it probable that the apparently transgressive relationship of the Damara System with the Nosib Formation, as suggested from Map 2, is in large measure due to faulting along these zones.

Thus, if the Lower Member of the Kamtsas Quartzite is used as a marker band it will be seen from the map that the somewhat oblique trend of the fault, bounding the Nosib Formation in the southeast, has resulted in a reduction in the thickness of the Duruchaus Member below this quartzite when the strata on Owinieikiro 213 are compared with those on Otjiwarumendu 119. Similar conditions are found to prevail if the overlying sediments are considered. The exposed width of strata between the Lower Kamtsas Member on Losberg 105 and the dolomite band running past the windpump (grid reference -16850/39120) in the centre of Goldene Aue 106 is approximately 5.6km. Only 13km. to the northeast, in the northwestern portion of Otjiwarumendu 119, the distance between the same two horizons has been reduced to some 3.1km. It is considered unlikely that this difference can be explained solely by non-deposition, in the area northeast of the railway line, of the Upper Kamtsas Member and of the basal quartzite-dolomite unit of the Damara System. A far more plausible explanation is that faulting along the shear zones has resulted in the wedging out of certain stratigraphic units, leading to the apparently unconformable relationship between Nosib and Damara sediments, especially on Eintracht 118.

The Quartzites and Associated Carbonate Rocks

(a) Introduction

It is proposed to describe these two rock types together since, as a study of the geological map (Map 2) will indicate, they are usually associated in the field with each other. The alternation of quartzites with limestones and dolomites appears to be characteristic of the early period of Damara sedimentation. This feature is well represented in the extreme west of the area mapped, on the farms Astra 205, Dorka 206 and Costa 207, and on Diana 117 in the northern portion of the region.

The quartzites often, but not necessarily everywhere, give rise to prominent relief. This fact was extensively used in the photogeological interpretation of the regional stratigraphy. Generally, the quartzites range from fine-grained, buff to grey, bedded types, showing heavy-mineral banding and conspicuous cross-bedding, through massive, reddish, felspathic varieties to sericitic, flaggy quartzites; calcareous quartzites are rare. Most of these types may be found at any level in the sedimentary succession, and may laterally grade into one another along a particular horizon. The stratigraphic position of a specimen of quartzite from this region can thus not be determined from study of the hand specimen. As will be seen below, even mineralogical investigations undertaken by the present author have not revealed significant differences between the various units.

The carbonate rocks associated with the quartzites also show a considerable number of types; lateral variations along strike from one variety to another are not uncommon. The most widespread variety is a fine- to medium-grained blue-grey rock, ranging in composition from a pure marble to a dolomitic marble. Tremolite-bearing varieties have been noted, as have local occurrences of coarse-grained, pure-white dolomite. The small amount of quartz usually present is concentrated along bedding planes, and causes these to stand out on weathered surfaces.

Locally, as in the Vierkuppenberg on Eintracht 118, a definite sequence in the dolomites could be established. A basal member of blue marble is followed by white, coarsely crystalline dolomite, the succession being capped by a reddish-brown limestone. This latter was found at isolated localities only.

The marbles and dolomites in the area may form prominent relief; the Vierkuppenberg is the best example of this. Elsewhere, the horizons manifest themselves as low ridges, or merely as gentle rises in the flat country. The concentration of camelthorn trees (Acacia giraffiae) on these calcareous bands has already been mentioned. Even in areas of deep sand, where the adjacent quartzite horizons would not be found cropping out, the marbles often form low pavements. In areas devoid of outcrop the deeper-red colour of the sand over these rocks usually helps to demarcate the horizon in the field.

(b) Distribution and Field Relationships

The Basal Unit

In the area between Witvlei and Omitara the Hakos Series begins with a quartzite horizon, and thus emulates conditions found in the vicinity of Dordabis (Martin 1965, p. 37). This basal quartzite, together with the overlying dolomite, can be traced intermittently for over 20 km. in the area mapped by the author. The contact with the underlying phyllites of the Duruchaus Member is exposed at one locality only on the farm Losberg 105 and, as mentioned above, provides little significant information.

Owing to poor topographical expression, exposures along this quartzite horizon are not good for most of its western portion, and the mapping here is, of necessity, largely inferential. However, the overlying dolomite was found to be better exposed. Apart from some folding on Costa 207, as deduced from a study of aerial photographs coupled with an inspection of the overlying strata, the quartzite-dolomite unit runs remarkably straight. The trend is parallel to and approximately 4 km. northwest of the Upper Kamtsas Quartzite. Dips are usually steep to the northwest.

The quartzite horizon is exposed locally on Costa 207, and on the boundary of that farm with Dorka 206. Here the rock is a jointed felspathic quartzite, rather weathered, and almost devoid of bedding.

In the kraal immediately south of the homestead on Dorka 206, isolated outcrops consist, under a thin skin of calcrete, of fine-grained, finely bedded blue quartzite containing disseminated iron oxides. Bands of reddish carbonate parallel to the bedding suggest that the rock is rather calcareous; this was borne out by subsequent study of a thin section.

On the farm Losberg 105, some 6 km. further to the northeast, float consisting of vein quartz and iron-stained quartzite was found below outcrops of the over-lying dolomite. From here northeastwards the quartzite manifests itself as a low ridge, standing 2 - 3 metres above the surrounding country. One kilometre north of the windpump situated in the centre of the farm, the quartzite is seen to be a pink, well-bedded, medium-grained rock, dipping steeply to the northwest. Cross-bedding shows locally overturned beds to be present. The horizon is conformably overlain by the lowermost band of Hakos dolomite. Exposures of both rock types are excellent in a small westerly plunging fold in the vicinity. Some brecciation has occurred along the contact between dolomite and quartzite.

From Costa 207 to the centre of Losberg 105, the thickness of this basal quartzite appears ro remain fairly constant, and is estimated as 150 metres. The overlying dolomite measures 200 metres at the Dorka homestead, but thickens to reach double that figure on Losberg 105. Immediately southwest of the Okahe-berg it forms two hills, the more southwesterly being 700 metres long, and rising some 50 metres above the plain. From this, its maximum development, the dolo-mite thins rapidly and dies out along the northwestern flank of the Okaheberg.

From the abovementioned small fold north of the windpump in the centre of Losberg 105, the basal quartzite member of the Lower Hakos Stage broadens out rapidly in a northeasterly direction. At the same time dips become very steep, and overturning to the southeast is evident. In contrast to the overlying dolomite, which here forms the hills described above, the quartzite does not give rise to any relief and is poorly exposed for a distance of nearly 1.5 km. Shearing is indicated by the presence of massive vein quartz, At the Okaheberg, which rises to a height of 150 metres above the surrounding country, the quartzite approaches 500 metres in thickness over a strike distance of 2.5 km. before thinning rapidly. In the exposure immediately southwest of the White Nossob River, it is only 5 metres thick, still overturned and rather brecciated. This section forms the western end of one of the numerous shear zones between Nosib and Damara sediments, and the thinning out of the quartzite horizon is no doubt partially due to faulting along this zone.

Northeast of the river, only one further exposure of this quartzite was observed, in a gravel pit along the route of the new Windhoek-Gobabis road. Here the band is almost vertical, only 1 - 2 metres thick, and lies between quartz-sericite schists.

The Costa 207 - Goldene Aue 106 Unit

As mentioned earlier in this chapter, the western portion of the region mapped is characterised by an alternating sequence of quartzites and dolomites. The lowermost quartzite-dolomite unit described above is overlain by a similar lithological association which, on Costa 207, forms prominent relief. On the boundary of that farm with Dorka 206, folding has given rise to an anticlinal hill (grid reference -7080/47070, exhibiting overturned bedding in its southern limb. In this locality it is of interest to contrast the tight folding in the quartzite with the broad plications of the overlying dolomite band. This incompetent horizon appears to have reacted to the folding stress by means of plastic flow, as evidenced by the great width of outcrop just east of the Dorka 206/Costa 207 boundary. For the area as a whole, the thickness of this dolomite horizon remains fairly constant at approximately 100 metres throughout its exposed strike.

On the farm boundary mentioned above, the quartzite horizon is some 400 metres thick, but swells to over 600 metres in the Loskop, a hill lying 1.5 km. further east. Between this prominence and the farm Goldene Aue 106, the quartzite forms a very low ridge only, but appears to reach its maximum thickness of 850 metres some little distance northeast of the Dorka homestead. Outcrop between the Loskop and Goldene Aue 106 is sporadic. Near the boundary between Goldene Aue 106 and Astra 205 a facies change occurs. Phyllites take the place of the lower portion of the quartzite, whose continuation in a northeasterly direction is abruptly terminated by a small syncline in the southern corner of Goldene Aue 106. The southeastern limb of this syncline is exposed over a width of some 20 metres, and then only over a strike length of approximately 100 metres. Outcrops are in the form of low pavements. The northwestern limb, on the other hand, forms a hill (grid reference -15300/43900) 300 metres long, rising 10 - 12 metres above the plain. The rock here closely resembles that found on Costa 207, and on the Loskop. This northwestern limb, with its very steep southeasterly dips, thins rapidly in the direction of the boundary with Astra 205, forming a low ridge with isolated quartzite blocks only. Some shearing is evident here between the quartzite and the overlying dolomite. The entire unit dies out on Astra 205 after a further short distance.

Occurring near the top of the quartzite, but entirely separate from the main dolomite horizon, is a further thin dolomite band, which was traced across almost the entire width of the farm Dorka 206.

Lithologically, the quartzites vary somewhat along strike. Specimen 8, collected on Costa 207, 1.5 km. west of the boundary with Dorka 206, is a very fine-grained quartzite containing much finely disseminated magnetite. It is a faintly bedded, grey rock, showing occasional pink stains, and exhibits a conchoidal fracture.

Specimens 31 and 32, taken from the western end of the Loskop, and from the anticlinal hill on the boundary fence Dorka 206/Costa 207 respectively, are very similar in hand specimen. The Loskop quartzite shows a somewhat pockmarked weathered surface.

Immediately north and northeast of the homestead on Dorka 206 the rock is flaggy, and rather felspathic.

The overlying dolomite exhibits little lithological variation along strike. It is a fine-grained, light-blue to grey rock, usually bedded and occasionally, as on Costa 207, exhibiting minor crenulations having a steep easterly plunge.

The Straussenkuppe-Vierkuppenberg Unit

The quartzite-dolomite sequence described above is, on Astra 205 and Dorka 206, overlain by an estimated 1400 metres of essentially pelitic sediments. These are followed by what is the best-developed and most persistent quartzite horizon in the entire region. Entering the mapped area from the southwest this quartzite forms the Straussenkuppe, an inselberg nearly 1 km. in length. It rises to 1641 metres above sea level in the southwestern corner of Astra 205, where the horizon is approximately 380 metres thick. The rock here is very similar to that of the band forming the Loskop, 4.5 km. to the south.

Trending roughly eastnortheast from the Straussenkuppe, the quartzite forms a low, sandy ridge carrying float with occasional outcrops. Approximately 1 km. west of the boundary fence with Goldene Aue 106 the horizon once more forms prominent relief. Numerous dip measurements have shown this small hill to be a synclinal feature, its axis plunging westwards at a moderate angle.

The centre of the farm Goldene Aue 106 is almost devoid of relief, and is covered by Kalahari sand. Accordingly, the quartzite is exposed once more only near the windpump (grid reference -16850/39120) in the centre of the farm. Here, the unit has thickened to approximately 1200 metres; this figure includes a dolomite band, 100 metres thick, lying in the centre of the quartzite horizon. This dolomite first outcrops 1 km. southwest of the windpump but could, from aerial photographs, be traced for a further 3 km.

towards Astra 205. One kilometre north of the windpump, a body of basic rock was found to occupy the centre of the dolomite horizon, and could be traced for a considerable distance northwards along strike.

This basic rock weathers like a typical dolerite, forming rounded boulders of a rusty-brown colour. Fresh specimens are grey-green, and rather fine-grained. A chilled margin is found along the northern contact with the dolomite. The rock will be described in detail in the section on the igneous rocks.

Northeast of the White Nossob River the quartzite horizon thickens further owing to the presence of intercalated quartz-sericite phyllites. Outcrops on the northeastern bank of the river, on the boundary Diana 117/Eintracht 118, reveal a grey, fine-grained quartzite which is thinly bedded and shows heavy-mineral banding, dipping steeply northwestwards. The rock is brecciated, and white vein quartz shows the exposure to be adjacent to one of the many shear zones that cross Eintracht 118. The dolomite band in the quartzite is only 20 metres thick where exposed on the river bank; the colour here ranges from pink to blue-grey. Immediately overlying this horizon are quartzites with interbedded graphitic schists.

Away from the river the dolomite band broadens and gains in height, roughly following the boundary between Diana 117 and Eintracht 118. After some folding accompanied by faulting, the band crosses the Windhoek-Gobabis road, at which point it is some 180 metres thick. The ridge, here 15 - 20 metres high, has died out by the time the railway line, 1.7 km. away, is reached. Between this point and the southwestern end of the Vierkuppenberg there are no outcrops.

The quartzite overlying the dolomite is cut off by a fault immediately east of the Hutberg on Diana 117. The underlying quartzite continues to broaden on Eintracht 118, especially in the area northeast of the railway line. Southeast of the Vierkuppenberg, the outcrop width is approximately 2 km. This is probably due to the presence of schists interbedded with the quartzite, and to duplication of certain horizons by faulting and folding.

Of interest in this vicinity is the presence of a conglomerate band. This occurs near the base of the quartzite, and becomes more prominent towards the northeast of the area mapped. The characteristics and significance of this unit will be discussed at some length later in this chapter.

Northeast of the railway line the dolomitic horizon in the quartzite reaches its maximum development of some 750 metres in the Vierkuppenberg. This ridge, approximately 1.5 km. long, is named after its characteristic profile of four peaks along the steep southeastern scarp slope. At its northeastern end the hill shows the three types of carbonate rock, referred to at the beginning of this chapter, to be well developed. Beginning with the basal blue dolomite, the sequence is:

	Approx. thickness
Pink dolomitic limestone	200 metres
White dolomite	270 "
Blue dolomite	280 "

The horizon again forms a prominent ridge in the eastern corner of Eintracht 118, continuing into Sandflats 123. In this area the fault that can be traced northeastwards from Goldene Aue 106, past the Hutberg and Vierkuppenberg, asserts itself as a zone of brecciation. Beginning just west of the windpump (grid reference -30240/32940) immediately southwest of the boundary between Eintracht 118 and Sandflats 123, the zone broadens out towards the northeast. Where it leaves the mapped area it forms a low rise consisting of massive vein quartz and highly brecciated quartzites.

Emplacement of the Dachsberg granite near the southwestern boundary of Sandflats 123 appears to have led to lateral compression, causing the coalescence of three dolomite bands in the vicinity of the windpump on Eintracht 118. The dip of the strata here is nearly vertical, and a considerable thickness of dolomite must have been faulted out, since the Vierkuppenberg horizon has here thinned to less than 100 metres. Remnants of the colour sequence described above are still found on the northern side of the shear zone, immediately west of the windpump, in the dolomite horizon that enters Eintracht 118 just west of the Vierkuppenberg. Northeast of the windpump the steeply dipping dolomite bands combine to form a ridge whose spine is formed by the fault zone. This latter broadens eventually to engulf completely all the dolomite bands, one of which reappears 2.5 km. further to the northeast, where the track to Airlie 124 crosses the fault zone.

Below the zone of brecciation, the lower portion of the quartzite horizon, together with the conglomerate, is well represented. It reaches a thickness estimated to be well over 800 metres in the southeastern corner of Sandflats 123.

The Joachimstal 107 - Astra 205 Unit

Since outcrops in the western portion of the area are not abundant, the geology of the northern part of Astra 205, together with that of Joachimstal 107 and Büschow 108, has had to be compiled largely with the help of aerial photographs. In the field, isolated exposures of further quartzite-dolomite units similar to the Straussenkuppe-Vierkuppenberg horizon, described above, were found. These could not, however, be studied in the same detail as the units occurring lower in the succession.

Tonal changes in the photographs reveal the existence of a large syncline, trending roughly westnorthwest across Büschow 108, Joachimstal 107 and the northwestern portion of Goldene Aue 106. The initially tight folds die out quickly towards the west, but the validity of the photogeological interpretation could, fortunately, be checked in the extreme west of Joachimstal 107. In this locality, 1 km. southeast of the boundary with Büschow 108, a small eminence, termed the "Quartzite Hill" by the present author, affords good exposures of what appears to be the highest quartzite-dolomite unit in the area mapped.

The exposure forms a ridge some 600 metres long, folded into an "S" shape, and apparently lying in the axial plane of the syncline already referred to. The ridge rises to a height of some 10 metres above the level of the surrounding country, which here consists of slightly undulating grassland on red sand. The immediate vicinity is devoid of outcrop. Float on the Joachimstal 107 - Büschow 108 boundary shows the quartzite horizon to continue northwards, but no exposures of quartzite or dolomite could be found in the bed of the White Nossob River, west of the Kuduberg. The southwesterly continuation of the dolomite overlying the Quartzite Hill was mapped from aerial photographs. This horizon widens considerably in the northern portion of Astra 205.

The Quartzite Hill consists of two parallel quartzite ridges, some 30 metres apart, dipping fairly steeply to the west. The intervening, somewhat lower ground is studded with Catophractes alexandrii, suggesting a softer, more calcareous formation to be interbedded with the quartzites. No exposure of this interbed was found. Dolomite was observed to under- and overlie the quartzite horizon.

The lower quartzite unit is a compact grey rock, showing a silky lustre on fresh surfaces. Higher up the quartzite is buff coloured, fine grained, well-bedded, and rather micaceous. On the outer (i.e. eastern) side of the southern portion of the "S" the quartzite forms a small but steep scarp, which rises some 4 - 5 metres above the ground sloping down to the plain.

The upper quartzite is somewhat coarser in grain than that of the lower unit, and is lighter in colour; brown predominates on weathered surfaces. The rock is very friable and more flaggy than the lower quartzite, splitting easily along the bedding planes. Cubes, 1 - 2mm in size, of limonite after pyrite are developed, as are occasional needles, up to 1cm long, of black amphibole.

Both quartzite units exhibit one prominent lineation; occasionally a second linear feature was observed. With an average westerly dip of 60° these quartzites, together with the softer interbed, attain a maximum thickness of 130 metres in this locality.

The lower quartzite rests, with what appears to be a slight angular unconformity, on dolomite. This latter unit, dipping to the west at approximately 70°, has an outcrop width of 40 metres. A precise thickness could not be obtained since the sand cover obscures all outcrop with increasing distance from the hill. Float in the sand suggests that this dolomite is underlain by a further quartzite horizon, but this could not be proved. In the most easterly exposure, some 30 - 40 metres below the contact with the lower member of the Quartzite Hill, the dolomite forms low pavements exhibiting the typical "elephant's hide" surface. The rock is dark blue on fresh surfaces, and is extremely fine grained.

Immediately below its upper contact this dolomite shows a green tinge, and contains lenses of brecciated ferruginous quartz. These possibly represent relics of former quartzitic interbeds. Weathered surfaces are very wrinkled in appearance, being covered by a network of protruding quartz-iron oxide veins. At one locality cubes of limonite after pyrite were noted. On the immediate upper contact a fresh surface shows the fine-grained dolomite to be in process of replacement by a coarse-grained pink carbonate, with concomitant introduction of iron.

Where the actual contact is exposed, the dolomite is seen to grade into the quartzite by means of a zone, up to 3 metres thick, of intense brecciation. If one includes the abovementioned remnants of quartz breccia in the dolomite, the zone is at least 10 metres thick. Outcrops here take the form of rounded boulders up to 1 metre high, of white quartz heavily impregnated with iron oxides. No trace of any original bedding can be seen, but in places iron oxides, now largely altered to limonite, give sections of the rock a pseudo-stratified appearance. Layers 2 - 3mm thick of limonite alternate with vein quartz in a fairly regular manner, yet surfaces normal to this banding show that the iron oxides form a complex system of veins cutting through the rock. This ferruginous cement between the vein quartz fragments locally attains a thickness of 15cm, and in the wider bands leached cavities are prominent on weathered surfaces. Examination of these cavities shows the iron oxides to have altered to an earthy or botryoidal form, possibly goethite. This mineral often exhibits iridescence, the colours resembling those of bornite.

The upper dolomite conformably overlies the quartzite; owing to poor exposures no estimate of thickness can be given. The rock is lighter in colour than the lower dolomite, and of coarser grain. Occasional siliceous layers, several centimetres thick, are present.

<u>The Hutberg - Kuduberg - Omatewaberg Unit</u>

The feature which dominates the central northern portion of the area mapped is the Kuduberg-Omatewaberg massif, an eroded anticline of Damara quartzite now transected by the White Nossob River. Both limbs of the anticline give rise to prominent relief, the Kuduberg at 1748 metres being the highest point of the country between Witvlei and Omitara. It forms a huge whaleback trending towards the northwest, and measuring 4.5 km. in length. Its counterpart on the northern side of the river, the Omatewaberg, is somewhat lower and only 2 km. long. The phyllites and schists underlying this quartzite horizon are exposed in the valley of the Nossob between the two hills.

Northeast of the White Nossob the southern limb of the anticline is not well exposed. On the river bank on Diana 117 the quartzite is medium grained and rather massive. Away from the river, the geology becomes masked by gravel and calcrete; north of the Windhoek-Gobabis road Kalahari sand is found. It is only in the extreme east of the farm Diana 117, between the road and the railway, that good exposures of the quartzite are found. Compression and faulting during the folding of the Damara rocks has resulted in the southern limb of the Kuduberg-Omatewaberg anticline meeting the Straussenkuppe-Vierkuppenberg unit nearly at right angles. The Kuduberg quartzite swings sharply to the northeast, and the core of this fold is now occupied by the Hutberg, a small conical hill rising approximately 60 metres above the surrounding country.

On the northern flank of the Hutberg, friable felspathic quartzites are exposed, dipping southwards. These are overlain by a thin band of fine-grained, grey quartzite, containing disseminated iron oxides.

The summit of the hill is composed of massive pink quartzite showing occasional cubes, 1mm in size, of pyrite. The fracture of this very fine-grained rock is conchoidal.

Northeast of the Hutberg the southern limb of the anticline does not outcrop again before being cut off against the southwestern end of the Vierkuppenberg by the fault described earlier.

In contrast to the above, exposures southwest of the White Nossob River are very good. In its north-eastern section, almost the entire width of the farm Joachimstal 107 is occupied by the Kuduberg. The central portion of the northern flank of this hill is well exposed by a meander in the river. The nose of the anticline, really an anticlinorium, plunges west-northwest at some 20° and straddles the boundary between Joachimstal 107 and Büschow 108. When viewed from a distance, the hill is seen to exhibit a large-scale layering parallel to the bedding; this sub-horizontal feature appears to be due to differential weathering. In the resistant bands the quartzite has a hard smooth surface. A fresh surface of the rock shows resilicification to have formed a skin approximately 1cm thick. Beneath this, the rock is "floury" and resembles the grey quartzite composing the softer layers in the hill. These latter bands weather with peculiar knobbly surfaces. The Omatewaberg exhibits a similar banding, which is well brought out on the aerial photographs. That portion of the anticlinal nose lying on Omatewa 113 is not well exposed, except immediately adjacent to the river. East of the Omatewaberg the quartzite does not rise above the level of the

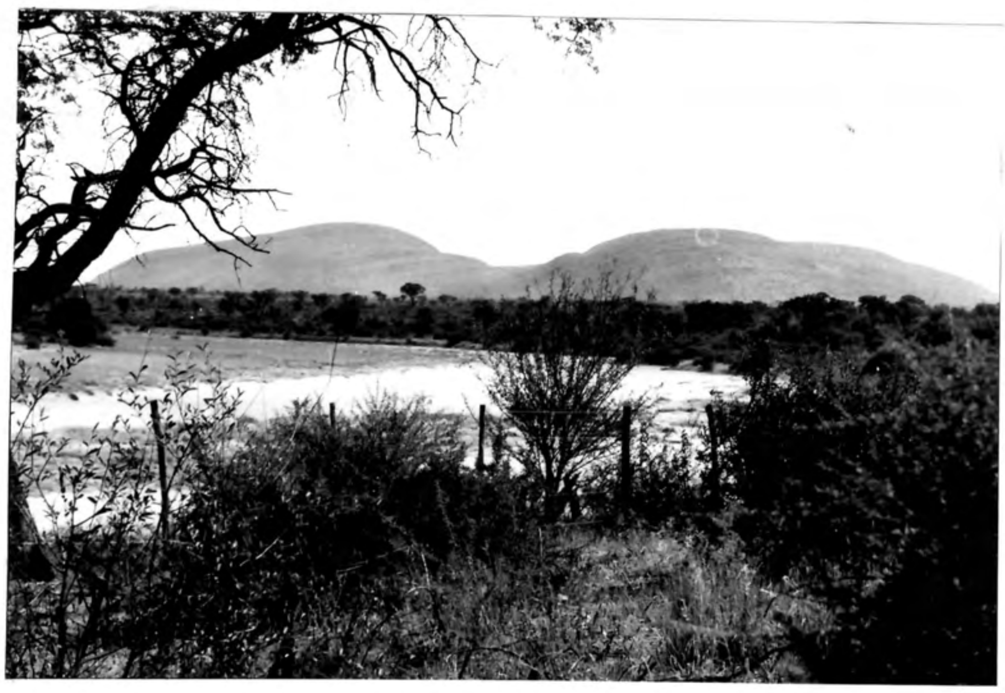


Plate IX. View northwestwards from Diana 117 to the Omatewaberg, showing the layering due to alternating bands of differing hardness in the quartzite. The dry bed of the White Nossob River is in the foreground.

surrounding country, and outcrops in the centre of Diana 117 are sporadic.

In the extreme eastern corner of Joachimstal 107, just northwest of the ruined farmhouse (grid reference -18050/34350), the quartzite forming the eastern continuation of the Kuduberg is well exposed. It is buff in colour, well bedded and breaks into large slabs. Regional metamorphism subsequent to the intrusion of a large dolerite body in the vicinity has obliterated any contact-metamorphic phenomena that might have been anticipated there. Just a short distance eastwards along strike, on the boundary with Goldene Aue 106 adjacent to the river, the upper portion of this quartzite horizon presents an entirely different appearance. Here the rock is pink, felspathic, massive and very compact. The surface weathers irregularly, forming small cavities. Besides the usual heavy minerals, the rock in hand specimen shows some epidote, as well as specks of a green mineral assumed to be malachite.

The limited exposure of both upper and lower contacts of the quartzite, coupled with the presence of folding, as found in the northwestern nose of the Kuduberg, make an assessment of the thickness of this unit very unreliable. The most accurately definable section across the strata is obtained adjacent to the White Nossob River on the farm Diana 117, where a thickness of 850 metres is suggested. In the Kuduberg itself the thickness could be greater; in the vicinity of the homestead on Omatewa 113 a figure of 1150 metres seems appropriate. This latter figure also fits the interpretation of the structure of the northern limb on Diana 117.

The quartzite unit described above is, as appears typical in this area, overlain by a dolomite band which can be traced, albeit intermittently, for a strike distance of over 35 km. This horizon was first noted on the southeastern flanks of the Hutberg, where a shear zone of white vein quartz separates the quartzite from the overlying blue carbonate rock. West of the Hutberg the horizon could be traced from aerial photographs by the stands of camelthorn trees growing on it. A gravel pit adjacent to the main road on Diana 117 exposes a portion of this unit, which was again found outcropping on the left bank of the White Nossob River, some 2 km. further west.

In the eastern corner of Joachimstal 107 the contact between quartzite and this overlying dolomite is never exposed, although it can usually be placed within a few metres. In this locality the dolomite horizon shows a variation of the colour sequence described for the Vierkuppenberg. It begins with a fine-grained, blue limestone (marble) showing abundant tremolite needles. This is overlain by a narrow bed of fairly coarse-grained, white dolomite, which in turn is followed by a medium-grained, blue dolomite. Some 400 metres to the west, immediately north of the ruin (grid reference -18050/34350) on Joachimstal 107, the dolerite intrusion already mentioned has displaced the lowermost limestone horizon, so that the white variety is the first to be exposed. It is overlain by and grades laterally into the blue variety, which here is very rich in tremolite. The thickness of the dolomite-limestone unit in this vicinity reaches 100 metres.

Approximately 1.2 km. west of the ruined house, the dolomite horizon is again found outcropping along the camp fence that trends southeastwards from the windpump on the White Nossob River. The unit, whose upper and lower contacts are not exposed, here (grid reference -16850/34300) forms an outcrop 50 - 60 metres wide. The dip is very shallow, southerly and in the range 10 - 30°. Occasional minor folds with southerly-plunging axes were also noted.

Commencing at the most northerly exposure and working up the succession, the unit starts with a zone 10 metres in width presenting a deep blue-black surface, on which stand out tremolite needles up to 1.5 cm in length. A section of the rock shows it to be a marble, consisting of alternating blue and white bands corresponding to the bedding. This type is overlain by lenses of coarse-grained, white tremolite-marble, showing a rusty brown outer skin, and having a sub-parallel arrangement of tremolite needles on the bedding planes. Locally in this horizon a green rock, consisting of calcite and tremolite in roughly equal proportions, is developed. The succession is capped by a medium-grained tremolite-bearing marble, again composed of alternating blue and white bands 2 - 5 mm wide. On weathered surfaces the white bands are seen to be more resistant than the blue layers.

From the exposure just described the dolomite horizon could, from aerial photographs, be traced westwards, curving round the nose of the Kuduberg. It was next seen to outcrop on the southern bank of the White Nossob River, in the sharp bend (grid reference -13600/29900) 2 km. below the boundary

Osombahe 112 - Omatewa 113. Here the upper few metres of the Kuduberg quartzite horizon are exposed, and are seen to be interbedded with narrow bands of amphibolite and biotite-epidote schist. The quartzite is followed by 3 - 5 metres of talc-carbonate schist, very well exposed on the river bank. The uppermost bedding plane of this rock, immediately below the overlying dolomite, shows the development of two sets of minor folds, the one running across the other at a high angle. This dolomite is the typical blue-grey variety, and is only 10 metres thick in this exposure. It is overlain by schists which may locally be graphitic.

The Omatewa 113 section of the dolomite had, perforce, to be interpreted from aerial photographs. Dolomite outcrop in the form of low pavements was, however, once more observed on the boundary with Altenstein 115. On the eastern boundary of the latter farm a quartz-filled shear zone nearly 300 metres wide cuts through the dolomite, forming a hill (grid reference -21800/28450) some 20 metres high. The dolomite horizon is once more well exposed in the vicinity of the windpump in the northern portion of Diana 117. From here the unit gains in height towards the southeast, forming a ridge standing 6 - 8 metres above the surrounding country. On the boundary between Diana 117 and Eintracht 118 the colour sequence blue-white-red, from the base of the horizon upwards, is developed again.

South of the Dachsberg on Sandflats 123, the dolomite disappears in the shear zone already described; the most easterly outcrop of this band in the area mapped is on the eastern side of the track running through Sandflats 123 to Airlie 124.

Between Altenstein 115 and Sandflats 123, the horizon described above is overlain, some 600 metres higher in the succession, by a further narrow dolomite band, which is terminated at both its western and eastern extremities by shear zones. Between these two bands there occurs a curious circular outcrop of dolomite in the northwestern corner of Eintracht 118. This appears to represent duplication of the lower horizon by folding. An unexposed granite cupola similar to that of the Dachsberg could have led to local updoming in this vicinity, resulting in the unusual shape of the outcrop.

A feature brought out by the mapping is the widespread occurrence of a zone of shearing between adjacent quartzite and dolomite-limestone units. Where dolomite overlies quartzite, this was noted as brecciation in the quartzite and as outcrops of vein quartz, on:

1. Eintracht 118, below the Vierkuppenberg; also west of this hill, near the boundary with Diana 117;
2. Diana 117, on the southeastern flank of the Hutberg;
3. Losberg 105, southwest of the Okaheberg.

Where quartzite overlies dolomite, brecciation was observed on Joachimstal 107, along the southeastern flank of the Quartzite Hill.

An explanation for this feature must take into consideration the varying degrees of competence of the rocks involved, as well as the difference in their reaction to folding stresses. The quartzite horizons are normally folded concentrically, whereas dolomite often yields by means of plastic flow. This leads to differential movement along the contact between the two types, and results in the observed zones of dislocation and local brecciation.

Petrography

(a) The Quartzites

It is proposed to deal, in some detail, with the petrography of one or two specimens from each of the major Damara quartzite units in the area mapped. This description will be followed by a discussion covering the stratigraphical and regional variations in the petrography and mineralogy of this important rock type. Mineral proportions quoted are volumetric percentages, obtained from micrometric analyses. These are given in Table 8, later in the chapter.

Specimen 35, collected from the kraal immediately south of the Dorka 206 homestead, is a fine-grained, finely bedded blue quartzite. A skin of calcrete, together with layers of reddish carbonate parallel to the bedding planes, suggests a high carbonate content. Under the microscope, the rock is seen to consist of granoblastic elongate quartz and carbonate crystals. Zones composed solely of quartz grains in the 0.02 - 0.05mm size range alternate with those in which both quartz and carbonate are present in equal amounts. The rock is traversed by bands of coarse-grained quartz-carbonate, up to 1mm wide, running parallel to the bedding, and represents a quartzite invaded and partially replaced by later quartz-carbonate solutions. The dolomite overlying the quartzite provides a source for this mineralogical component. Plagioclase is present in minor amounts, but iron oxide is rather abundant, being uniformly disseminated throughout the rock. Owing to its high modal carbonate content of 21.8% this specimen is not typical of the Damara quartzites.

As in the case above, specimen 62 comes from the lowermost band of Damara quartzite, from the southwestern end of the Okaheberg on Losberg 105. In hand specimen the rock is pink and massive. In thin section granoblastic quartz grains with lobate sutures and undulose extinction are seen to make up the bulk of the rock. The average grain size is between 0.3 and 0.4mm, but occasionally mortar structure with grains averaging 0.05mm in size is developed. In places a cement of clay, now altered to sericite, occurs interstitially to the quartz grains. Both potash and soda felspars are present, occasionally in micropegmatitic intergrowths with quartz. Orthoclase is usually cloudy with incipient sericitisation, whereas microcline and plagioclase are still fresh. Mica is found chiefly as isolated laths of muscovite. Iron oxides include magnetite and its alteration product, limonite. Accessories are biotite, sphene and zoned tourmalines.

Specimens 8, 31 and 32 were taken from the next quartzite horizon higher up in the succession, on the farms Dorka 206 and Costa 207. In hand specimen all are massive and range from grey to pink in colour. Under the microscope a reduction in grain size to approximately 0.2mm is evident when compared with rocks from the lowermost Damara quartzite horizon. The clay matrix is also less abundant. The felspar content

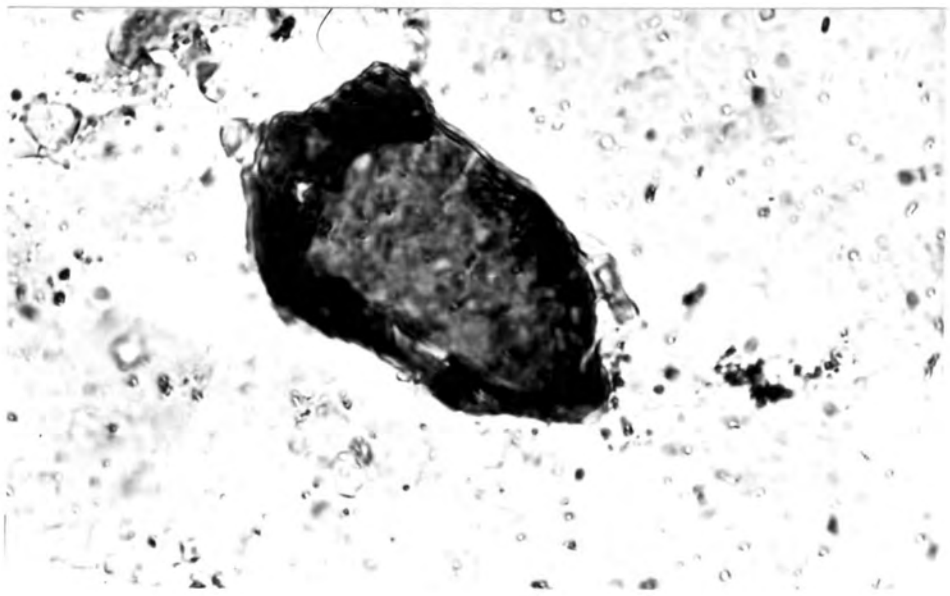


Plate X. Micrograph of quartzite from the Loskop on Dorka 206, showing a zoned crystal of tourmaline, forming part of the accessory minerals. X 500, crossed nicols.

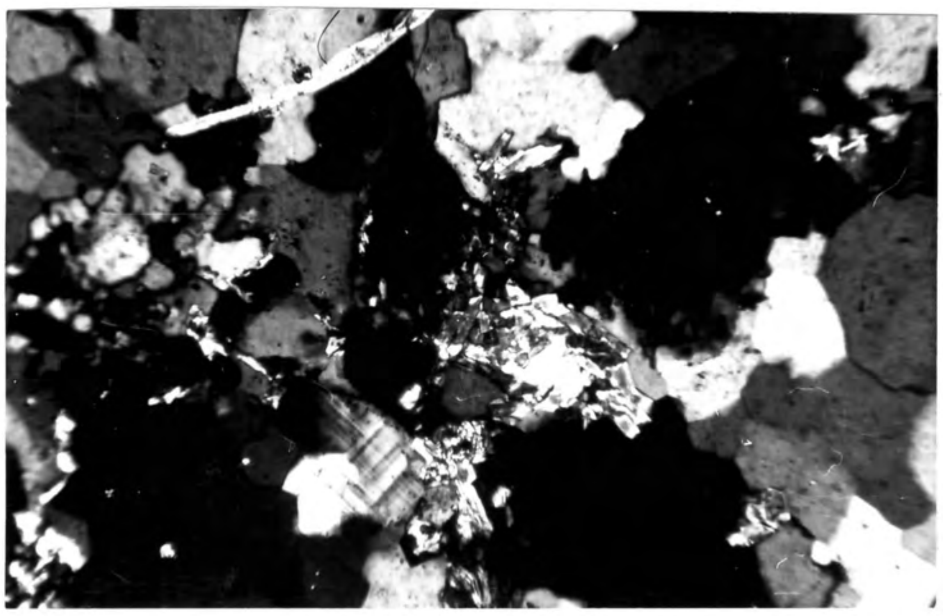


Plate XI. A slide of Damara quartzite showing the now sericitized clay cement between the grains. X 100, crossed nicols.

ranges from 6.7% for specimen 8 from Costa 207, to 16.1% for specimen 31 from the Loskop on Dorka 206; the quartz content varies in inverse proportion. As was the case for specimen 62, orthoclase is cloudy and beginning to alter, whereas microcline and plagioclase are still fresh. The iron oxide content averages 0.9%. Accessories include zoned tourmaline, apatite, zircon and epidote.

In hand specimen as well as in thin section, specimen 7 from the Straussenkuppe on Astra 205 is rather similar to the rocks described immediately above. At 0.5mm, the average grain size is somewhat larger. A little sericite, representing a former clay cement, is still present between the quartz grains. These are granoblastic with undulose extinction, and occasionally show overgrowths of later quartz, not in optical continuity with the original grains. Some micropegmatitic intergrowths with felspar were noted. Magnetite occurs as dust and as occasional anhedral grains. Accessories are apatite, tourmaline and zircon.

Some 15 km. further to the northeast, along the same horizon, specimen 20 was collected from the kraal adjacent to the Diana 117 homestead. Of approximately similar grain size as that of previously described specimens, the rock shows no bedding, and in outcrop has a weathered brown skin up to 1 cm thick. In terms of composition, the only features of note are a somewhat higher magnetite content than that noted previously, and the presence of andesine instead of the more common plagioclase, albite.

The Kuduberg-Omatewaberg unit and its easterly extension yielded several samples. Specimen 21,

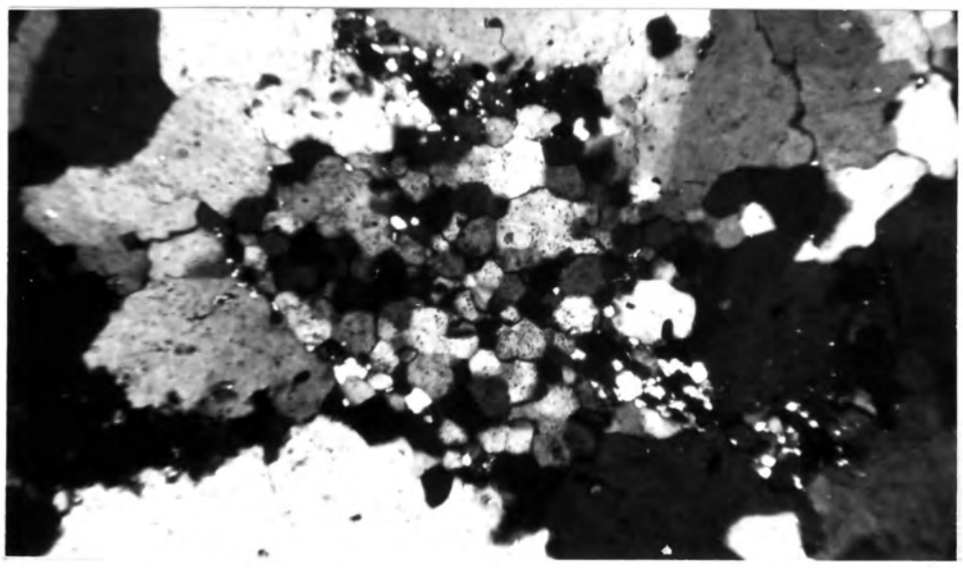


Plate XII. Damara quartzite from the Straussenkuppe on Astra 205 under the microscope. Mortar texture is well developed. X 100, crossed nicols.

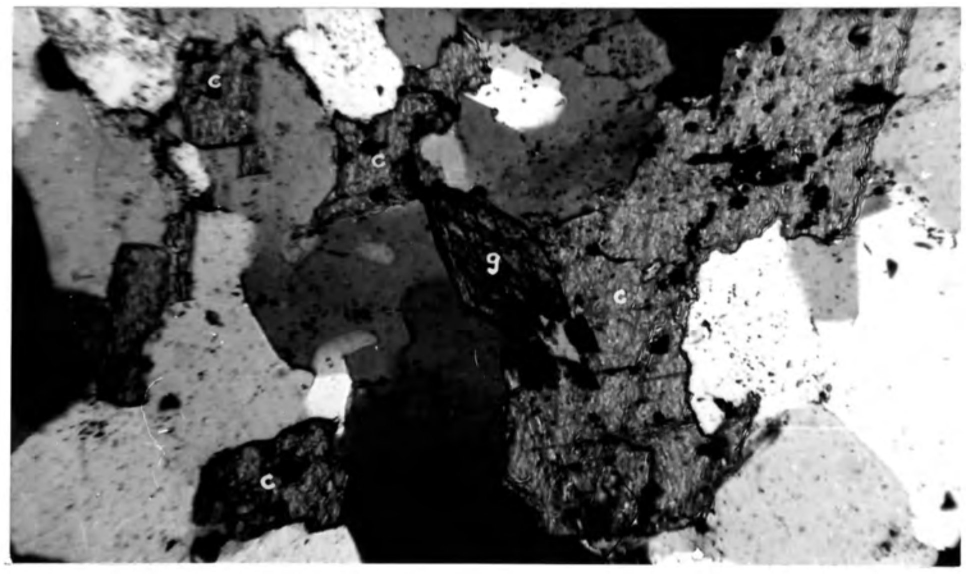


Plate XIII. Thin section of quartzite from the Hutberg on Diana 117. Glaucophane (g), here shown in basal section, forms one of the accessory minerals. It is partly enclosed by calcite (c). X 100, crossed nicols.

from the summit of the Hutberg, is a fine-grained, compact, pink quartzite. In thin section it shows granoblastic-polygonal texture. Mortar texture is occasionally developed. Microcline and albite are again fresher than the orthoclase. Some antiperthite grains are present. Instead of the usual iron oxide, magnetite, pyrite predominates in this rock. Cubes up to 1mm on edge are common, and are often seen to be in process of replacement by magnetite; the latter is itself, on the grain edges, partially altered to haematite and limonite. The specimen differs from the usual Damara quartzites in that it contains 1.4% of carbonate. Further, epidote amounts to 0.5%. Accessory minerals are sphene, apatite, zircon, tourmaline, biotite and glaucophane. This latter mineral is present as very isolated grains, usually associated with calcite. It occasionally shows the typical amphibole cross-section, and displays the customary striking pleochroism.

Specimen 23 was obtained from the same locality as that above. It is also a fine-grained, massive quartzite, grey in colour. In thin section the rock exhibits granoblastic texture. As in specimen 21, the average grain size is 0.3mm; mortar texture is again developed locally. In contrast to that above, the quartz grains have undulose extinction. The carbonate content was determined to be 1.8%. The calcite is idioblastic, rhombs up to 0.7mm across being common. The mineral is often poikiloblastic and contains either wholly or partially enclosed grains of quartz, felspar, iron oxides, mica and chlorite.

TABLE 8

MICROMETRIC ANALYSES OF 13 DAMARA QUARTZITES

Specimen No.	7	8	21	23	31	32	35	41	62	82	84	104	106
Quartz	82.8	87.8	80.3	77.7	79.5	84.4	72.4	85.0	82.4	87.6	89.9	77.9	82.0
Orthoclase	8.6	4.4	8.3	12.7	10.6	9.4	Tr	-	7.1	6.0	6.0	-	0.6
Microcline	1.4	1.1	2.6	1.5	1.4	0.6	Tr	-	0.4	1.1	-	-	-
Albite	3.4	1.2	5.2	3.1	4.1	3.6	1.4	5.4	1.8	0.9	1.4	-	0.3
Mica	Tr	0.4	Tr	Tr	Tr	0.3	-	0.1	Tr	1.2	1.7	21.9	16.7
Sericite	2.5	4.0	Tr	Tr	3.4	0.4	Tr	Tr	5.5	2.2	-	-	-
Iron Oxides & Sulphides	0.8	1.1	0.9	2.6	0.8	0.9	4.4	1.9	2.7	1.0	0.6	0.1	0.2
Carbonate	-	-	1.4	1.8	-	-	21.8	1.9	-	-	-	-	-
Accessories	0.5	-	1.3	0.6	0.2	0.4	-	5.7	0.1	-	0.4	0.1	0.2
TOTAL	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

At certain localities on the Hutberg, smooth weathered surfaces of the pink quartzite show development of curious apple-green spots. These are rounded to elongate, and may measure up to 4cm across. On breaking the rock across several of these spots, they were seen to be confined to the immediate outer skin. One such discolouration showed development of a felted mass of tiny green needles, which were identified under the microscope as epidote. It appears that, even where such needles are not visible, the green colouration on weathered surfaces of the rock is caused by local, above-average concentrations of epidote group minerals.

Specimens 82 and 84 were taken from the western and eastern end, respectively, of the Kuduberg. Of average grain size 0.3mm, they are very similar in mineral content. In contrast to the Hutberg quartzites, their felspar content is much lower. Mica, especially sericite in specimen 82, is present in larger amounts than is the case further east along this horizon. Some of this sericite is interstitial, and probably represents a former clay cement between the quartz grains.

Specimens 104 and 106 were collected from the uppermost exposed quartzite horizon in the region i.e. the Quartzite Hill on Joachimstal 107. Both average 0.2mm in grain size. Their light colour suggests a low heavy-mineral content and this is borne out by a study of thin sections. Both specimens are very "clean", the rocks being composed almost entirely of quartz and muscovite. The quartz shows undulose extinction and often encloses the mica poikiloblastically. Accessories are epidote, tourmaline, zircon, sphene and apatite.

Mention must be made of two further varieties found in the region mapped. Both are of extremely local occurrence and are not typical of the Damara quartzites as described above.

Specimen 15 was collected from the eastern side of the track leading from Otjiwarumendu 119 to Airlie 124, approximately 900 metres north of the southern boundary of Sandflats 123. In outcrop the rock forms one isolated boulder only, and is a fine-grained, massive quartzite with much interstitial epidote. Thin-section study shows the following minerals to be present in the approximate amounts given below.

Epidote	60%
Quartz	37%
Iron Oxides	2%
Amphibole	1%

The rock is undoubtedly related to the adjacent shear zone, and should, on the basis of its unusual composition, be termed an epidosite. In this connection, it is worth quoting Deer, Howie and Zussman (1962, Vol. I, p. 184):

"Some rocks consist almost wholly of an epidote mineral and are named epidotites. These have been defined (Flawn, 1951) as compact massive rocks composed mostly of epidote (or zoisite) with minor amounts of amphibole, pyroxene, felspar, chlorite, quartz, sphene, calcite, vesuvianite or garnet. The acceptance of the term epidotite is not universal and some authors (e.g. Francis, 1958) prefer the name epidosite."

Finally, specimen 41 was collected from the eastern contact of a large basic dike on Goldene Aue

106, 800 metres north of the homestead. The rock must be regarded as a former contact-metamorphic quartzite now regionally metamorphosed, and owes part of its mineral assemblage to invading solutions emanating from the dike during its period of emplacement. The rock is grey in colour and resembles the typical quartzites of the region. On the immediate contact with the dike it becomes very fine-grained and creamy-white in colour; the two varieties of quartzite are separated by a sharp contact parallel to the bedding planes. The fine-grained white variety shows development of needles of black amphibole up to 2cm in length; these are randomly orientated in the plane of bedding. Amphibole also occurs as felted crystals in veins cutting across the rock.

The thin section studied includes the contact between the white and grey rock types. The latter type shows a granoblastic rock of uniform texture and average grain size 0.1mm. Quartz is the dominant mineral. Some plagioclase was noted, while chlorite and magnetite are present in only very small amounts.

Across the sharp contact, in the white variety, a quartz-felspar matrix of average grain size 0.01mm contains porphyroblasts of quartz and felspar up to 0.05mm long. Also present, as laths 0.1 to 2mm long, is green pleochroic hornblende, poikiloblastically enclosing quartz. Carbonate and iron oxides occur in equal amounts in the rock. Apatite is fairly abundant; some biotite is present.

The composition of this, and of the other quartzites described above is, with the exception of number

15, given in Table 8.

General Discussion

In thin section each quartzite generally shows a considerable variation in grain size. Particles of 0.05mm are very common, since most specimens show mortar texture. At the other end of the scale, granoblasts of 0.6 to 0.8mm are also frequently encountered. On the whole, grain sizes average between 0.2 and 0.5mm in all the Damara quartzites examined under the microscope. As would be expected, the highest exposed unit is somewhat finer-grained than the lower horizons. No marked trend in grain-size variations along the strike of any single unit was noted.

Mineralogically, the rocks investigated are composed principally of quartz, felspar and mica, but do show considerable variations in the relative proportions of these minerals.

The quartz content varies between fairly narrow limits, viz. 77.7 - 85.0%. Only three of the specimens listed in Table 8 fall outside these limits, one being below and two being above; the total range is from 72.4% to 89.9%. Total felspar content shows a great variation between the limits of 0 and 17.3%. Potash felspar predominates over plagioclase. In the western part of the area the quartzites become "cleaner" in that the felspar content decreases. As mentioned above, samples from the highest exposed horizons in the area consist essentially of quartz and mica.

Iron oxides are ubiquitous but again decrease in amount higher in the succession. Pyrite is rare, having presumably been replaced by magnetite and limonite.

Carbonates are not common. Accessory minerals show a wide variety and comprise zircon, apatite, tourmaline (occasionally zoned), sphene, epidote and glaucophane.

A point of interest is the occurrence, in the quartzite units of the Hakos Series, of a matrix of clay minerals, now altered to sericite, between the quartz and felspar grains. This matrix decreases and finally disappears as one proceeds upwards through the succession.

When the volumetric compositions quoted in Table 8 are compared with those given by Pettijohn (1957, p.291) it is seen that the Damara quartzites contain a sufficiently high proportion of quartz to warrant the term "arkosic quartzites". Only specimen 35 contains less than 75% by volume of quartz. It has been shown to be extensively replaced by carbonate, and as such is not representative of Damara quartzites. The remainder of the specimens investigated correspond to Pettijohn's definition of subarkoses, or felspathic quartzites. As already mentioned earlier in this chapter, the same holds good for the specimens of Kamtsas quartzite investigated. Despite these conclusions, however, the term "quartzite" will, for the sake of consistency and convenience, be retained throughout the remainder of this text.

In an attempt to establish a trend in the Damara quartzites, and to differentiate the latter from those of the Nosib Formation, specimens collected from various stratigraphical levels were assessed in terms of the end-member classification proposed by Pettijohn (op. cit., pp. 4 - 7). Figure 1 shows a plot of the 13 rocks quoted in Table 8. The figure is an adaptation of Pettijohn's classification of sandstones, cited by Krumbein & Sloss (1963, p. 157). For this the minor constituents of the rocks have been ignored, and the amounts of quartz, felspar and clay (the mica and sericite) recalculated to 100%. In order to show the spread more clearly, only the "quartz" corner of the diagram, suitably enlarged, is depicted. No systematic variations in the end-members with respect to stratigraphic position could be established from the diagram. Of significance, however, are the positions of specimens 9, 10, 63 and 67, from the Kamtsas Member of the Nosib Formation. These quartzites are seen to be almost entirely lacking in a mica (clay) fraction. This lack of matrix has already been noted during the descriptions of the thin sections.

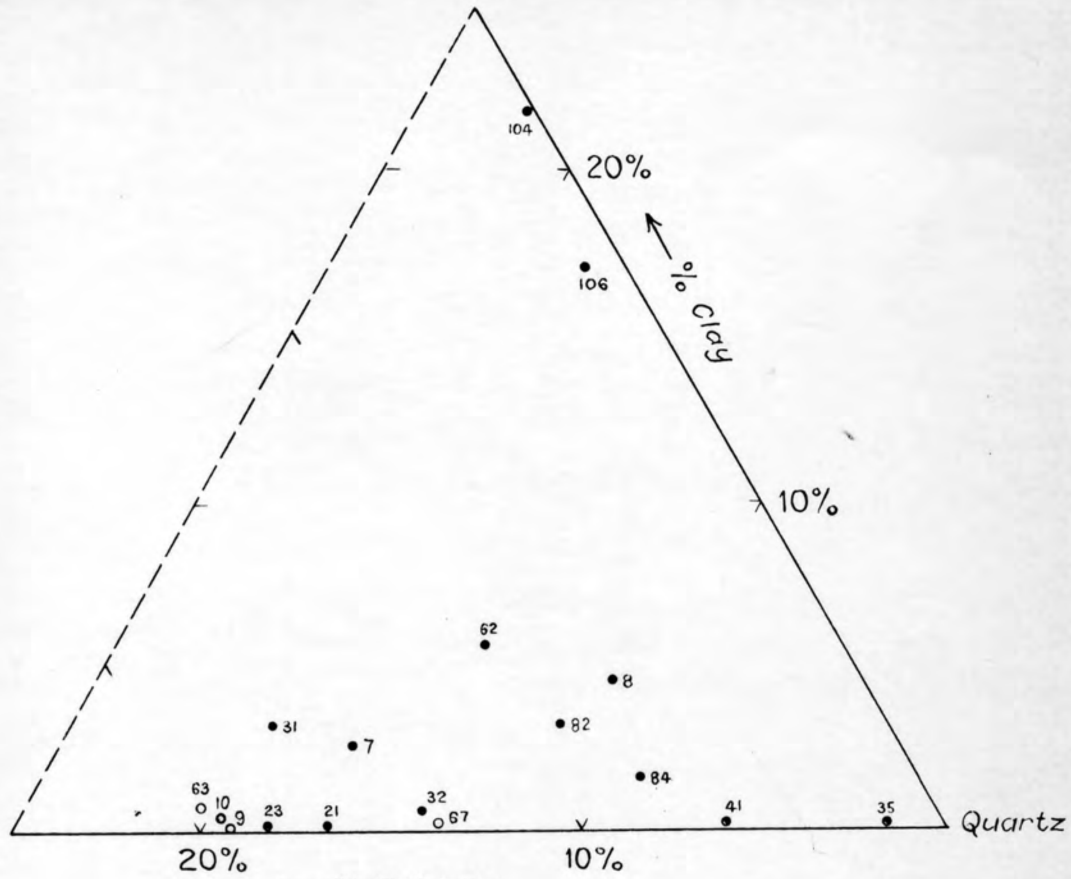
In Figure 2 these same rocks were plotted after their compositions had been recalculated so that K felspar plus plagioclase plus quartz equals 100%. Again, no definite trend in relation to the stratigraphic positions of the samples could be established. However, the Kamtsas quartzites are once more seen to occupy a special position on the diagram.

Although no definite conclusions can be reached on the basis of the few quartzite samples investigated, especially in view of the "anomalous" plot of specimen 67 from the Nosib Formation suite, it does appear that under the microscope rocks from the latter may easily be distinguished from those of the Damara System. The Kamtsas quartzites show very little mineralogical

Figure 1

118a

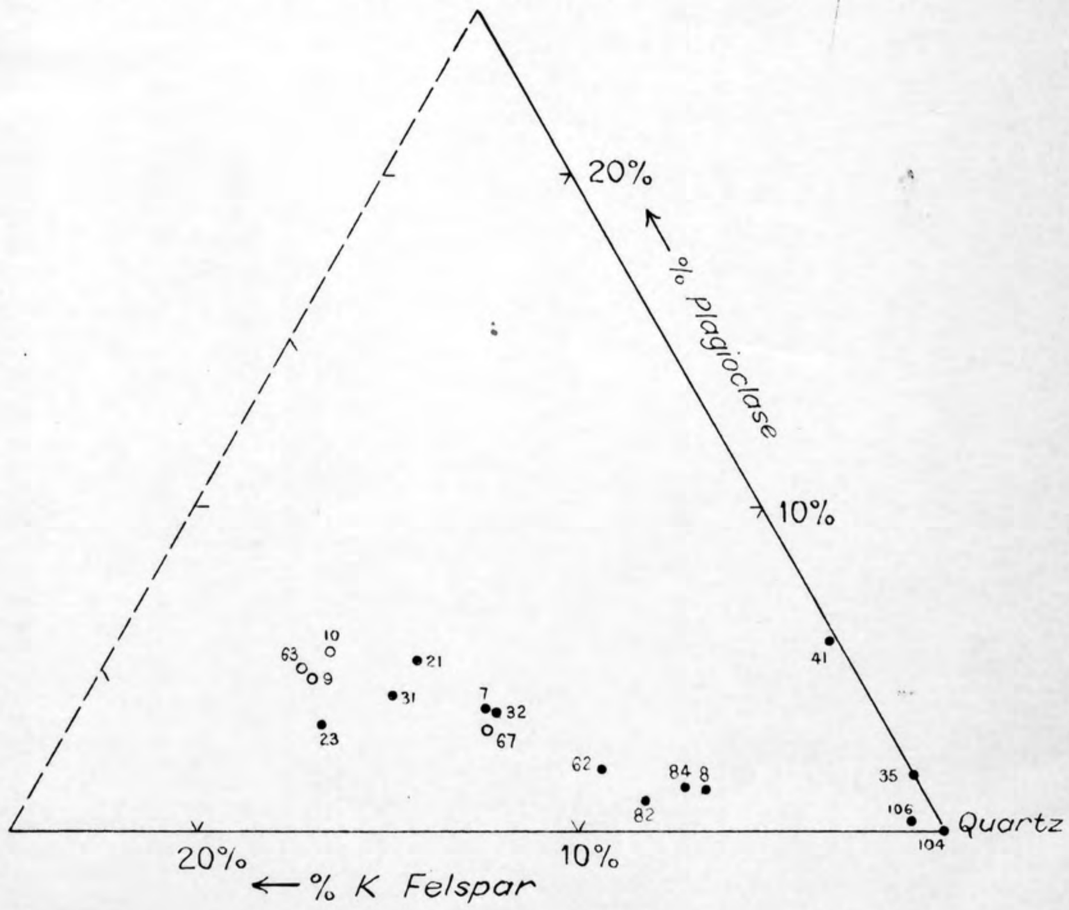
Quartz - Felspar - Clay Plot for 13 Damara System and 4 Nosib Formation Quartzites



•7 *Damara System Quartzites-Plot with sample number*
o63 *Nosib Formation Quartzites-Plot with sample number*

Figure 2

Quartz-K Felspar-Plagioclase Plot for 13 Damara System and 4 Nosib Formation Quartzites



•7 *Damara System Quartzites - Plot with sample number*
o63 *Nosib Formation Quartzites - Plot with sample number*

variation. They differ from the Damara quartzites in their generally higher felspar content, and in the almost total absence of a mica; no clay matrix is present. This suggests significant differences in the mode of deposition of the Kamtsas and Damara quartzites.

As already stated, no regular trend could be established between Damara quartzites from various stratigraphical levels, except that there appears to be a general decrease in grain size and felspar content as one proceeds westwards across the region. This does not necessarily mean that one is higher in the succession.

In view of these findings, it is suggested that the answer to differentiating between the various horizons could lie in a study of the heavy-mineral content of these quartzites.

(b) The Carbonate Rocks

As was done in the case of the Damara quartzites, representative specimens from each of the major limestone units occurring within the area mapped will be described. Two slides were cut from most specimens. In each case, in order to differentiate between calcite and dolomite, one of these slides was subjected to the staining technique described in the chapter on laboratory methods. Micrometric analyses were carried out on 10 specimens of carbonate rocks; the results of these investigations are given in Table 9 below.

Specimen 66 was collected from the lowermost band of Hakos dolomite, from the small hill immediately southwest of the Okaheberg on Losberg 105. The rock is blue-grey in colour, very fine-grained, and exhibits typical "elephant's hide" weathering. Bedding is brought out by differential weathering.

In thin section the specimen shows granoblastic-polygonal texture. Dolomite is the chief constituent, with grain size varying from 0.05 to 0.3mm; the average lies close to 0.1mm. The larger crystals no doubt result from recrystallisation of the smaller grains. Quartz, usually with minute inclusions, occurs as anhedral crystals between the carbonate grains, and may form discrete veinlets. Very subordinate plagioclase was noted. Muscovite is found as isolated laths up to 0.6mm long, occurring in a sub-parallel arrangement apparently corresponding to the bedding in the rock. Some iron oxides, as well as minor amounts of carbon, were noted.

The large-scale colour banding occurring locally in the carbonate rocks of the Hakos Series has already been referred to elsewhere. Samples of each variety were collected immediately west of the northernmost windpump (grid reference -30240/32940) on Eintracht 118, adjacent to the track leading past the Dachsberg to Sandflats 123.

Specimen 2, from the basal member of the dolomite unit north of the breccia zone, is a fine- to medium-grained, very finely bedded blue-grey rock. The thin section shows it to consist almost entirely of granoblastic elongate dolomite crystals of average size 0.4mm. Isolated grains of quartz are present; magnetite occurs as scattered anhedral to euhedral grains. Plagioclase was noted in very minor amounts only. Traces of carbon are present, especially along later dolomite-filled veins traversing the slide. A visual estimate of the composition of the rock gave:

Dolomite	97%
Quartz	2%
Magnetite	1%
Plagioclase	Tr.

The rock must thus be regarded as an exceptionally pure dolomitic marble.

This rock is overlain by a massive, fine-grained, white dolomite showing a brown weathered surface. Iron oxides form discrete specks, 0.5mm across. The thin section shows specimen 1 to consist essentially of granoblastic-polygonal dolomite grains averaging 0.2 - 0.3mm in size. Subordinate quartz crystals in the same size range were noted. Isolated porphyroblasts up to 3mm long of dolomite and quartz occur in the slide. Muscovite is subordinate, forming laths whose arrangement appears sub-parallel to the original bedding of the rock. This direction is also indicated by a very weakly developed preferred elongation of the dolomite crystals. The white colour of the rock, together with the absence of any visible carbon, suggests that the latter constituent is largely responsible for the blue-grey tones that are so characteristic of the Hakos dolomites generally.

Estimated visually, the composition of specimen 1 is:

Dolomite	96%
Quartz	2%
Muscovite	2%
Magnetite	Tr.
Plagioclase	Tr.

The uppermost layer of the Hakos dolomite horizon in the locality under consideration differs from the two varieties described above in that it reacts vigorously with cold dilute HCl, thereby denoting a high $CaCO_3$ content. Underneath a brown outer skin the rock is seen to be a fine- to medium-grained pink limestone, in which the fine bedding is brought out by colour differences between adjacent lamellae. Isolated quartz grains, 4 to 10mm across and elongated in the plane of bedding, are present.

Slides of specimen 3 show a dolomite of granoblastic texture. The grains, usually somewhat flattened and elongated in the plane of bedding, vary in size from 0.2 to 0.8mm, and show prominent twinning. They occasionally form layers of interlocking crystals, but are more commonly seen to be set in a matrix of anhedral calcite crystals. This calcite matrix is of considerably lower relief than the dolomite and appears cloudy, possibly due to the presence of finely-divided carbon. Grain size variations are similar to those found in the dolomite grains. A later generation of calcite, stained a deeper red by Mitchell's dye, forms narrow veins running across the bedding, and often cuts through crystals of dolomite.

Quartz is present interstitially to the carbonate, and shows undulose extinction. Polysynthetically twinned plagioclase occurs in minor amounts, as laths up to 0.3mm long.

Two iron oxides are found in the rock, Magnetite occurs as scattered subhedra, and as cubes up to 0.5mm across. Limonite is conspicuous, being concentrated in zones 1 - 2mm wide, as irregular streaks parallel to the bedding. Within these zones it forms a cement between the dolomite grains. Elsewhere, it may form a thin skin over the carbonate grains. Generally, this iron oxide is widely distributed through the rock, and accounts for the rusty colour so characteristic of this horizon.

A visual estimate gave the following composition for the rock:

Dolomite	48%
Calcite	30%
Quartz	15%
Limonite	6%
Magnetite	1%
Muscovite	Tr.
Plagioclase	Tr.

It is suggested that the rock is, in all probability, a detrital dolomite, derived by the partial erosion of the underlying dolomitic rocks. Deposition occurred together with a calcisiltite, which now forms the calcite matrix. At intervals, iron oxides appear to have been precipitated as well; these were then redistributed through the rock during metamorphism.

Specimen 4 was collected from the extreme southwestern end of the Vierkuppenberg, on Eintracht 118. In hand specimen it is a fine-grained, blue-grey rock, in which the fine bedding is well brought out on weathered surfaces. It is atypical of Hakos dolomites in that, at this particular locality, weathered surfaces are seen to be covered by numerous small knobs, which stand out somewhat above the general surface of the rock. Under the hand lens, these knobs, 2 - 3mm

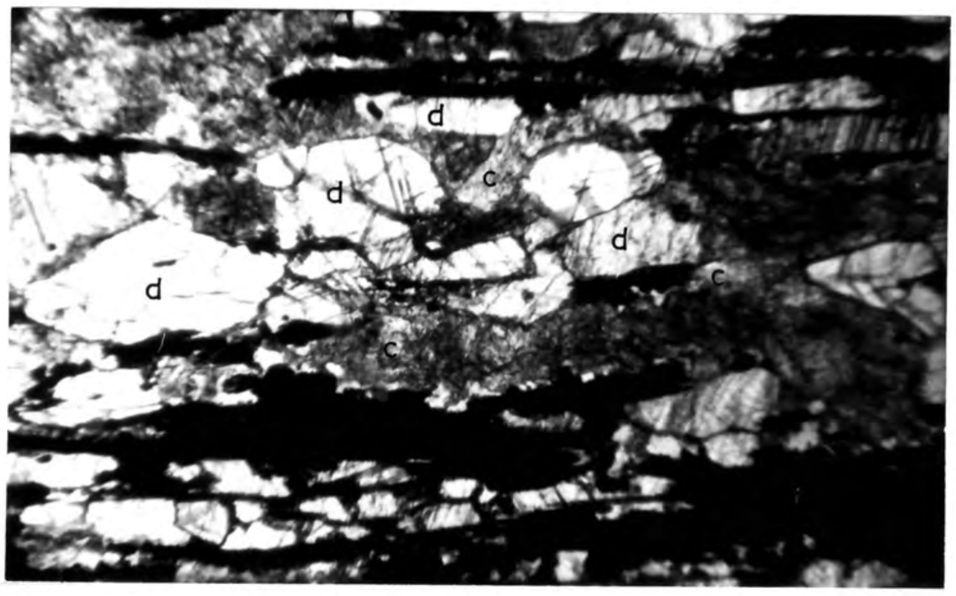


Plate XIV. Red-brown dolomite from Eintracht 118 under the microscope. Anhedral calcite (c) occurs between euhedral grains of dolomite (d). Limonite is abundant, as streaks parallel to the bedding. X 35, crossed nicols.

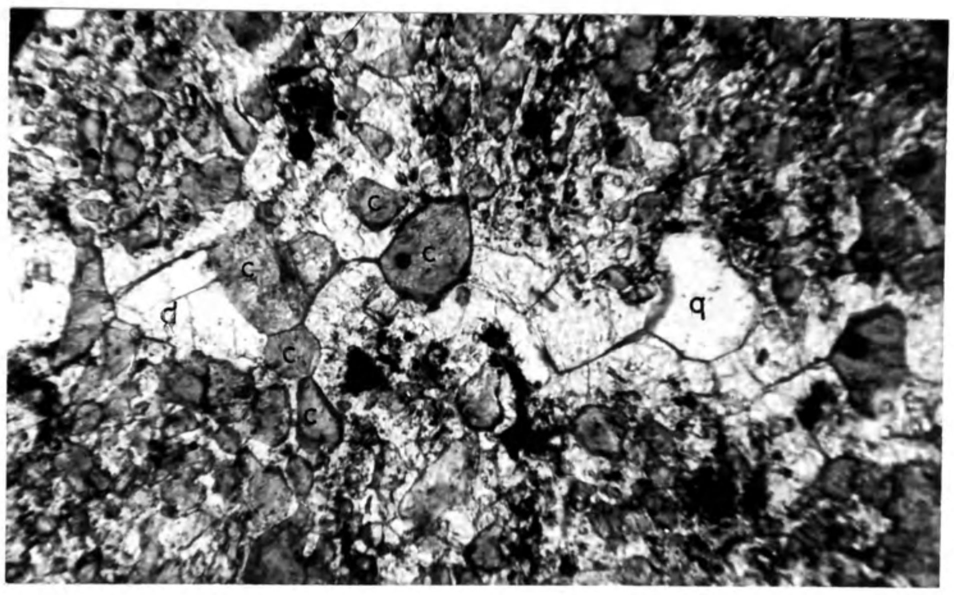


Plate XV. Thin section, stained with Mitchell's dye, of blue Hakos limestone from the Vierjuppenberg, Eintracht 118. Dark grains of calcite (c), isolated crystals of dolomite (d), and one fragment of quartz (q) in a matrix of danburite. X 100, crossed nicols.

across and usually rounded to elongated, are seen to be finely bedded. The bedding in the inclusions does not necessarily coincide with that of the rock as a whole. The rock reacts vigorously with cold dilute HCl.

The thin section shows calcite to be the dominant mineral, occurring as interlocking twinned crystals averaging 0.3mm in size. Interstitial to the calcite are isolated subhedral grains of dolomite, 0.1 - 0.2mm across. Locally, the texture is poikilotopic, i.e. larger calcite grains enclose smaller, rounded fragments of dolomite in the size range 0.05 - 0.15mm (Chilingar et. al. 1967, p. 303). These may probably be taken as evidence of dedolomitisation of the rock. Sub-rounded grains of quartz in the 0.1 - 0.3mm size range are fairly common. Isolated twinned laths of albite were noted. Sphene occurs in very minor amounts as anhedral grains. Iron oxides, chiefly magnetite, are scattered through the rock. One cube of pyrite, measuring 0.7mm on edge, was noted in the slide. Furthermore, the rock is full of minute black specks, which are probably carbonaceous remnants of organic material.

Of considerable interest are the bedded inclusions already mentioned. These, some 2 - 3mm long, are usually somewhat elliptical, and are composed of grains, ranging in size from 0.05 to 0.25mm, of calcite, quartz, and a mineral identified as the calcium boro-silicate danburite, $CaO.B_2O_3.2SiO_2$. Carbonaceous material is abundant, occurring as parallel streaks which suggest the inclusions to represent fragments derived from an originally bedded rock. The danburite in this specimen occurs;

TABLE 9

MICROMETRIC ANALYSES OF 10 DAMARA CARBONATE ROCKS

Specimen No.	4	43	44	49	66	88	97	98	109	111
Dolomite	5.0	30.1	94.3	90.9	91.8	95.3	97.4	93.9	0.6	6.2
Calcite	82.6	55.5	Tr	-	-	-	-	-	88.9	83.8
Quartz	4.7	6.5	4.4	8.0	5.9	3.5	1.7	4.9	1.3	0.1
Plagioclase	0.5	-	0.2	Tr.	0.2	Tr.	Tr.	-	-	-
Muscovite	0.1	0.3	Tr.	0.3	1.6	1.0	0.7	1.0	3.7	1.3
Tremolite	-	7.0	-	-	-	-	-	-	5.3	8.2
Iron Oxides	1.2	0.6	1.1	0.3	0.5	0.2	0.2	0.2	0.2	Tr.
Accessories	5.9*	-	-	0.5	-	-	-	-	Tr.	0.4
TOTAL	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

* Includes 5.7% of Danburite

1) With calcite in the inclusions, of which it may form up to approximately 25%, layers of danburite often alternating with layers of calcite;
2) As veinlets cutting across the inclusions;
3) In the form of partial rims to the inclusions;
4) As isolated larger crystals, and as clusters of such crystals in the matrix of the rock.

Identification of this rather uncommon mineral was a somewhat protracted affair. The following microscope data were derived from a cluster, measuring 1mm by 3mm, of danburite crystals in the calcite matrix of the rock. Morphologically, there is a strong resemblance to orthoclase, the crystals being equant to slightly elongated. No cleavage was noted, but the mineral shows a very cracked surface. Birefringence is estimated at 0.005, the colour between crossed nicols being grey of the first order. An optic picture shows the mineral to be biaxial negative, with a 2V angle estimated to be at least 85^{o}.

In order to carry out a refractive index determination on the mineral a small piece of specimen 4 was dissolved in dilute HCl. The large amount of carbonaceous material in the residue, together with the finer grains of quartz, was removed by elutriation. The filtered and dried residue contained some carbonate, quartz and the unknown mineral (danburite).

A refractive index determination yielded the following optical constants:

N_z 1.639 N_x 1.633

Determinative tables suggested the mineral to be either andalusite or danburite. In order to distinguish

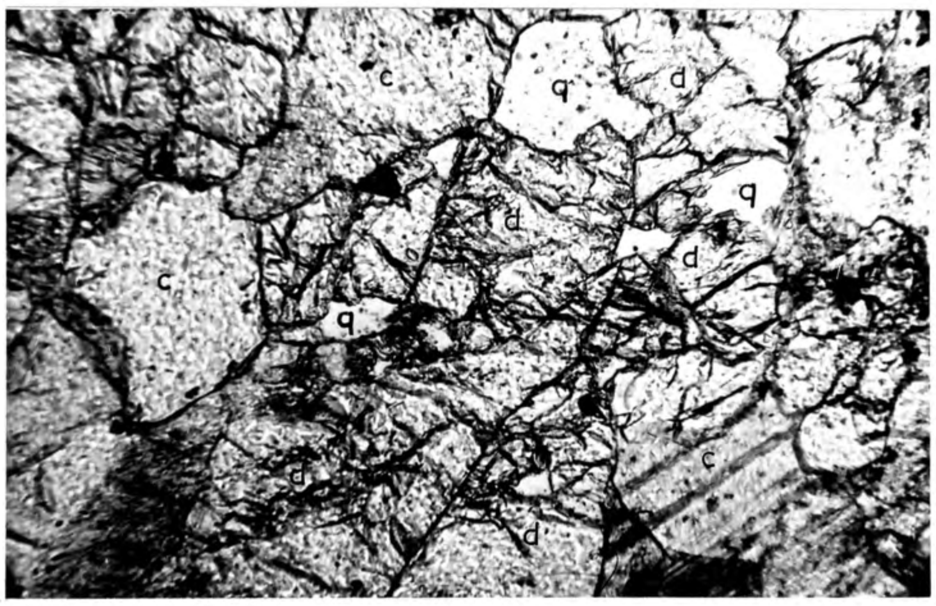


Plate XVI. Micrograph of blue limestone from the Vierkuppenberg, Eintracht 118, showing well-developed crystals of danburite (d) in calcite (c). A little quartz (q) is also present. X 100, plane-polarized light.

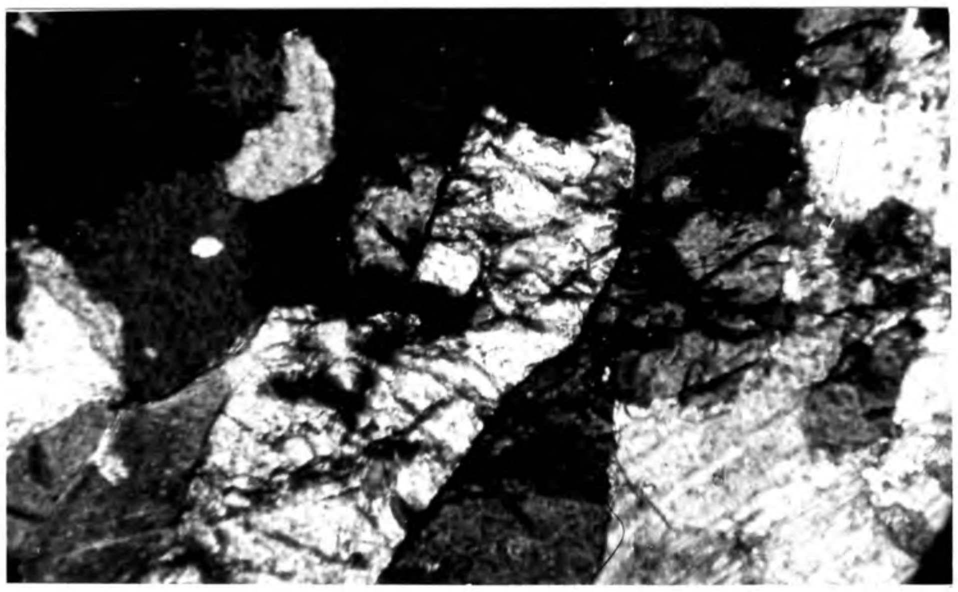


Plate XVII. As above. X 100, crossed nicols.

between these two, the mineral was subjected to X-ray diffraction. From the data presented in Table 10, it will be seen that, for the 26 peaks featured on the diffractogram, there is a good correlation with the data given in the KWIC Guide and the ASTM cards. There is thus little doubt that the mineral is indeed danburite.

The provenance of the boron required for the formation of this mineral presents a problem, since mapping has shown the nearest exposed logical source, the Dachsberg granite on Sandflats 123, to be 6 km away. Evidence obtained from a study of the thin sections of specimen 4 suggests that the bedded inclusions, of unknown origin, are the source of the danburite in the limestone here being considered. With the advent of metamorphism subsequent to deposition the danburite was mobilised to a certain extent, migrating out of the inclusions and spreading throughout the rock. It was then redeposited at favourable loci, such as possible pores, and at the interfaces between the rock matrix and the bedded inclusions. According to Dana (1958, p. 613) danburite occurs with microcline and oligoclase in dolomite at the type locality Danbury, in Connecticut. Winchell & Winchell (1959, Part II, p. 259) cite further occurrences in granite at Russell, New York, and in pegmatites and metamorphic rocks at many other localities.

The volumetric composition of specimen 4 is quoted in Table 9.

Approximately 1.5 km westnorthwest of the windpump (grid reference -16850/39120) in the centre of the farm

TABLE 10

X-RAY DATA FOR DANBURITE, $CaO.B_2O_3.\ 2SiO_2$

ASTM CARD DATA		KWIC GUIDE DATA		DATA FROM SPECIMEN No. 4	
dÅ	I/I_1	dÅ	I/I_1	dÅ	I/I_1
4.33	20			4.37	10
3.96	60				
3.59	100				
		3.57_B	100		
		3.56_A	100	3.56	100
3.41	60				
3.24	60			3.24	60
2.99	90			2.98	90
		2.96_A	70		
		2.96_B	100		
		2.74_B	80	2.74	50
2.73	90				
2.66	70			2.66	40
		2.65_A	75		
2.46	50			2.44	20
2.14	70			2.14	30
2.02	50			2.02	20
1.95	70			1.95	30
1.91	20			1.89	10
1.83	20			1.82	20
1.76	20			1.75	10
1.72	70			1.71	40
1.66	60			1.65	20
1.57	50			1.57	10
1.52	20			1.52	5
1.50	50			1.49	10
1.45	70			1.44	10
1.40	50			1.40	5
1.37	50			1.37	10
1.35	20			1.35	5
1.33	20			1.32	10
1.29	20			1.29	10
1.26	20			1.26	10
1.23	50			1.23	10

Where: dÅ equals interplanar spacing (in ångstrom units)
I/I_1 equals Intensity of line (as percentage of intensity of maximum peak).

Subscripts A & B in KWIC GUIDE DATA column refer to data from two different specimens.

Goldene Aue 106 are to be found two parallel dolomite bands, which here form a small eminence rising some 15 metres above the level of the surrounding country. Collected from the southern end of the lower horizon (grid reference -16650/38750), specimen 49 is a fine-grained, blue dolomite with a typical brown, weathered surface. Quartz veinlets 2 - 3mm thick trend parallel to the bedding, which is distinguished only with difficulty. Bedding planes locally carry a white flaky material, soapy to the touch; this is probably sericite.

The thin section of this rock shows dolomite to be the only carbonate present, occurring as granoblastic elongate grains 0.05 to 0.1mm long, together with interstitial quartz and some muscovite. Also present are very isolated fibrous laths, up to 1mm long and showing one cleavage, of a colourless mineral. Between crossed nicols, this mineral has first-order grey to white interference colours, parallel extinction, and is length-fast. The interference figure, which lies almost normal to the cleavage direction, is biaxial negative with $2V_x$ approximating to 40°. From these data the mineral was identified as wollastonite. A type of flow banding is visible in the section. Locally, thin veins of coarser-grained quartz and carbonate were noted, trending parallel to the bedding.

The slide is traversed by a vein, 1cm wide, cutting obliquely across the bedding and consisting of coarse-grained quartz-carbonate. The average grain size is 0.5mm, although carbonate crystals exceeding 1.3mm in size were occasionally observed. The texture of the vein minerals is granoblastic-polygonal, the quartz showing well developed triple points. Wollastonite is again present in the vein. Dolomite occasionally

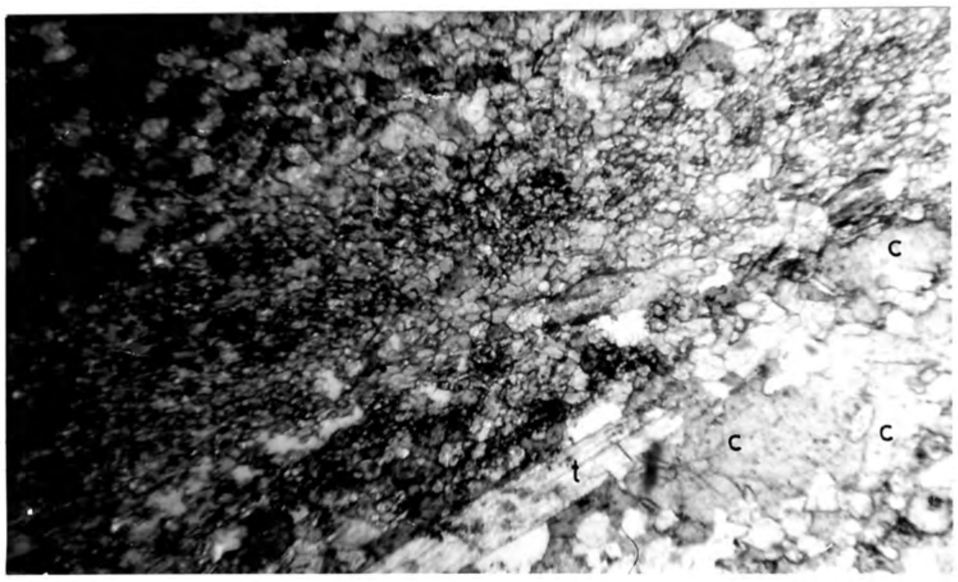


Plate XVIII. Thin section, stained with Mitchell's dye, of fine-grained blue Hakos dolomite undergoing dedolomitisation. Coarse-grained calcite (c) is seen replacing the fine-grained anhedral dolomite, which it also locally encloses poikiloblastically. One needle of tremolite (t) is visible. X 35, plane-polarized light.

encloses quartz poikiloblastically.

Two further specimens of blue-grey dolomite were collected in the extreme eastern corner of Joachimstal 107, adjacent to the boundary fence with Goldene Aue 106 (grid reference -18400/34200). Specimen 43, from the horizon immediately overlying the Kuduberg quartzite, is fine-grained, finely bedded, and contains abundant needles of tremolite.

In thin section the rock is seen to be heteroblastic i.e. composed of crystals with a range of sizes (Spry 1969, p. 159). It consists of occasionally elongate calcite crystals in the size range 0.05 - 0.7mm, interbedded with layers of granoblastic-polygonal dolomite of average grain size 0.05mm. The individual layers are approximately 1mm thick. The dolomite may occur as grains interstitial to the calcite; locally, calcite may poikiloblastically enclose dolomite. Quartz occurs as interstitial grains, or occasionally in poikiloblastic intergrowths with calcite. Veinlets up to 0.3mm thick trend parallel to the bedding. Muscovite, as laths not usually exceeding 0.05mm in width and 0.3mm in length, locally occurs between the calcite grains. Tremolite is found as needles up to 4mm long with random orientation in the plane of bedding; perfectly euhedral basal sections, typical of amphiboles, were also noted. Iron oxides are not abundant, occurring chiefly as dust. A considerable amount of carbonaceous material is present.

The rock described above is overlain by a rather pure, white dolomite. Slide 89 shows a granoblastic polygonal texture and average grain size 0.5mm. Quartz occurs in minor amounts as small interstitial grains between the dolomite. Occasional remnants of what appears to have been a calcite matrix were noted.

As mentioned earlier, in this locality there is found a variation of the colour sequence blue-white-red developed on the farm Eintracht 118. Accordingly, the top of the dolomite in the eastern corner of Joachimstal 107 consists, not of the red variety, but of a medium-grained, massive, blue dolomite. Slide 44 reacted but faintly to Mitchell's dye, described in Chapter V. It is suggested that the rock consists of dolomite containing small amounts of $CaCO_3$ in solid solution in the lattice. This would account for the faint colouration produced by the dye. When compared with specimen 43, the rock is coarser and of a far more uniform grain size; the average lies close to 1mm. Grains are interlocking, usually with scalloped boundaries. Quartz occurs as rounded grains up to 0.2mm across between the dolomite crystals, or as inclusions of the latter. Plagioclase and muscovite occur in minor amounts. Iron oxides are present as particles ranging in size from dust to grains 0.1mm across. Some carbon is present, but no tremolite was noted.

The colour sequence described above appears to be characteristic of this horizon, and was again found to be well developed some 2 km west of the boundary of Goldene Aue 106 and Joachimstal 107, along the camp fence running approximately southeast from the windpump on the White Nossob River. A feature of note at this locality (grid reference -16850/34300) is the abundance of tremolite in the rock. The basal member is a medium-grained marble consisting of alternating blue

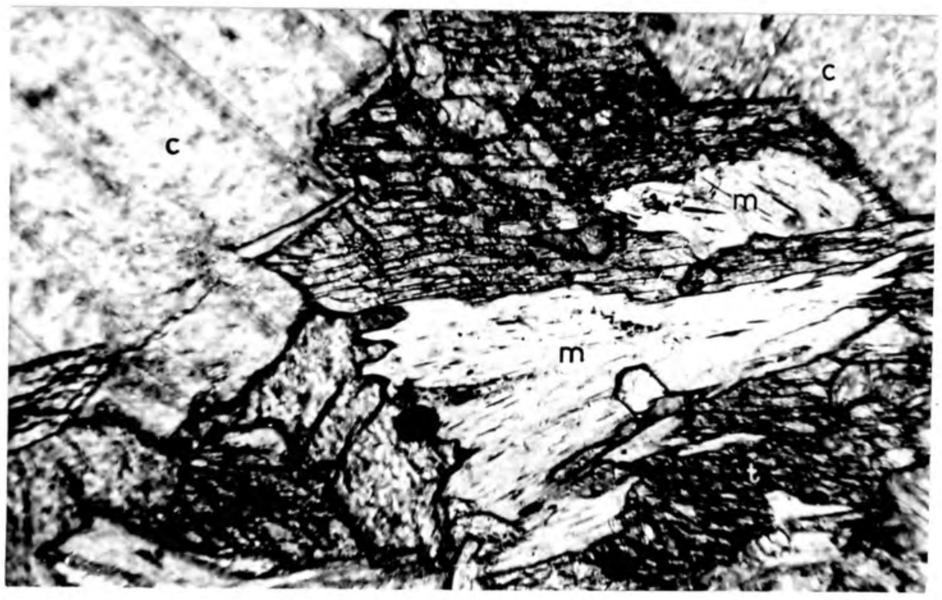


Plate XIX. Stained thin section of blue-white limestone from Joachimstal 107, showing calcite (c) surrounding tremolite (t), a basal section of which is intergrown with muscovite (m). X 100, crossed nicols.

Plate XX. Micrograph of white, massive limestone from Joachimstal 107 showing calcite (c), talc (ta), tremolite (t) and brucite (b). X 100, crossed nicols.

and white bands parallel to and defining the bedding. Sections of specimen 109 show calcite to be the dominant carbonate, dolomite being very rare. Tremolite needles up to 3mm long are common, often intergrown with muscovite parallel to the cleavage. Basal sections of tremolite penetrated by muscovite laths were also noted. Some carbon and sphene are present. Quartz is rather rare.

Slide 110, from a rock closely resembling No. 109 in hand specimen, shows bands approximately 2mm wide of coarse-grained calcite alternating with very fine-grained dolomite. Tremolite is developed chiefly in the calcitic layers, and is again often intergrown with muscovite. Some talc is developed; quartz is a minor constituent. Carbon is found chiefly along the grain boundaries of the dolomite layers.

The central portion of this dolomite horizon is represented by the typical white, massive variety. Slide 111 shows heteroblastic calcite to form the bulk of the rock, occasionally poikiloblastically enclosing dolomite. The latter may also occur interstitially to the calcite. Tremolite is abundant, sometimes intergrown with very subordinate muscovite. Some brucite, talc,and quartz are present. The composition of the rock is given in Table 9.

The succession is capped, as was the case on the boundary with Goldene Aue 106, by a coarsely banded, blue-white marble, which here shows development of tremolite.

Specimen 88, from a bed higher up in the succession, was collected on Joachimstal 107 at a locality 800 metres north of the point where the new tar road crosses the boundary between that farm and Goldene Aue 106 (grid reference -14600/38450). In hand specimen the rock is pale-blue and extremely fine-grained. Bedding is visible only on weathered surfaces. The thin section shows the texture to be somewhat heteroblastic, the dolomite grains ranging in size from 0.05 to 0.15mm. Recrystallisation appears to be in process. The quartz content is very low; plagioclase and muscovite are present as accessories only.

In conclusion, two specimens from the highest exposed dolomite horizons in the area mapped will be described. Both were collected from the vicinity of the Quartzite Hill, in the extreme west of the farm Joachimstal 107. Staining shows both to be dolomites.

Specimen 97, from the horizon below the Quartzite Hill, is a very fine-grained rock showing the characteristic "wrinkled" weathered surface, and varying in colour from blue-grey to buff. In thin section the average grain size approximates to 0.05mm. Quartz, muscovite, plagioclase and iron oxides are present in very small amounts only. One quartz-filled vug, 2mm across, occurs in the slide.

Specimen 98, from the exposure above the Quartzite Hill, is a rock whose weathered surface varies in colour from blue to brown, and clearly shows the bedding. On fresh surfaces bedding may occasionally be detected by colour differences between adjacent lamellae, and by development of white mica on the bedding planes. Under the microscope the rock is seen to be of larger grain size than specimen 97. The dolomite crystals are in process of recrystallisation, there being a large variation in grain size. Crystal boundaries are ragged and scalloped; clusters of large grains are separated from one another by areas of very small dolomite particles. Accessory minerals are as for specimen 97; muscovite and especially quartz are more abundant.

Classification of Carbonate Rocks

Despite the fact that the present work is primarily intended as a descriptive treatment of the regional geology, the variety of carbonate rocks encountered in the area mapped warrants a more detailed treatment of this subject. Both limestones and dolomites are present in the area, and it is felt that the occurrence of the latter needs to be discussed in some detail.

The use of the comprehensive classification of carbonate rocks set out in Chilingar, Bissell and Fairbridge (1967, Vol. 9a, pp 113-120) is not considered justified in view of the more generalised nature of the present investigation.

A scheme of classification based on chemical composition and formulated by Pettijohn (1957, p 418) is as follows:

	% Calcite	% Dolomite
Limestone	95	5
Magnesian limestone	90-95	5-10
Dolomitic limestone	50-90	10-50
Calcite Dolomite	10-50	50-90
Dolomite	10	90

On this basis, for instance, specimen 4 would be termed a limestone, specimen 113 a magnesian limestone, while specimens 1, 2, 44 and 88, to cite but a few, would be classed as true dolomites. The present author feels that the above classification is not strictly applicable in the case of rocks containing appreciable amounts of other minerals besides dolomite and calcite. Thus, all the Hakos dolomites investigated carry quartz, whilst tremolite is often present in significant amounts.

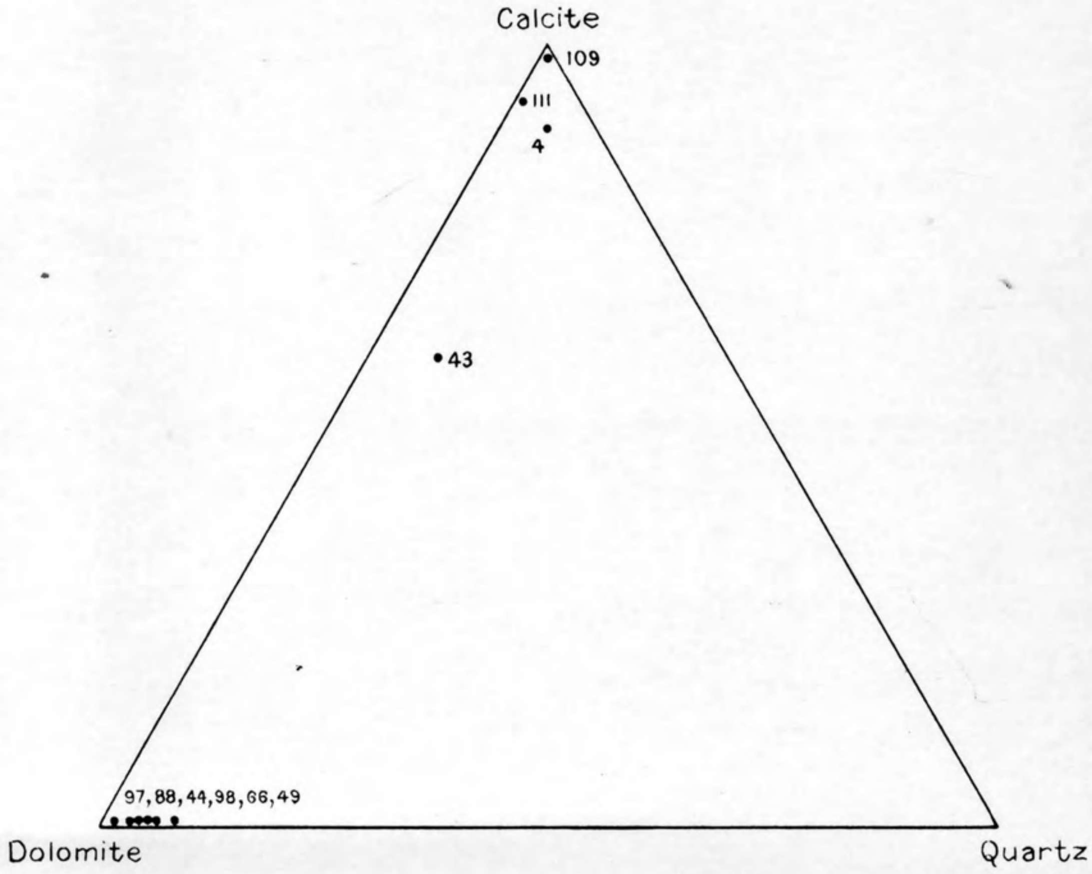
A further drawback of this classification, as pointed out by Toens (1966, p. 5, quoting Fairbridge 1957, p. 129) is that it fails to take into account the amount of calcite held in solid solution by dolomite, and vice versa. Recent X-ray diffraction studies have shown that a high Mg content in a carbonate does not necessarily indicate the presence of dolomite. The existence of high-magnesian calcite containing up to 30% $MgCO_3$ was discovered by these means (Chilingar et al., 1967, p. 270).

It is believed that some evidence for such solid solution of one carbonate within another was found during the present investigation. Application of Mitchell's dye in most cases gave either no stain at all, suggesting all the carbonate in the slide to be dolomite, or resulted in a deep red colouration being produced, signifying the presence of calcite. In the case of slides 1 and 44, however, only a faint pink tinge was produced despite repeated applications of the dye. Under the microscope it was seen that all the carbonate crystals in the slide were affected to the same degree. It is therefore suggested that, in these cases, the colouration is produced by a small amount of $CaCO_3$ held in solid solution by the dolomite.

Taking into account the various points mentioned above, it is felt that the generalised limestone-dolomite-quartz grouping devised by Pettijohn and cited by

Figure 3

Calcite - Dolomite - Quartz Plot of 10 Damara Carbonate Rocks



• 4 *Plot with sample number*

Krumbein & Sloss (1963, p. 177) is the classification most suited to the varieties of carbonate rock here being considered. For this, the specimens whose volumetric compositions are given in Table 9 have been plotted in Figure 3. As was done in the case of the Damara and Nosib quartzites, the minor constituents have here been ignored, and the totals of quartz, dolomite and calcite recalculated to 100%.

The Process of Dolomitisation and Dedolomitisation

The presence of both dolomite and calcite within the same rock, i.e. slides 3, 4, 43, 109, 110, 111 and 113 warrants a brief discussion of the problems connected with dolomite formation and dedolomitisation. These processes have been investigated by many authors; an excellent account summing up the present state of knowledge is given by Friedman and Sanders in Chilingar et al. (op. cit. pp. 267-348).

According to these authors, dolomites are abundant in the stratigraphic column, and are usually associated with limestones. The fact that Palaeozoic dolomites by far, in terms of volume, outrank those found elsewhere in the stratigraphic column, has led to the widespread belief that former times were more favourable for dolomite formation. According to Chilingar et.al. (p.4) Precambrian waters possibly had a higher Mg/Ca ratio and lower pH than is the case at the present time. These factors would have prevented the formation of hard protective and skeletal parts in organisms, suggesting that the Precambrian carbonate rocks owe their origin to biochemical control of pH in lagoons by algae, and to direct chemical precipitation out of sea water. A higher partial pressure of CO_2 in the atmosphere in

Precambrian times is thought to have favoured dolomite precipitation. Steidtmann, quoted by Toens (1966, p. 67) feels that there is evidence for a change in chemical composition of the sea, and especially for an increase in the ratio of Ca:Mg with the passage of time.

Teodorovich, mentioned in Chilingar et. al. (p. 274) also suggests that Precambrian and Early Paleozoic dolomites were formed by direct precipitation from sea water. A systematic reduction of the partial pressure of CO_2 in the atmosphere in Late Paleozoic, Mesozoic and Cenozoic times is said to have resulted in a decrease in dolomite formation. All the post-Cambrian dolomites are considered by Teodorovich to have been formed by replacement of limestone. However, in the light of the discovery of dolomite in Recent sediments by workers such as Friedman, Fairbridge, Chave, Goldsmith and Graf, to name but a few, the above theories are no longer wholly tenable.

Friedman and Sanders (in Chilingar et. al., pp.308-338) drew up the following classification of dolomites, based on their origin:

1. Syngenetic dolomite, defined as dolomite that has formed penecontemporaneously in its environment of deposition as a micrite (i.e. consolidated or unconsolidated ooze or mud) or as fine-grained crystals.
2, Detrital dolomite, formed by the recycling of existing dolomites.
3. Diagenetic dolomite is defined as dolomite that has formed by replacement of calcium carbonate during or after consolidation of the sediment. It may also have formed penecontemporaneously by

replacement of grains and cement of calcium carbonate sediments. Such replacement in all probability takes place on a volume-for-volume basis; the molecule-for-molecule transformation from calcite to dolomites involves a 12.1% volume shrinkage, which would be accompanied by an increase in porosity and/or brecciation in the replaced rocks.

4. Epigenetic dolomites are those that have been formed by replacement of limestone, the dolomite being localised by post-depositional structural elements. It is closely related to faults and fractures in carbonate rocks, and is often connected with mineral deposits.

According to Friedman and Sanders (in Chilingar et. al., p. 334):

> "The different classes of dolostone are mere variations on a theme: dolomite owes its origin to hypersaline brines. Dolomites, which are related to bacterial origin, are uncommon exceptions indicating that dolomite may form by other processes; however, it seems safe to conclude that all dolostone deposits found in the geologic record, other than those that are recycled, formed under evaporitic conditions.
>
> Hence all dolostones, whether syngenetic, diagenetic, or epigenetic, are the result of the action or reaction of hypersaline brines."

Such brines are believed to form by one of two processes:

1. Capillary concentration. Here (Chilingar et. al., p. 335):

> "......... due to the excess of evaporation over rainfall, interstitial waters in the sediments transpire upward through the porous marginal sediments and evaporate at the sediment-air interface .... Dolomite is formed, by evaporation, at the surface and the concentration of the unevaporated water is increased."

According to Friedman and Sanders (Chilingar et. al., p. 267) capillary concentration:

> "........ leads to dolomite formation in supratidal and intertidal environments on broad shallow shelves with interfingering gypsum and/or anhydrite (landward) and marine carbonates (seaward). Under conditions of humid climate, however, anhydrite and gypsum may not develop."

2. Refluxion. In this process, brines form as outlined above, in areas where evaporation exceeds precipitation plus runoff. Friedman and Sanders state (Chilingar et. al., p. 335):

> "Water is lost by evaporation, which lowers the water level on the shelf and increases the concentration and density of the water. The resulting heavy brine sinks and flows seaward down the sloping shelf. Surface currents tend to replenish the lost water by bringing low salinity water from the ocean in respect to hydrostatic head, while at depth oppositely directed currents as a result of density distribution maintain the seaward flow. If the return flow (reflux) of this brine to the sea is prevented by natural barriers, such as reefs or sills, it migrates to the lowest possible topographical depressions and seeps slowly through the underlying sediments, which are progressively dolomitized."

In a lake at Salt Flat Graben, West Texas, both capillary concentration and refluxion are operative, the former along the margins of the basin, the latter at its centre.

In refluxion, the brine seeps slowly through the underlying sediments, which are thereby dolomitised. However, dolomite may be precipitated directly from the brine, with aragonite possibly forming an intermediate phase. A layered dolomite mud would result at the bottom of the basin. For direct precipitation of dolomite, the following conditions must be met (Chilingar et. al., p. 268):

> "The Mg/Ca ratio of the brine must be increased from that of sea water to a ratio larger than that which should be in equilibrium with both calcite and dolomite for dolomite to form. This ratio can be raised by the removal of calcium from the brine to form aragonite or gypsum or both; however, gypsum is only deposited in

> very shallow water where a supply of oxygen is ample, because it tends to be degraded to H_2S and iron sulfide by bacteria where the oxygen supply is less. Hence layered dolomite formed under these conditions is indicative of a deeper water environment, of unspecified depth, with gypsum deposited in correlative positions along shore. Precaution is advised, therefore, in interpreting all syngenetic dolomite of supra-tidal origin."

Friedman and Sanders continue (Chilingar et. al., p. 336):

> "At Salt Flat Graben it was shown that the degradation of gypsum is genetically related to dolomite formation. Dolomite and gypsum are an antipathetic pair. Formation of dolomite requires: (1) brine concentration as indicated by enrichment of the heavy isotopes in dolomite; (2) the reduction of gypsum to H_2S, iron sulfide, and native sulfur, with possible presence of calcite as a by-product coincident with dolomite formation; and (3) enrichment of the Mg/Ca ratio of the brine as a result of gypsum or aragonite precipitation. Native sulfur would be removed in solution. Where abundant dolomite is formed, gypsum is not an important phase but its degradation products are".

A study of the Recent dolomites of South Australia by workers such as Alderman, Skinner and Von der Borch, (in Chilingar et. al., pp. 281-282) has shed much light on the processes connected with direct precipitation of dolomite from solution. It was found that dolomite is formed where the water is very saline, the pH high, and plants abundant. The plants extract CO_2 from the water during photosynthesis; this raises the pH and promotes the precipitation of a mixture of high-magnesian calcite and calcian dolomite.

In this connection it is of interest to note that conditions actually found prevailing in S. Australia are identical with those postulated by Toens (1966, p. 64) as being most favourable for the formation of primary chemically precipitated dolomite.

Replacement of dolomite by calcite is known as dedolomitisation. From studies of rock fabrics under the microscope Friedman and Sanders (Chilingar et. al., p. 301) cite the following as evidence of dedolomitisation;

(1) Remnants of incompletely replaced dolomite grains within calcite crystals (poikilotopic fabric).

(2) Calcite pseudomorphs after dolomite.

(3) Palimpsest remnants in which ghosts of former rhombic dolomite crystals remain in the form of zones of ferric oxides, or crystal boundaries within a new generation of calcite crystals.

The authors continue (Chilingar et. al., p. 301):

"Dedolomitisation is aided by the presence of sulfate ions, which tend to combine with the magnesium from dolomite to form $MgSO_4$ and calcite. The sulfate may come from evaporation of interstitial brine or oxidation of pyrite or other sulfide minerals.

According to Tatarskiy (1949) a genetic relationship exists between the presence of interstitial anhydrite and dedolomitisation, with $MgSO_4$ forming as a by-product, according to the reaction:

$$Ca.Mg(CO_3)_2 + CaSO_4 \rightarrow 2CaCO_3 + MgSO_4$$

Efflorescent $MgSO_4$ has been reported on outcrop surfaces of carbonate rock which have been dedolomitised. Gypsum interlayered with the dolostones apparently does not aid the dedolomitisation process."

Dolomite Formation, Dedolomitisation and Metamorphism of the Hakos Dolomites

The basal unit of the Hakos Series, from which specimen 66 was taken (grid reference -19100/42500) appears to have originated as a rather pure limestone which has subsequently been dolomitised. Originally pelitic portions of the sediment are now represented by muscovite. Metamorphism has had little effect on the rock apart from initiating recrystallisation, leading to the formation of isolated larger porphyroblasts.

Emplacement of the Dachsberg granite has not materially affected the dolomites in the vicinity of the windpump on the northern boundary of Eintracht 118. In specimens 1 and 2, the complete absence of tremolite and talc rules out any reaction between quartz and dolomite to have taken place. Winkler (1967, pp. 24-25) states that the reaction between dolomite and quartz cannot be used as an accurate indicator of temperatures reached during metamorphism. Even if the depth of burial, and hence the pressure of the gas phase were known, the equilibrium temperature in the reaction:

$$3\ CaMg(CO_3)_2 + 4\ SiO_2 + H_2O \rightleftharpoons Mg_3\left[(OH)_2.Si_4O_{10}\right] + 3CaCO_3 + 3\ CO_2$$

is profoundly influenced by the molar fractions of CO_2 and H_2O respectively present in the gas. This is shown graphically by Turner (1968, p. 136).

The blue, and the white members of the Hakos dolomite unit in this vicinity are regarded as representing dolomitised limestones. A possibly detrital origin for the red variety represented by specimen 3 has already been referred to.

The thin sections of specimen 4, from the south-western end of the Vierkuppenberg, show rounded inclusions of dolomite enclosed in the calcite crystals that constitute the bulk of the rock. According to Friedman and Sanders (in Chilingar et. al., 1967, p. 301) such poikilotopic textures are one of the criteria for dedolomitisation.

Slide 4 contains much carbon. The insoluble residue obtained during the acid leaching of the rock in connection with the extraction of the danburite showed appreciable amounts of originally organic matter to be present. This leads to speculation regarding the origin of the rock. Toens (1966, pp. 66-67) discusses the evidence for organically precipitated dolomite. Although the existence of pure dolomite originating in this manner has never been proved, workers such as Fairbridge, Skeats and Twenhofel have demonstrated the presence of considerable amounts of $MgCO_3$ held in solid solution by organically secreted calcite. Figures obtained by these authors, and quoted by Toens (p. 66), range from 7 to 43% $MgCO_3$. Toens suggests that, with the passage of time, and the addition of $CaCO_3$ from an outside source, this material could undergo molecular reorientation to form dolomite.

The presence of carbonaceous matter in Specimen 4, and the evidence for dedolomitisation obtained from slides of this specimen, lead the present author to suggest that at least locally, the Hakos dolomites may in part be of organic origin.

Specimen 49, collected from the southern end of the dolomite hill in the centre of Goldene Aue 106, is of interest in that besides dolomite and quartz, it contains some wollastonite. This last-named mineral, according to Winkler (op. cit., p. 35) is not characteristic of low-temperature metamorphic facies, nor is it found in low-pressure (i.e. shallow-depth) contact-metamorphic zones. Winkler suggests that, for wollastonite to form according to the reaction:

$$CaCO_3 + SiO_2 \rightleftharpoons CaSiO_3 + CO_2$$

the molar fraction of CO_2 in the gas phase must have been very high, probably approaching 1. Thus, the assumption of a reaction temperature some 20-50°C lower than the experimentally established equilibrium temperature for a given molar fraction of CO_2 does not result in any great errors.

In this particular instance, geological mapping has revealed the existence of a basic dike (grid reference -16900/39000) in close proximity to the dolomite horizon in question. It is not unlikely that the western end of this dike does, in fact, approach the dolomite more closely than is indicated on the map. This could not be established in the field owing to the poorly exposed nature of the dike, but it seems likely that development of the wollastonite is connected with the emplacement of this small intrusion. Assuming a depth of burial of 4-8 km, curves given by Winkler (p. 34) indicate that temperatures of 650-700°C and pressures of approximately 2000 bars would have prevailed at the time of emplacement. The low (0.5%) wollastonite content, coupled with the complete absence of $CaCO_3$ in specimen 49, suggests that the rock was originally a rather pure dolomite. The $CaCO_3$ necessary for wollastonite formation could possibly have represented a small calcite fraction as yet not dolomitised, or it could have resulted from incipient dedolomitisation of the rock.

In view of the quartz still present interstitially in the rock it is surprising that, with the drop in temperatures that must have followed emplacement of the dike, no tremolite or talc were formed in the dolomite.

One possible explanation is the outward migration from the area of pore fluid during emplacement of the dike. The "dry" nature of the rock would have hampered any subsequent reaction between quartz and dolomite.

It is noteworthy that the only development of tremolite in the area mapped is in the dolomite horizon flanking the southeastern portion of the Kuduberg, from the boundary Goldene Aue 106 - Joachimstal 107 to a point some 2 km west of this. The quartzitic nature of the rock, together with its situation near the core of the syncline that trends westsouthwestwards across Joachimstal 107, were probably decisive factors controlling the formation of tremolite. As already mentioned, the presence of this mineral can be used only as a very rough indication of the degree of metamorphism. Winkler (op. cit., p. 25) equates it with the "greenschist" facies of regional metamorphism, corresponding to temperatures lying above $400^{\circ}C$.

On the boundary between Goldene Aue 106 and Joachimstal 107 immediately south of the White Nossob River, the base of the Hakos dolomite band under consideration shows, in thin sections of specimen 43, layers of very fine-grained dolomite alternating with layers of much coarser-grained calcite. The locally developed poikilotopic texture suggests dedolomitisation and recrystallisation to be taking place. Dedolomitisation would have been aided by metamorphism, which has resulted in the development of some 7% by volume of tremolite in the rock, according to the following equation (Winkler, p. 25).

$$5\ CaMg(CO_3)_2 + 8\ SiO_2 + H_2O \rightleftharpoons Ca_2Mg_5\left[(OH)_2/Si_8O_{22}\right] + 3CaCO_3 + 7CO_2$$

Carbonaceous material is abundant in the slide.

The central portion of the horizon consists of white dolomite. The uppermost band of the whole dolomite unit is a rather pure, blue dolomite possibly containing $CaCO_3$ in solid solution, as suggested by the faint stain produced by Mitchell's dye in slide 44. Traces of carbon were noted.

Some 2 km further west, the same colour sequence blue-white-blue, from the base of the dolomite horizon upwards, was once more observed. Carbon is again absent from the white variety, but features prominently in the blue-grey types. Tremolite is well developed in all horizons. Expressed in terms of Pettijohn's classification, the horizon consists of a basal and central portion ranging in composition from a dolomitic limestone to a calcitic dolomite. The uppermost unit is a magnesian limestone. Locally developed poikilotopic textures between calcite and dolomite, together with the variations in grain size already noted elsewhere between these minerals, are suggestive of dedolomitisation. The development of tremolite during metamorphism would, of course, have materially assisted in this process.

In view of the variations in composition and carbon content, it is very likely that this particular dolomite horizon is of composite origin. Reviewing the distribution of Paleozoic dolomites, Chilingar et. al. (1967, p. 7), citing Fairbridge (1957) point out that.

> ".....in the offshore direction in a non-evaporite facies as one proceeds seaward the dolomitized sediments are generally replaced by non-dolomitized limestones of colder and

> deeper water character. Where the two alternate, one visualises a eustatic cyclicity. The near-shore dolomitized carbonate is richer in terrigenous insolubles and initially Mg-rich algal nuclei, whereas the non-dolomitized layers lack such nuclei. The correlation between dolomitization and clastics showing nearness to the shore was demonstrated by many authors....... In certain deep-water limestones, one may also note a rise in the insoluble fraction, but these rocks do not become so readily dolomitized."

These postulates may probably be applied to the case under consideration.

Specimens 97 and 98, from the highest exposed dolomite unit in the area, are very pure dolomites showing evidence of recrystallisation only. No tremolite or carbon was noted. For dolomitisation to have taken place, deposition in relatively shallow water must be postulated for these rocks if the interpretation of Chilingar is accepted. The fine grain size in the quartzite horizon (i.e. the Quartzite Hill on Joachimstal 107) intervening between the two dolomite bands shows deposition to have occurred at some distance from the shore. That the water was sufficiently shallow for some erosion to have taken place on this quartzite horizon is demonstrated by the higher quartz content of the upper dolomite when compared with the lower unit (see Table 9).

The absence of tremolite may be explained chiefly by the very low quartz content of the rock. Further, in contrast to the tight plications of the strata in the northern portion of Goldene Aue 106, the folds in the west of Joachimstal 107 are broad and open. The lower stress field would be expected to result in a somewhat lower grade of metamorphism than is the case further east.

In summing up the foregoing discussion, it may be concluded that:

(1) The characteristic blue-grey colour found in carbonate rocks of the Hakos Series is due to the presence of finely disseminated carbonaceous matter. Where this is absent the rock is of a pure white colour.

(2) Deeper, colder water favours deposition of limestones rather than dolomites. It follows that dolomite formation is restricted to shallow-water environments. Since most of the carbonate rocks investigated show evidence of dedolomitisation, such as dolomite grains poikilitically enclosed by calcite, it must be inferred that conditions during Hakos times favoured the formation of dolomite.

(3) Dolomite is formed by the following processes:

(a) Direct precipitation from water saturated in respect to $MgCO_3$ and $CaCO_3$;

(b) Precipitation of high-magnesian calcite by algae;

(c) Replacement of limestone by hypersaline brines.

All the above processes require stagnant shallow-water environments with a restricted circulation; evaporitic conditions are the logical extension of the above set of conditions. Although no gypsum was observed in the area under consideration, it is known that $CaSO_4$ is reduced by bacterial action with the liberation of H_2S; evaporitic conditions can thus not be ruled out.

(4) The almost ubiquitous presence of carbonaceous matter in the Hakos dolomites strongly suggests an organic origin for these rocks. Although organically precipitated dolomite has never been definitely identified, it has been postulated to

have been deposited in Paleozoic times. Alternatively, the presence of carbon in the Hakos dolomites could be explained by the almost contemporaneous dolomitisation of organically secreted high-magnesian $CaCO_3$.

(5) Very localised deposits, such as the red limonite-bearing dolomite found on Eintracht 118, may be of detrital origin.

The Conglomerate on Eintracht 118

As mentioned elsewhere in this work, a quartzite unit trends eastnortheastwards from the Straussenkuppe on Astra 205, broadening out considerably on Goldene Aue 106 and Eintracht 118. It is on this last-named farm, near the base of the quartzite, that a conglomerate occurs. First discovered in a gravel pit (grid reference -24660/36920) on the northern side of the Windhoek-Gobabis road, the horizon could be traced for only a short distance southwestwards from this point before lensing out. Towards the northeast, however, the conglomerate becomes a more prominent feature.

In the gravel pit on Eintracht 118 it consists of pebbles of a white, sugary quartzite, set in a schistose quartz-sericite matrix. The pebbles are somewhat flattened in the plane of schistosity, and are all rather elongated. Lengths vary from 10cm to at least 20cm. Of interest is the fact that all the long axes of the pebbles pitch steeply in the plane of schistosity of the rock. This westerly direction of pitch approximates to the general trend and plunge of the regional fold axes.

Thin section No. 5, of a pebble from this exposure, shows the rock to consist of:

Quartz	95%
Orthoclase	3%
Microcline	2%
Plagioclase) Iron Oxides)	Tr.

The texture is heteroblastic, owing to partial recrystallisation having taken place. Quartz grains vary in size from 0.1 to 0.7mm. The felspar is generally rather cloudy. Microcline is porphyroblastic, and shows sieve texture, containing rounded inclusions of quartz. Micropegmatite is prominently developed.

In terms of composition, the matrix of the conglomerate does not differ greatly from the pebbles. A slide of specimen 6 has the following visually estimated volumetric composition:

Quartz	88%
Orthoclase	5%
Microcline	1%
Muscovite/Sericite	6%
Iron Oxides	Tr.

The slide shows the rock to consist of alternating bands of finer (0.05mm) and coarser (0.5 to 1.0mm) grained quartz. The felspar, again somewhat altered and cloudy, occurs as laths up to 2mm long. Much miccropegmatite is developed. Bedding planes, approximately 1mm apart, are characterised by wisps of colourless to pale-green mica, usually crinkled into small folds of wave-length 1mm.

The conglomerate is only a few metres thick in the exposure on Eintracht 118. From here the unit could be traced intermittently northeastwards; both the width of the unit and its pebble size increase in this direction. East of the Dachsberge on Sandflats 123, adjacent to the track leading from Otjiwarumendu 119 to Airlie 124, the conglomerate was again encountered (grid reference -32880/33100). Although no outcrop as such could be located, the surface at this point is liberally scattered with the characteristically shaped pebbles. These could be traced for some distance along strike. When compared with those from Eintracht 118, the pebbles on Sandflats 123 are larger, averaging some 30cm in length, and are rather more flattened.

In the most northeasterly exposure visited by the author, on the farm Spandau 149, some 6 km northnortheast of the northeastern corner of the area mapped, the conglomerate is at least 20 metres thick, and forms a low rise. The pebbles here are even larger than those on Sandflats 123.

A short distance from the southern boundary of Spandau 149, just south of the road leading westwards to the homestead on Airlie 124, the conglomerate horizon has been thrown into tight folds with a southwesterly plunge. These folds lie in the continuation of the major zone of brecciation described from Sandflats 123 and the northern part of Eintracht 118. Accordingly, much faulting and shearing has taken place, with the result that some of the pebbles have been intensely deformed, resembling corkscrews in certain instances.

The position of this conglomerate horizon has important stratigraphical implications. On the 1963 edition of the 1:1000000 Geological Map of South West Africa, it is correlated with the Opdam Formation of the Dordabis System. As far as can be ascertained by the present author, the only basis for this correlation is:

(i) The sheared nature of this conglomerate on Ottawa 150;

(ii) The occurrence, in this vicinity, of a thin amphibolite band, possibly representing a former lava flow immediately beneath the conglomerate.

According to Martin (1965, p. 16) the Opdam Formation is characterised by several quartz-pebble conglomerates with phyllitic matrices; mafic amygdaloidal lavas are also common. It thus appears that the Spandau-Eintracht conglomerate horizon has been correlated with the Opdam Formation solely on the evidence of the lithological combination lava-conglomerate.

The Opdam normally underlies the Doornpoort Formation. Rocks with a southeasterly dip and tentatively correlated with the latter are known from the farm Christiadore 104, a short distance to the south. Accordingly, if the conglomerate were part of the Opdam Formation, one would expect dips to be towards the east. Since this is not the case, overfolding or faulting must be postulated. In this connection, it is known that the thrust fault between Nosib and "Tsumis" rocks does extend northeastward at least as far as Spandau 149. Exposures east of the conglomerate are poor, so that stratigraphic evidence is unobtainable from this area.

However, if the conglomerate is traced southwestwards, it is seen, especially on Eintracht 118, to lie well inside the Damara belt. Dips everywhere are steeply westerly, and since no unconformity was observed either above or below the conglomerate, the horizon must be regarded as an intraformational feature of the Damara System, rather than a portion of the Opdam Formation. The stratigraphical evidence is felt by the author to be conclusive in this respect.

The possibility of subdividing the Damara System in the area here being considered must be mentioned briefly.

Martin (op. cit., p. 24) quotes the following maximum thicknesses for the various members of the Damara System in the Windhoek district:

Khomas Series	10,000	metres?
Upper Hakos Stage	700	"
Chuos Tillite	600	"
Lower Hakos Stage	1,600	"

In view of the fact that an estimated thickness of at least 8,000 metres of sediments overlies the Nosib Formation in the area covered by Map 2, it is evident that not only the entire Hakos, but also a considerable portion of the Khomas Series must be present here.

Discussing problems of nomenclature of the Damara System, with special reference to the boundary between Hakos and Khomas Series, Martin (pp. 42 - 43) states:

> "This lithologically important boundary between marbles and schists is, if larger areas are considered, composed of laterally interfingering units, in which large-scale facies substitutions occur. It is quite certain that this lithological boundary does not even approximately conform to a time boundary. This being the case, it is questionable whether the Khomas sequence should retain the status of a series. It would certainly be more realistic to call this unit, in spite of its great thickness, a member instead of a series. If the designation 'series' is to be retained, then the highest marble band should form the boundary............"

K. Seeger of the South West Africa Geological Survey (personal communication) is of the opinion that the sediments overlying the dolomite horizon (grid reference

-13500/38600) in the eastern portion of Joachimstal 107 may possibly be correlated with the Khomas Series. However, in view of Martin's statements above, the present author feels that the base of the Khomas Series should more correctly be placed at the top of the upper dolomite unit in the Quartzite Hill area in the extreme west of Joachimstal 107. This would, of course, make the Upper Hakos Stage considerably thicker than anywhere else in South West Africa.

A further point of interest is the possible equivalence of the Eintracht-Spandau conglomerate with the Chuos Tillite, which elsewhere in South West Africa serves to separate the Lower from the Upper Hakos Stage. Locally a typical glacial deposit, the horizon is very variable lithologically. It may be present as a phyllite, quartzite, itabirite, conglomerate or pebbly schist.

Accordingly if, as already mentioned, the lower contact of the Khomas Series is placed in the vicinity of the Quartzite Hill, and the conglomerate is taken to represent the Chuos Tillite, a broad subdivision of the Damara System between Witvlei and Omitara becomes possible. Thicknesses of the various members would then approximate to:

Khomas Series	>2,500 m
Upper Hakos Stage	3,500 m
Conglomerate (Chuos?)	0 - 20 m
Lower Hakos Stage	2,000 m

The presence of isoclinal folding in certain of the schists between the more competent horizons makes a more accurate assessment of thicknesses impossible.

The Schists

Between the more resistant and hence better exposed members of the Damara System, namely the quartzites and dolomites, there occur considerable thicknesses of less competent, schistose rocks. These generally have little topographical expression and are usually poorly exposed. Most of the examples described below were collected from the immediate vicinity of the White Nossob River, where outcrops are more abundant. The schists are usually steeply dipping and may in places be isoclinally folded. They comprise quartz-chlorite, quartz-mica and quartz-epidote schists, as well as quartz-sericite and graphitic phyllites. Narrow interbeds of quartzite and dolomitic limestone occur. Quartz veins parallel to the strike are ubiquitous, and form part of the regional shear pattern. The minor amphibolites associated with the schistose rocks will be described in the following section.

Specimen 68, from an exposure (grid reference -22900/39650) in a gully on the southern bank of the White Nossob River, is a fine-grained quartz-chlorite rock containing lenses of pink limestone 2-3mm thick. These lenses show up the folding in the rock. In thin section, the specimen shows a quartz-calcite-chlorite groundmass containing crystals of granoblastic-polygonal dolomite. These may exhibit inclusions of quartz, and range from 0.5 to 1mm in size. Flow texture is occasionally evident in the dolomite, in which folding has led to local distortion of the cleavage planes. The quartz in the groundmass is somewhat elongated in the plane of bedding; grains range from 0.05 to 0.3μm in length. Albite is present in minor amounts. Green pleochroic chlorite, as scaly aggregates and wisps parallel to the bedding, is associated with subordinate biotite. Sphene, as grains 0.1mm long is abundant; tourmaline is an accessory only. A visual estimate of the composition is given in Table 11.

In connection with the prospecting activities in the eastern corner (grid reference -20900/38850) of the Goldene Aue 106, some detailed geological mapping was carried out by the author. Map 3, included in the pocket at the back of this volume, shows the variety of rock types that have had, of necessity, to be included under the general symbol Ds on Map 2.

Within the area covered by Map 3, specimen 54 was collected from a prospecting trench some 75 metres southwest of the White Nossob River. It is a dark-green to black, finely laminated quartz-chlorite-biotite schist, breaking easily into fragments approximately 1cm thick. A faint crenulation, giving rise to a lineation on the schistosity planes, was observed. Isolated specks of malachite occur in this rock.

Under the microscope a thin section of specimen 54 shows thin laths of chlorite, muscovite and green biotite, elongated parallel to the schistosity. Granoblastic elongate quartz up to 0.2mm long occurs between the micaceous minerals, as does porphyroblastic apatite. The latter is often bent where it has been involved in the irregularly spaced crenulations that cross the slide at an angle to the schistosity Tourmaline occurs as stout laths of ditrigonal prismatic cross-section. It may be zoned, with a green rim surrounding a blue core. The slide is traversed by a band, approximately 3mm wide and running parallel to the schistosity, of granoblastic quartz-plagioclase in the size range 0.05 to 0.15mm. Green pleochroic chlorite is associated with a little brown biotite. Later veins, still parallel to the schistosity, consist of elongate quartz crystals up to 0.5mm long, as well as subordinate xenoblastic carbonate. Malachite occurs as "porphyroblasts" in the micaceous layers. Iron oxides are present in small amounts.

Specimen 55, also from Goldene Aue 106, comes from a prospecting trench immediately adjacent to the White Nossob River. It is a quartz-sericite schist carrying abundant malachite. In the thin section, tight folding is apparent, with much recrystallisation of the constituent minerals to form larger grains, especially in the fold closures. The slide shows two outer zones of very fine-grained quartz-muscovite-sericite schist, enclosing a central band, 2.5mm wide and parallel to the bedding, of coarser biotite and chlorite in a quartz-felspar matrix. Tourmaline is found throughout the slide. Apatite was noted in the central zone only. Malachite occurs as blebs and as veinlets parallel to the bedding, especially in the central zone.

Of interest is the presence of two varieties of biotite. An olive-green type is found throughout the rock. It occurs as thin laths 0.3 to 0.4mm long in the outer zones of the slide, and as stouter laths up to 0.6mm long in the central section, where they are not strictly parallel to the bedding. The sides of the central zone are rimmed by long laths of brown biotite;

a broad zone of this mineral also runs up the middle of the central zone in the slide. This brown variety may be intergrown, parallel to the cleavage, with the green variety, and is associated with chlorite and malachite.

Concerning the colour variations found in biotites Deer, Howie and Zussman (1962, Vol. 3, p. 71) state:

> "......the principal factors which influence colour are TiO_2 content and the ratio Fe_2O_3/(Fe_2O_3 plus FeO). High TiO_2 gives a reddish brown colour while high ferric iron gives green. It is the balance of these two factors, however, rather than their absolute values which determines the colour. Thus a biotite with low TiO_2 will yet be brown provided that Fe_2O_3 is low, and one with low Fe_2O_3 can be green if there is very little TiO_2. Intermediate proportions of Ti and Fe^{+3} result in yellowish or greenish brown colourations."

A visual estimate of the mineralogical composition of specimen 55 is given in Table 11.

Interbedded with the schists described above, and well developed in the area covered by Map 3, are thin bands and lenses of pink dolomitic limestone. These are usually slightly better exposed than the surrounding schists, and are useful markers in helping to determine the style of folding.

In hand specimen, these dolomitic limestones closely resemble those found interbedded with the Duruchaus phyllites. Specimens 52 and 53, from the eastern corner of Goldene Aue 106, are medium-grained, finely-bedded pink rocks. Bedding planes are accentuated by concentrations of quartz and, locally, iron oxides. Crystals of limonite after pyrite are common. A lineation running obliquely across the bedding planes is very prominent. Tight folding is exhibited in specimen 53.

TABLE II

APPROXIMATE MINERALOGICAL COMPOSITION OF SOME DAMARA SCHISTS.

SPECIMEN NO.	18	27	28	48	53[1]	54	55[2]	68[3]
Quartz	64	51	50	35	26.1	30	25	35
Plagioclase	-	1	1	Tr.	2.0	5	7	1
Biotite	-	14	15	45	-	18	35	1
Muscovite	35	8	7	20	0.3	30	23	-
Chlorite	-	12	8	-	-	14	5	20
Carbonate	-	Tr.	8	-	70.3	Tr.	-	41
Epidote	-	10	10	-	-	-	-	-
Iron Oxides	1	2	1	Tr.	1.3	2	1	-
Tourmaline	-	)	-	Tr.	-	Tr.	1	Tr.
Apatite	-	) 2	-	-	-	1	Tr.	Tr.
Sphene	-	)	-	-	-	-	Tr.	2
Cu Minerals	-	-	-	-	-	Tr.	3	-
TOTAL	100%	100%	100%	100%	100.0%	100%	100%	100%

1. Grain Count. Carbonate content made up of : Dolomite 28.5%, Calcite 41.8%
2. Biotite content made up of (approx.) : Green variety 20%, brown variety 15%
3. Carbonate content made up of (approx.) : Dolomite 30%, Calcite 11%

A slide of this rock shows a very fine-grained groundmass of dolomite, quartz and felspar, in the size range 0.01 to 0.1mm. In this are developed bands 2-3mm thick and parallel to the bedding, composed of xenoblastic calcite with an average grain size of 0.5mm. This calcite appears to be a product of dedolomitisation, since it is poikiloblastic, enclosing rounded grains of dolomite, and sometimes also of quartz. Elsewhere the latter shows evidence of recrystallisation to grains 0.5mm across. Muscovite and iron oxides are present in minor amounts. Results of a grain count carried out on this slide are given in Table 11.

Specimen 48 comes from higher up in the stratigraphic succession, and was collected on the small hill (grid reference -16900/38500) in the centre of the farm Goldene Aue 106. It is a well cleaved, fine-grained grey phyllite, in which the cleavage appears to be parallel to the bedding. Foliation planes show a crenulation measuring 4-5mm in wavelength, resulting in a lineation with a shallow southwesterly plunge.

The thin section shows the rock to consist of laths of mica, forming bands parallel to the foliation and enclosing, between adjacent layers, grains of granoblastic elongate quartz. Layers rich in muscovite/sericite alternate with those where biotite predominates. Iron oxides, plagioclase and tourmaline are accessories. A crenulation, of average wavelength 0.5mm, traverses the slide obliquely to the foliation; an incipient cleavage, axial-planar to these small folds, is developing.

A few examples of graphitic schists are known from the area under consideration. Specimen 13, from the southern bank (grid reference -11980/29470) of the White Nossob River on Büschow 108, is a bedded, grey, somewhat graphitic rock, exhibiting one lineation. Under the microscope it is seen to consist of granoblastic elongate quartz with subordinate plagioclase, usually untwinned, in the size range 0.05 to 0.4mm. Occasional bands of sericite are present, parallel to the bedding. Finely disseminated carbon is prominent in the slide. Xenoblasts of sphene, often including quartz, are conspicuous and are usually associated with later veins of coarse-grained quartz.

Specimens 99 and 100 were collected from a gully on the southern bank of the White Nossob River, close to the boundary Goldene Aue 106/Joachimstal 107 (grid reference -18000/34750). Both are well bedded and very fine-grained grey rocks, exhibiting two lineations on the bedding planes. In thin section both rocks appear "dirty", owing to the abundance of finely disseminated carbon. Quartz, plagioclase and pale biotite are the chief constituents; slide 99 contains short laths of epidote, as well as some muscovite.

The large amount of carbon present in specimens 13, 99 and 100 suggests deposition to have taken place in stagnant water, where reducing conditions prevailed.

Of interest is the occurrence of a talc schist on Büschow 108. This rock, of a lustrous grey-white colour, highly schistose and soapy to the touch, occurs as a narrow band below the Hakos dolomite in the bend of the White Nossob River (grid reference -13570/29900). A bedding plane, exposed by and sloping westwards to the river, shows two sets of folds, the one crossing the other at a considerable angle.

Slide 13, from a specimen of this rock, shows a carbonate occurring as idioblasts up to 1mm across, but more usually as ragged xenoblasts set in a matrix of talc. Owing to the fact that the section was cut parallel to the bedding, the talc is seen chiefly in the shape of basal sections with low interference colours. Isolated laths show moderate birefringence, have parallel extinction, and are length-slow. The mineral is biaxial negative, with a very small 2V angle of some 10°. The composition of the rock approximates to:

Carbonate 30% Talc 70%

Specimen 18 comes from an exposure on the side of the track leading through Diana 117 to Diana North 116, near the northern boundary of the area mapped (grid reference -23060/27620). It is a medium-grained schistose rock, rusty to green in colour, consisting of quartz "blows" from 1mm to 1cm thick, between layers of pale mica. Folding on a small scale can be observed.

A thin section of this rock shows bands of coarse quartz, of grain size up to 2.5mm and exhibiting lobate sutures, alternating with layers of finer-grained (approximately 0.5mm) quartz and muscovite. The latter, slightly pleochroic from pale-green to pink, forms laths and shreds up to 2mm long, and may give rise to monomineralic layers. The bedding, or schistosity, is presumed to be parallel to the mica laths, which show a slight crenulation. The approximate composition of this quartz-muscovite schist is

154a

Plate XXI. Folds in quartz-sericite schist on Diana 117, showing boudinaging of a quartz vein.

given in Table 11.

Mention must be made of the quartz-mica schists exposed on the northern bank of the White Nossob River, in the core of the Kuduberg-Omatewaberg anticline (grid reference -17340/31280). Samples 27 - 30 differ somewhat in hand specimen, but all are essentially soft, grey schistose rocks containing randomly orientated biotite. Cubes of pyrite up to 4mm across, often altered to haematite and limonite, are apparent, as are octahedra of magnetite. A slight crenulation, giving rise to a lineation of very shallow dip, is visible in the outcrop.

In thin section, specimen 27 is seen to consist of granoblastic-polygonal quartz of average grain size 0.2mm, associated with randomly orientated muscovite laths of length 0.1 to 0.5mm. Minor plagioclase, as andesine, is present. Olive-green biotite exhibiting pleochroic haloes was noted, locally altered to chlorite. Colourless epidote, optically biaxial negative with a 2V angle of some 85°, is abundant as laths and granular aggregates of high relief. Subordinate carbonate, sphene, tourmaline and apatite were noted, as were cubes of pyrite up to 2mm across, altering to haematite.

Slide 28 is similar but shows the rock to be of average grain size 0.1mm. Carbonate is more abundant than in Slide 27, occurring as ragged xenoblasts often enclosing quartz, biotite and magnetite. A crenulation of wavelength 0.5mm is evident.

A little further east, close to the boundary with Altenstein 115, more quartzitic members of the schists give rise to "whale-backs". These ridges, approximately

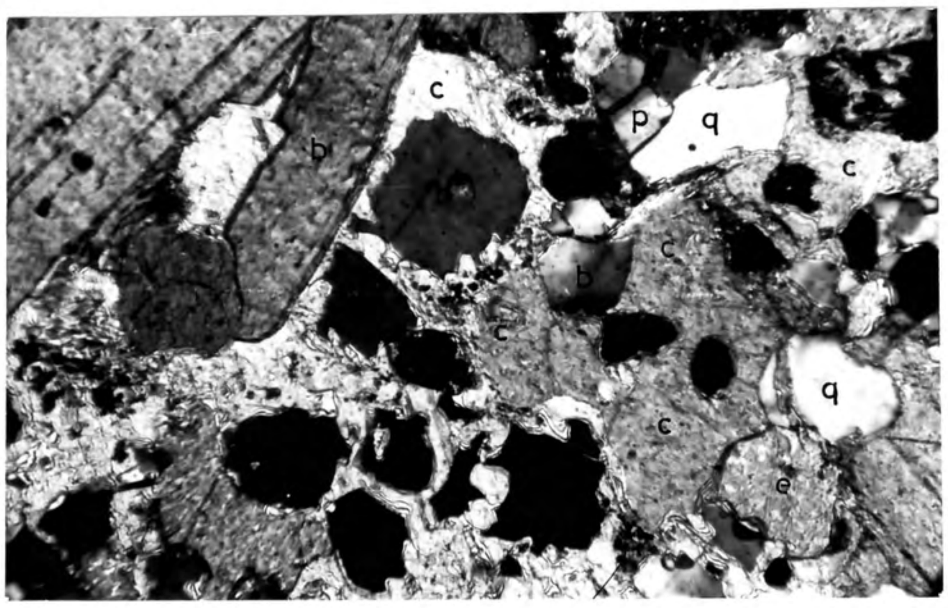


Plate XXII. Micrograph of quartz-biotite schist from Omatewa 113, showing calcite (c) poikiloblastically enclosing green biotite (b), quartz (q), epidote (e) and plagioclase (p). X 100, crossed nicols.

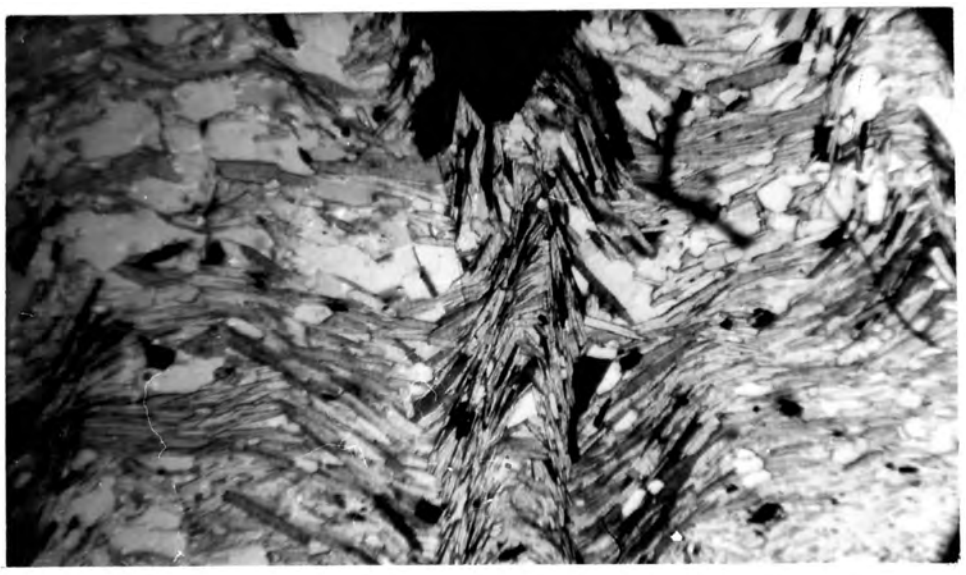


Plate XXIII. Mica schist from Omatewa 113 in thin section. Laths of both muscovite and biotite are present, with interstitial quartz. Folding has led to the formation of a crenulation cleavage. X 35, crossed nicols.

20 metres long, rise some 5 metres above the valley floor to approach the height of the calcrete-covered surface between the Kuduberg and the Omatewaberg. Isolated interbeds show remnant cross-bedding, dipping very steeply either side of the vertical; the northerly component predominates. Since the overlying quartzites have a very shallow dip, it must be assumed that the schists are isoclinally folded in this axial zone. Exposed surfaces are almost horizontal with a shallow westerly dip. These flat surfaces correspond to a type of regional foliation. They are finely crenulated, with a lineation running due west down the dip.

The Amphibolites

Under this heading are included melanocratic rocks of doubtful origin, occurring as thin interbeds in the Damara schists. They can, in certain instances, be traced for considerable distances along strike, and have been found to be entirely conformable with the surrounding sedimentary assemblage. This is borne out by a study of Map 3.

Cannon (1963) discusses briefly a classification of amphibolites based on the proportions of plagioclase and quartz in the rocks.

Much has been written on the problems connected with distinguishing between ortho- and para-amphibolites. The latter usually result from the metamorphism of calcareous or dolomitic shales, since only these sediments have an original composition corresponding to that of amphibolites. Para-amphibolites may thus be regarded as decarbonated mixtures of calcite or dolomite with pelite, whereas ortho-amphibolites are completely recrystallised meta-dolerites, meta-basalts, or meta-basic tuffs. Leake (1964, p. 238) points out:

> "Attempts to find chemical differences between ortho- and para-amphibolites have been prejudiced because banding has been taken as complete proof of a sedimentary origin whilst metamorphic segregation, shearing together of rocks, and tectonic thinning of interbedded sequences of meta-sediment and meta-basic sills have been completely discounted. Consequently, many published conclusions that there are no chemical differences between ortho- and para-amphibolites cannot be accepted uncritically. In fact, if banding were a reliable indication of a sedimentary origin then there would often be no need to search for chemical differences between the two groups of amphibolites."

The author continues (p. 239)

> "....pelites and basic igneous rocks both have a fairly wide range of trace element concentrations and so no completely diagnostic abundance criteria have been discovered, though the frequent high contents of Cr and Ni in basic igneous rocks have received much comment. Such rocks usually have, also, higher Ti and lower Niggli K values than mixtures of pelite or semi-pelite with dolomite or limestone. Nevertheless, because of common alkali metasomatism, including sericitization, and because there are very great ranges in the composition of igneous rocks and, to a lesser extent of pelites, none of these features is always useful. In summary, it can be said that amphibolites rich in Cr, Ni, and Ti, and having low k values are almost certainly igneous in origin, but amphibolites having low Cr, Ni, and Ti values and high k values can be either igneous or sedimentary in origin. ....The most valuable distinction between ortho- and para-amphibolites is likely to be based not so much on the absolute concentrations of certain elements as on the nature of the trends of variation in the amounts of these elements, and their relationship to known igneous and sedimentary trends. The extent to which metasomatic changes, other than decarbonation, have been important in the genesis of amphibolites should become clear through the deviation of the plots from both igneous and sedimentary trends."

By these means, Leake (1963) working on the amphibolites of the N. W. Adirondacks, N.Y., was able to establish a characteristic igneous trend of variation, corresponding to the trend established from Karroo dolerites by Walker & Poldervaart (1949, p. 647). These trends differ markedly from those for pelite-limestone and pelite-dolomite mixtures.

From Somalia, Skiba and Butler (1963) used Sr-An relationships in plagioclases to differentiate between metagabros and country-rock (para)amphibolites.

Using the methods pioneered by Leake, Van de Kamp (1969) made valuable contributions regarding the origin of amphibolites from the Beartooth Mountains in Wyoming and Montana. On the basis of major element chemical variations, and of trace element abundances and ratios, Van de Kamp (op. cit., p. 1135) considers that:

> ".... these amphibolites....... are formed from basic and intermediate igneous materials. This fact, combined with the demonstrated problems of producing hornblende-plagioclase rocks from shale-carbonate mixtures, suggests that nearly all amphibolites are derived from basic igneous rocks, even if they appear as meta-sediments. A few amphibolites may represent metasomatized sediments."

Van de Kamp (1970) came to similar conclusions from studies of the Dalradian Green Beds in Scotland. There, amphibolites intimately and finely interbedded with psammites and pelites were, at the turn of the century, regarded by workers such as Gunn, Hill and Barrow as being of sedimentary origin. Later, Phillips studied the chemistry of these beds and demonstrated their resemblance to rocks of igneous origin. From major and trace element chemical data Van de Kamp was able to prove an origin by metamorphism of igneous material. He found that (p. 300):

> "...... these para-amphibolites and greenschists represent metamorphosed basic tuffs, originally deposited in a region of pelite sedimentation. Para-amphibolites occurring in marble in south-eastern Ontario have also been shown to be

> metamorphosed tuffs (Van de Kamp, 1968). There are probably few amphibolites formed by nonmetasomatic metamorphism of pelite-carbonate rocks."

From a review of pertinent literature Van de Kamp finds that extensive desposits of basaltic tuff are frequently found in unmetamorphosed sequences of various ages. Such rocks may thus be regarded as the progenitors of amphibolites.

From the brief discussion above, it must be evident that valid conclusions regarding the origin of a certain suite of amphibolites can be reached only once a considerable number of chemical and trace element analyses have been carried out. From the area between Witvlei and Omitara, spectrographic determinations for Ni and Cr were carried out on 8 specimens, representing both melanocratic rocks of definite igneous, and of doubtful origin. In all cases values obtained for these two elements were 200ppm or less. In view of Leake's remarks cited above, the rocks of doubtful origin in this assemblage could be either ortho- or para-amphibolites.

It is now proposed to describe a few of the Damara amphibolites and greenschists in greater detail.

Samples 50 and 51 were collected from the eastern corner of Goldene Aue 106. Specimen 50, from an outcrop just north of the zone of copper mineralisation shown on Map 3 some 75 metres southwest of the White Nossob River, is a massive, dark rock composed of dark-green amphibole and bright green epidote. The latter often occurs as radiating fibrous crystals. Under the microscope, the epidote, of average grain size

0.5mm, is colourless to slightly yellow. The 2V angle is close to 90°, the mineral being biaxial negative. Large portions of the rock are monomineralic, being composed solely of epidote. Amphibole is found as ragged laths, sometimes up to 1.5mm long and enclosing quartz and sphene. Twinning is not uncommon. The following data were obtained for this amphibole:

Pleochroism	Yellow-green	Green	Blue-green
Refractive indices	1.647	ND	1.663

$2V_x$ is approximately 80°, and the extinction angle is 19°.

From its optical properties the mineral would appear to belong to the hornblende group. However, consideration of the mineral assemblage in adjacent rocks suggests that it is more likely to be an actinolite. This latter is, according to Turner & Verhoogen (1960, p. 534), together with tremolite the characteristic amphibole of the lower two zones of the greenschist facies.

Magnetite, altered to haematite, is present, as is abundant ilmenite, partially altered to leucoxene. Calcite occurs as xenoblasts up to 1mm across, often enclosing ilmenite, epidote, amphibole and quartz. The latter is also present as very subordinate interstitial crystals, or it may be enclosed in the amphibole. Chlorite, apatite, zircon, and sphene were observed in minor amounts. A modal analysis of the rock is given in Table 12.

From the massive nature of the rock, together with the abundance of ilmenite and the paucity of quartz, it is felt that the horizon could well represent an igneous interbed within an otherwise pelitic assemblage.

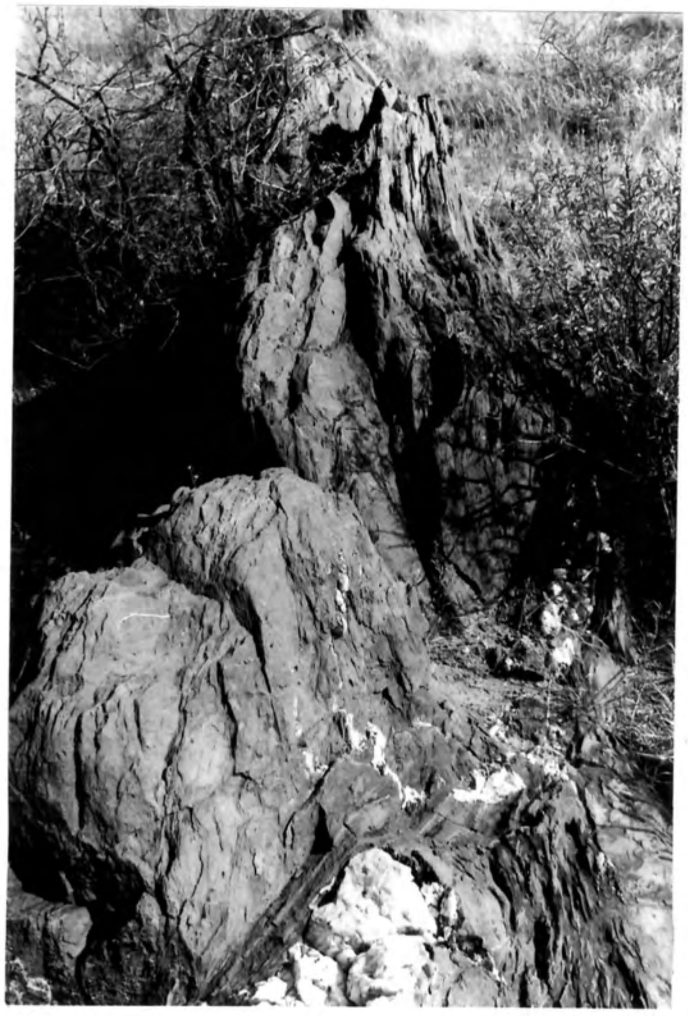


Plate XXIV. Prominent outcrop of chlorite schist on Goldene Aue 106, adjacent to the White Nossob River.

A further horizon, mapped as amphibolite, occurs some 50 metres south of the zone of mineralisation marked on Map 3. It was traced for a considerable distance along strike, and near the White Nossob River forms a prominent outcrop, 1 - 1.5 metres high and 2 - 3 metres wide. The rock is olive-green, fine-grained and somewhat schistose; epidote and biotite can be recognised with the hand lens.

Thin section 51, from a specimen of this rock, shows chlorite to be the dominant mafic mineral, occurring as bent laths and as sheaf-like bundles of laths, 0.5 to 1mm long. Local alteration to biotite is evident. Muscovite is very common in the rock, as is colourless epidote. Magnetite, as ragged crystals and and as occasional euhedra, makes up a fairly large proportion of the mineral assemblage. Quartz, usually strained and showing undulose extinction, occurs interstitially. Porphyroblastic plagioclase, of maximum symmetrical extinction angle 15^{o} and hence probably andesine, is full of small epidote crystals. Some poikiloblastic calcite is present. Apatite is an accessory.

The composition of specimen 51 is given in Table 12. In view of the mineral assemblage quoted above, it is likely that this rock represents an original sediment rich in iron, potash and aluminium.

Two specimens are available from the southeastern side of the zone of brecciation in the southern portion of Sandflats 123 (grid reference -31910/33425). Both are considered to have come from the horizon of basic rock normally to be found below the Eintracht pebble

TABLE 12

MICROMETRIC ANALYSES OF DAMARA AMPHIBOLITES

Specimen No.	12	16*	26	50	51	87	90*
Amphibole	51.4	75	-	33.7	-	76.5	37
Plagioclase	33.7	2	-	-	6.0	Tr.	37
Quartz	4.8	10	17.2	5.1	23.1	0.8	3
Biotite	0.1	-	42.4	-	13.4	-	-
Muscovite	-	3	8.7	-		-	-
Chlorite	Tr.	5	2.8	0.4	26.4	-	-
Garnet	0.3	-	-	-	-	-	-
Iron Oxides	3.0	3	1.5	3.4	8.8	0.4	3
Epidote	1.9	2	20.8	51.8	19.8	-	10
Sphene	3.6	Tr.	4.1	2.9	-	20.9	10
Carbonate	Tr.	-	1.5	2.4	1.2	-	-
Apatite	1.2	Tr.	1.0	0.3	1.3	1.4	-
TOTAL	100.0%	100%	100.0%	100.0%	100.0%	100.0%	100%

* Visual estimate only.

conglomerate. This latter bed is not exposed at this particular locality.

Specimen 16 is a very fine-grained, massive grey-green rock, in which none of the constituents can be distinguished in hand specimen. In thin section it consists chiefly of blue-green, pleochroic amphibole, as fragments approximately 1mm long in a sub-parallel arrangement. Quartz and very subordinate plagioclase occur interstitially to the amphibole. Chlorite and muscovite are found as ragged porphyroblastic laths. Epidote is locally well developed. Iron oxides, as sub-parallel blebs and streaks, are conspicuous. A little apatite is present.

Specimen 17, from the same locality, was found outcropping as a band only 2 - 3cm thick. It differs from specimen 16 only in that it shows a foliation. Under the microscope, amphibole is seen to alternate with layers of quartz-plagioclase. Chlorite and plagioclase are conspicuously porphyroblastic, forming crystals up to 1mm long that stand out against the average grain size of 0.05 to 0.1mm for the rock. The low quartz content is possibly suggestive of an igneous origin for these two specimens.

Similar, if somewhat coarser-grained rocks, occur on the banks of the White Nossob River west of the homestead on Omatewa 113. Specimens 12 and 90, both from very narrow basic interbeds in the schists and quartzites of the vicinity, were collected from opposite sides of the river on Omatewa 113 and Büschow 108 (grid references -13210/29760 and -13760/29650 respectively). In both, amphibole, epidote and felspar can be made out

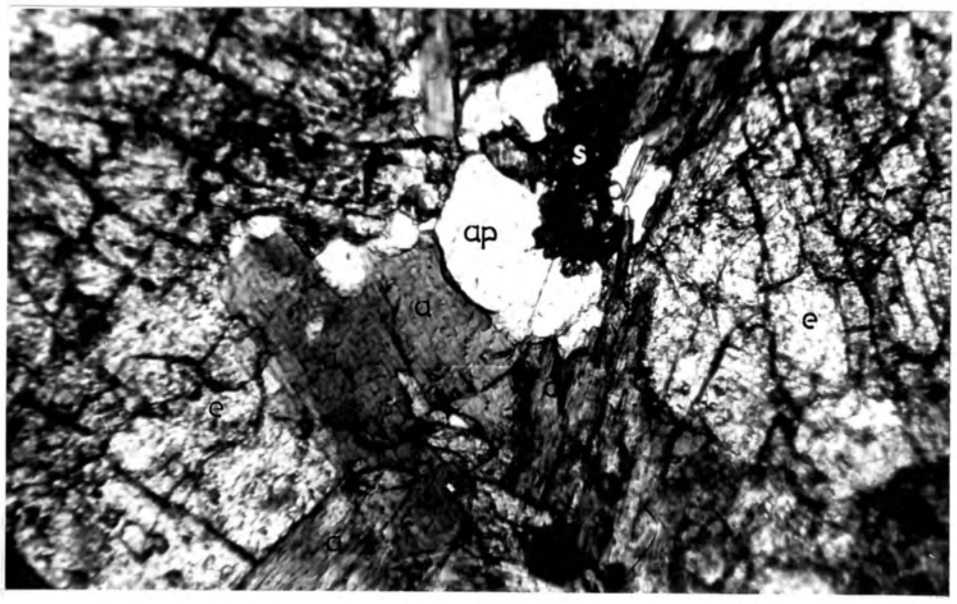


Plate XXV. Amphibolite from Goldene Aue 106 under the microscope. Apatite (ap), sphene (s) and blue-green amphibole (a), surrounded by epidote (e). X 100, crossed nicols.

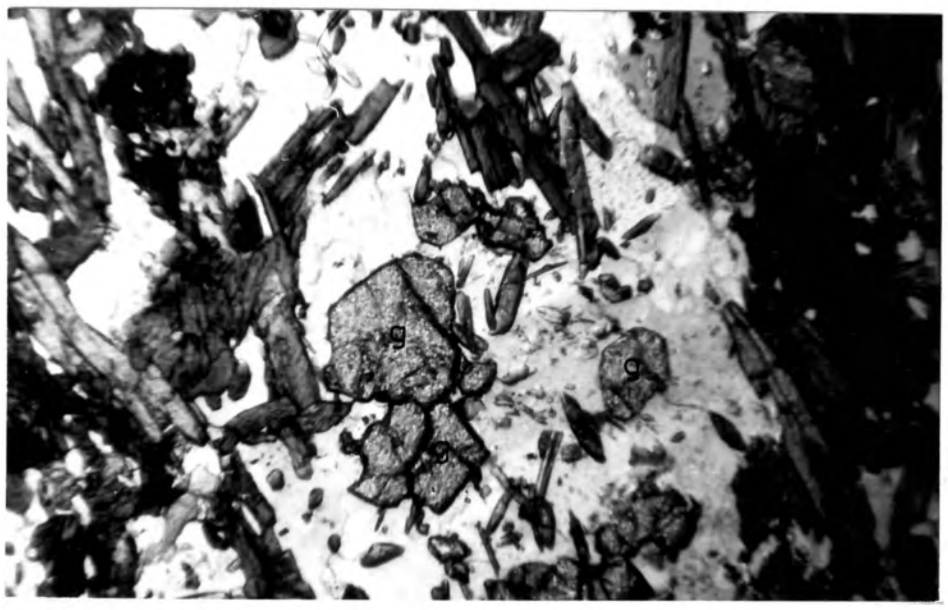


Plate XXVI. Micrograph of amphibolite from Omatewa 113, showing limpid plagioclase poikiloblastically enclosing garnet (g) and amphibole. X 35, plane-polarized light.

with the hand lens. In the thin sections, the amount of quartz is seen to be minimal, blue-green amphibole and albite making up the bulk of the rock. Sphene and epidote are found in both specimens, but occur in appreciable quantities only in specimen 90. Of interest is the presence of isolated subidioblasts, up to 0.5mm across, of colourless garnet in slide 12. The composition of both rocks is given in Table 12.

Specimen 26 comes from the same locality as the two amphibolites described above. It is a faintly foliated, dark-green biotite-epidote schist, occurring as an interbed 5 - 10cm thick in Damara quartzites. It was collected from the left bank of the White Nossob River (grid reference -14420/28915) on Omatewa 113.

The thin section shows a rock of very "clean" appearance, in which most minerals are sub- to idioblastic, with sharp crystal outlines. Olive-green biotite is the principal constituent, having been derived from chlorite, which is still present in small quantities. Muscovite is less prominent than biotite and may form broad, poikiloblastic laths, enclosing quartz and epidote. The latter minerals usually occur interstitially to the micas. Idioblastic magnetite, probably after pyrite, forms cubes of sides up to 0.8mm. Iron oxide grains of much smaller dimensions occur associated with abundant sphene. Carbonate, always poikiloblastic, is present as isolated crystals up to 2mm across. No plagioclase was noted in the slide.

The complete absence of plagioclase and amphibole appears to make an igneous origin unlikely for this rock. Rather, it is suggested that the schist represents a

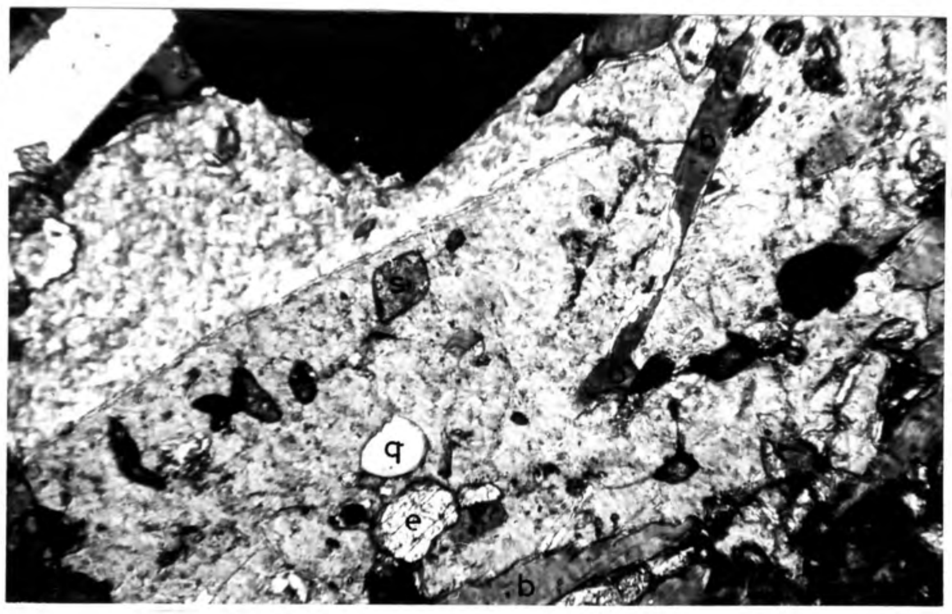


Plate XXVII. Thin section of mica schist from Omatewa 113, showing a broad lath of muscovite enclosing green biotite (b), sphene (s), epidote (e) and quartz (q). Part of a large euhedral grain of magnetite is visible along the upper edge of the photograph. X 100, crossed nicols.

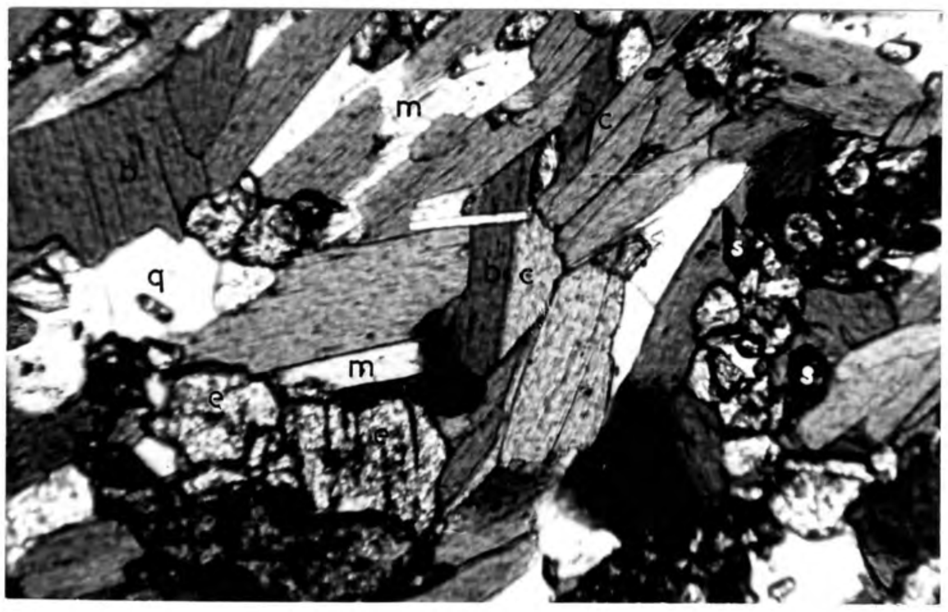


Plate XXVIII. The same slide as above, showing intergrowths of green biotite (b) and chlorite (c). Also visible are grains of sphene (s), muscovite (m), quartz (q) and epidote (e). X 100, plane-polarized light.

metamorphosed calcareous pelite, interbedded with the Damara quartzites. The preponderance of biotite and muscovite must be attributed to a period of potash metasomatism associated with the regional metamorphism.

Finally, mention must be made of another basic rock of unusual composition, found outcropping along the crest of the dolomite ridge (grid reference -14560/38300) in the eastern part of Joachimstal 107. The exposure trends roughly parallel to the regional strike. A similar rock, possibly connected with this occurrence, was found along a camp fence some distance to the southwest (grid reference -12590/38890), where it occurs as loose fragments strewn over the surface of the sand.

In specimen 87, from the dolomite ridge, a fresh surface shows a mass of white needles set in a green amphibolitic matrix. Study of a thin section of this rock shows the needles to be sphene, set amongst dark blue-green, strongly pleochroic amphibole. A little quartz, plagioclase and iron oxides, as well as fairly abundant apatite are also present. No layering or schistosity could be observed in the slide.

The high content of amphibole and sphene suggests that the rock represents a metamorphosed lava of amphibolitic composition.

The ubiquitous occurrence, within the rocks mentioned above, of a blue-green amphibole which may be actinolite poor in Al_2O_3 (Turner & Verhoogen 1960, p. 534) possibly allows a comparison to be drawn between these Damara schists and the basic metamorphic rocks of the central Abukuma Plateau in Japan. There, Schidô and Miyashiro (mentioned in Deer et. al.(1963) Vol. 2, p. 304), using hornblende as a zonal index mineral, distinguished three zones in order of increasing metamorphic grade. The lowest zone is characterised by actinolite, whereas rocks of the intermediate zone contain blue-green hornblende. Only in the highest zone is hornblende with N_z green to brown to be found. Furthermore, work by Schidô in the Nakoso district of Japan has shown that, although actinolite and hornblende can co-exist in low-grade metamorphic rocks, an abrupt change takes place with increasing grade of metamorphism. Actinolite disappears, hornblende becoming the sole amphibole present in the rock. Compton (quoted in Deer et. al., p. 304), working in the metavolcanic rocks of the northwestern Sierra Nevada in California, has corroborated these findings.

In this connection, it must be mentioned that no amphibole identified with certainty as actinolite has been observed by the present author in any of the Damara rocks investigated. Accordingly, in view of the remarks above, it must be concluded that the area under consideration no longer falls within the lowest zone of regional metamorphism.

The Igneous Rocks

In this section it is proposed to describe at some length those rocks, occurring in the area between Witvlei and Omitara, that are thought to be of igneous origin. In part they are considered to predate the metamorphism of the Damara sediments, since thin sections of certain specimens clearly show metamorphic textures. Since neither intrusive nor volcanic rocks have been found by the present author in the Nosib sediments of the region under consideration, it appears that the igneous activity post-dated the deposition of these sediments. This is in contrast to the findings of Guj (1970) referred to earlier in this chapter, from the Nosib Formation elsewhere in South West Africa.

(a) The Dachsberg Granite

This rock forms the twin cupolas known as the Grosser and Kleiner Dachsberg in the southern portion of Sandflats 123 (grid reference -31100/32150). Because of the relatively flat, sandy nature of the country north of Eintracht 118, the larger of the two hills, the Grosser Dachsberg, forms a conspicuous landmark.

Owing to the absence of exposures around the base of the Dachsberge, field relationships between the granite and the sediments are not easy to assess. There is an abrupt change in the strike of the dolomite bands in the northern part of Eintracht 118. The sediments trend roughly eastsoutheast on Altenstein 115, Diana 117 and Eintracht 118, only to swing sharply around the southern side of the Dachsberge, finally striking nearer northeast on Sandflats 123. This change of strike, together with the slight elongation of the Dachsberg "massif" in the direction of the fold axial plane in this vicinity, suggests the granite to be of probably late syntectonic origin. The temperature of emplacement appears to have been low, since there has been no visible interaction between quartz and dolomite in the adjacent Hakos dolomite bands.

In hand specimen the rock is massive, although a faint foliation could be discerned in the outcrop. Pink felspar, usually very fine-grained but forming occasional phenocrysts 3-4mm in length, is the dominant constituent. Quartz is present as rounded inclusions approximately 1mm in size. Mafic minerals are very subordinate. Without reference to a thin section, the rock would be termed a syenite.

Slide 14, from a specimen of this rock, shows plagioclase and microcline, with much development of myrmekite. Quartz is present in far greater amounts than could be deduced in hand specimen. The groundmass varies in grain size from less than 0.1mm to at least 0.6mm, an average lying close to 0.3mm. The principal constituents are quartz and plagioclase, the latter ranging in composition from oligoclase to andesine. The felspars are generally cloudy; plagioclase twinning is not universally developed. Orthoclase, assumed to be present in small amounts, could not be positively identified. For this reason the results of a micrometric analysis of this rock, quoted in Table 13, should be treated with some reserve.

Green biotite, a little apatite, sphene and iron oxides were noted. One grain, 0.8mm long, of a colourless isotropic mineral rimmed by calcite, occurs in the slide and was identified as fluorite.

Of interest are the phenocrysts, which make up approximately 17% by volume of the rock. Generally sub-angular, they consist of plagioclase or microcline.

Rounded inclusions of quartz are common. Some microcline phenocrysts contain irregular patches of twinned oligoclase, thus presenting a perthitic appearance.

Myrmekite, consisting of irregular patches of plagioclase riddled with vermicular quartz, is prominently developed in the slide. It usually forms a partial

TABLE 13

APPROXIMATE MODES OF 12 SPECIMENS OF IGNEOUS ROCKS FROM THE DAMARA SYSTEM

Specimen No.	14*	36	38	39	40	46	57	59	60	61	92*	94*
Microcline	12.1	-	-	-	6	-	-	-	-	-	-	-
Plagioclase	55.6	40	1	41	70	5	6	73	75	16	22.5	47.5
Quartz	29.3	-	1	-	-	-	1	-	-	1	1.0	1.4
Biotite	1.2	-	-	-	-	-	-	Tr.	Tr.	-	-	0.2
Augite	-	-	-	-	-	-	-	-	-	-	-	21.5
Brown hornblende	-	-	-	-	-	-	-	-	-	-	Tr.	12.4
Blue-green amphibole	-	55	55	50	20	75	45	20	20	75	57.6	2.1
Chlorite & Uralite	-	Tr.	-	-	-	-	-	-	-	-	-	3.6
Epidote/clinozoisite	-	-	40	5	1	15	40	2	2	Tr.	8.2	0.1
Sphene	-	5	3	3	2	3	4	4	2	8	5.2	-
Apatite	0.4	Tr.	-	Tr.	1	-	-	1	1	Tr.	0.2	0.4
Iron Oxides	1.0	Tr.	Tr.	1	Tr.	2	-	Tr.	Tr.	Tr.	5.3	10.8
Carbonate	0.4	--	Tr.	-	-	-	4	-	-	-	-	-
TOTAL	100.0%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100.0%	100.0%

* Figures from micrometric analyses

rim around the phenocrysts, although isolated patches have also been noted in the groundmass. Becke, cited in Hatch et. al. (1961, p. 174) states that the amount of quartz in the intergrowth increases as the host plagioclase becomes more basic. Myrmekitic intergrowths are usually found along plagioclase-potash felspar boundaries, and the juxtaposition of these two contrasted felspars is regarded by Sederholm (in Hatch et. al., p. 174) as essential for the formation of these "synantectic" reaction products.

Wiles (1961, p. 49), quoting Cheng, repeats the generally accepted view that myrmekite is produced by the replacement of potash felspar by oligoclase. From a study of gneisses in the Urungwe district of Rhodesia, Wiles found that whenever both oligoclase and microcline are present, the former appears to have replaced the latter. Both have been corroded and replaced by quartz. It appears that soda and lime, released by the initial replacement of oligoclase by potash-felspar, furnish most of the material necessary to form myrmekite. This in turn replaces the potash felspar. Wiles (p. 49) continues:

> "From the careful examination of the myrmekite and microcline relationships in a number of the Urungwe slides there would at first appear to be much evidence that does not support Cheng's view. In many occurrences where microcline and myrmekite are in contact, it is not clear which is replacing which and several instances were seen where the microcline was clearly replacing the myrmekite. This apparently anomalous state of affairs can be explained quite simply if it is appreciated that both types of replacement must have been going on simultaneously. For vermicular quartz to develop by the replacement of microcline by plagioclase the latter should, according to the theory advanced, have a smaller percentage of silica in its composition than the former. A determination of the felspar in these gneisses by universal stage methods revealed a plagioclase of average composition Ab_{80} which

contains about one per cent. less silica than the microcline, thus allowing free silica to be formed on replacement of the latter by the former. The quartz enclosed in the secondary plagioclase is not always vermicular in form but is, on occasion, of micrographic appearance."

The cloudy, altered nature of the felspars in slide 14 has already received mention, and precluded a detailed study of the myrmekite. However, it would appear that the Dachsberg granite, initially probably approaching a quartz-diorite in composition, suffered some potash metasomatism. This led to the partial replacement of the plagioclase phenocrysts by microcline - hence the "perthitic" texture. Any hornblende present would at the same time have been converted to biotite. Subsequent reaction between microcline and plagioclase led to the formation of myrmekite i.e. untwinned plagioclase, probably of composition close to Ab_{80} containing vermicular quartz. Metasomatism must have been accompanied by considerable recrystallisation, and would account for the range in grain size, and for the local development of triple points between adjacent quartz crystals. In composition, the rock now represents a granodiorite.

(b) The Mafic Intrusions

(i) Joachimstal 107

In the extreme eastern corner of the farm, between the ruined farmhouse and the White Nossob River, there occurs a body of dolerite (grid reference -18150/34100) measuring approximately 275 x 375 metres. This dolerite does not give rise to prominent outcrops. Rather, the area underlain by this rock type forms a depression sloping down from the ruined farmhouse (grid reference -18050/34350) to the White Nossob River. This depression is traversed by a deep gully, which runs parallel to the boundary between Goldene Aue 106 and Joachimstal 107.

Outcrops of dolerite do occur within the depression, but are more abundant and prominent along the northwestern and southeastern contacts of the intrusion with the Damara quartzites. Spheroidal boulders, exhibiting a brown outer skin and "onion-peeling" weathering, are typical. The rock is very dark in the fresh specimen, and ranges from medium- to coarse-grained. Felspar crystals up to 6mm long may occasionally be seen, with interstitial pyroxene and amphibole. Iron oxides are conspicuous in specimen 94, from the centre of the intrusion, whilst specks of bright yellow sulphide were noted in specimen 92 from the northwestern margin of the dolerite.

Only on this margin was any evidence of chilling observed in the rock. Thin-section data for specimen 92 yielded an average grain size of 0.5mm, compared with a mean of roughly 2-3mm for specimens collected from the centre and southwestern margin of the dolerite. Micrometric data for specimens 92 and 94 are quoted in Table 13. Slides 91, 93 and 94 are rather similar, but since No. 94 was the least altered, it alone was selected for detailed study.

Plagioclase is the dominant mineral in the rock, and occurs as broad, prominently twinned laths. Although twinning on the albite law preponderates, some pericline twins were noted. Many laths show evidence of zoning. Such crystals, when investigated by means of the universal stage, were seen to consist of a core of average composition An_{58}, with a rim ranging from An_{27} to An_{49}. The felspar laths are full of tiny, colourless needle-like inclusions of random orientation; these are probably zircons. Some apatite, as well as a little micropegmatite, is present in the slide. A peculiar clouding of the felspars will be discussed in detail below.

Occurring as stout prisms, or as typical basal sections, and occasionally partially enclosing laths of felspar, is a colourless clinopyroxene, sometimes exhibiting zoning. The following optical constants for this mineral were obtained, using a crush of the whole rock:

$$N_z\ 1.717 \quad N_x\ 1.698.$$

Owing to the difficulty of obtaining a section suitable for the direct determination of N_y, a value of 1.704 for this constant was arrived at by calculation, using data for nine specimens of augite given by Hess (1949) and 11 specimens of augite quoted by Deer et. al. (1963, Vol. 2). The approximate composition of the pyroxene was then determined by reference to curves drawn up by Hess (1949).

Zone	$2V_x$	Extinction Angle on (010)	Approx. Comp.
Inner	45°	45°	$Ca_{34}Mg_{35}Fe_{31}$
Outer	49°	41°	$Ca_{39}Mg_{32}Fe_{29}$

The clinopyroxene thus lies on the compositional boundary between augite and ferroaugite. The zoning appears to be the reverse of that normally found, in that the 2V angle increases towards the margin of the crystals. Similar findings were made by Walker and Poldervaart (1949, p. 643) in samples of Kokstad type dolerite from Mount Arthur in East Griqualand.

The augite in the slide is seen to often be rimmed by, or intergrown with, a strongly coloured amphibole, for which the data below were determined, again using universal stage and immersion methods.

	N_z	N_y	N_x
Pleochroism:	Deep purple-brown	Brown	Pale-brown
Refractive Index:	1.688	ND	1.672
Maximum extinction angle:	17^o		
$2V_x$ 64-72^o			

The mineral is a brown hornblende, and owes its purple tint to a high content of TiO_2. According to the order of crystallisation established from Karroo dolerites by Walker and Poldervaart (p. 625), brown amphibole and biotite aré precipitated later than the pyroxenes. This would account for the hornblende rim around the augite. However, the intergrowths of augite and hornblende, occasionally noted in slide 94, suggest a certain overlap in the periods of crystallisation of the two minerals. Magnetite, probably also titaniferous and sometimes enclosing pyrite, may itself be enclosed by brown hornblende. Replacement of hornblende by the iron oxide has been noted.

The brown hornblende may grade marginally into an apple-green variety, which also occurs as discrete laths. Both these types grade into a strongly pleochroic blue-green variety, probably rich in soda. A little uralite, presumably of actinolitic composition according to Deer et. al. (1963, Vol. 2, p. 260) was noted. Brown biotite, occasionally found intergrown with green hornblende, appears to be formed by the alteration of magnetite. Apatite, epidote and quartz occur in minor amounts only. No olivine is present.

Mention must be made of the prominently developed

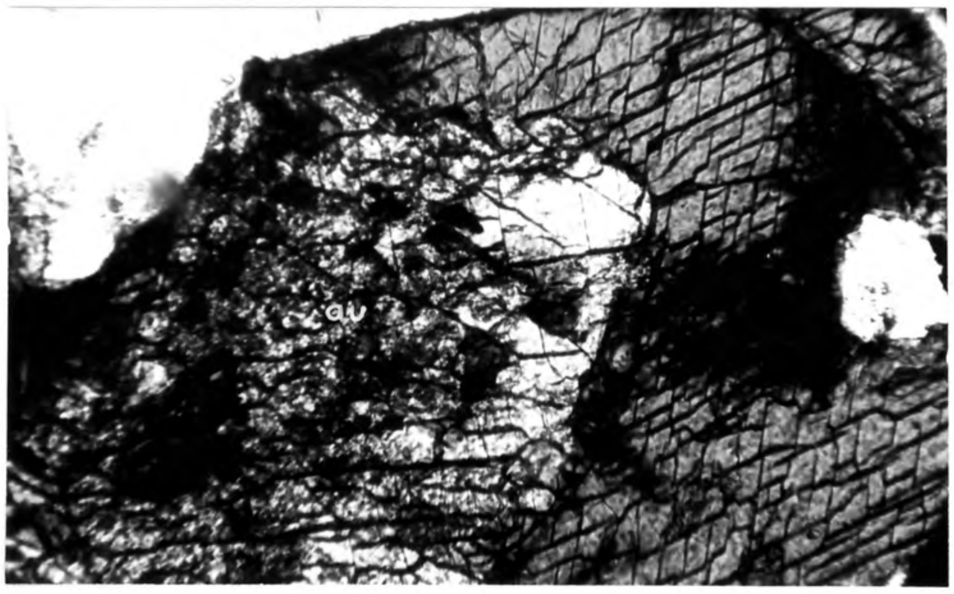


Plate XXIX. Micrograph of dolerite from Joachimstal 107, showing a basal section of augite (au) rimmed by primary, purple-brown titaniferous hornblende. X 100, crossed nicols.

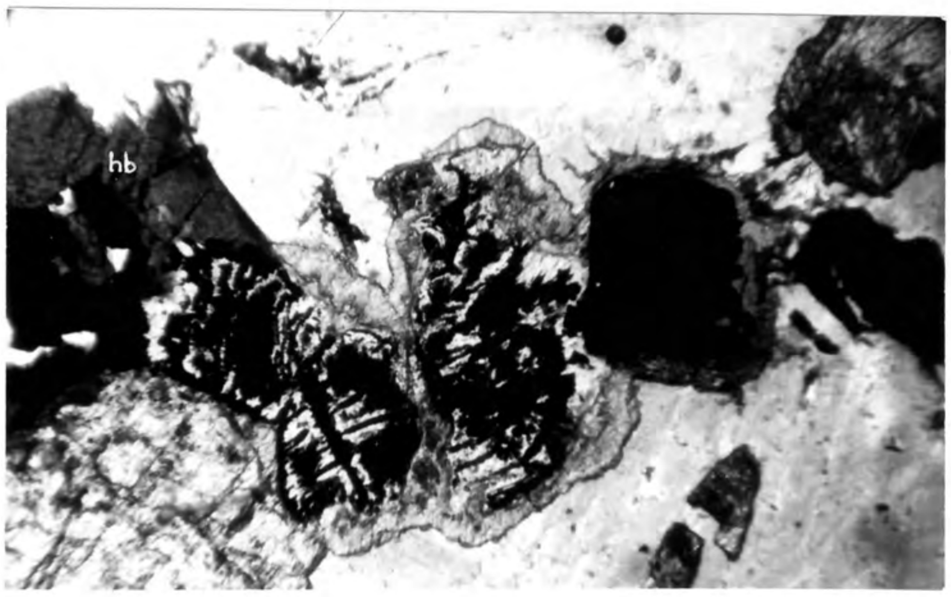


Plate XXX. The same slide as above showing prominently developed reaction rims between magnetite and plagioclase. In the two central grains, the iron oxide is seen replacing augite. Also present is hornblende (hb). X 35, crossed nicols.

reaction rims, always found around magnetite where the latter abuts on plagioclase. The rims, 0.1 - 0.2mm broad, are composed of blue-green fibrous chlorite, together with some uralite. The augite appear to alter to a colourless chlorite; crystals so altered may also exhibit narrow rims of uralite.

The faint clouding of the felspar in the slide, already referred to above, is visible as a flesh-coloured tint in plane-polarised light, and produces a yellow discolouration between crossed nicols. The clouding does not appear to be related to the presence of zircon and apatite in the felspar, since it occurs even in laths that are free of such inclusions. The rims of the plagioclase laths, demonstrated by universal stage methods to be more sodic in composition than the centres, are generally clear, the clouding being strongly developed only in the interiors of the crystals. This clouding is seldom of equal intensity throughout any one grain. Normally, the tint is uniform along the length of an individual felspar twin, but may vary considerably from lamella to lamella. In a polysynthetic twin, the immediate vicinity of a twin plane may be completely clear, clouding being developed only towards the centres of adjacent twins. For this reason, individual twins may occasionally be recognised in plane-polarised light. This fact has already been noted by other authors.

MacGregor, cited by Thomson (1969, p. 77), and Poldervaart and Gilkey (1954, p. 75) have given a summary of the various causes of clouding in felspars. These authors conclude that the phenomenon is due to the presence of microscopic or sub-microscopic inclusions within the felspar crystal. The typical brown colouration

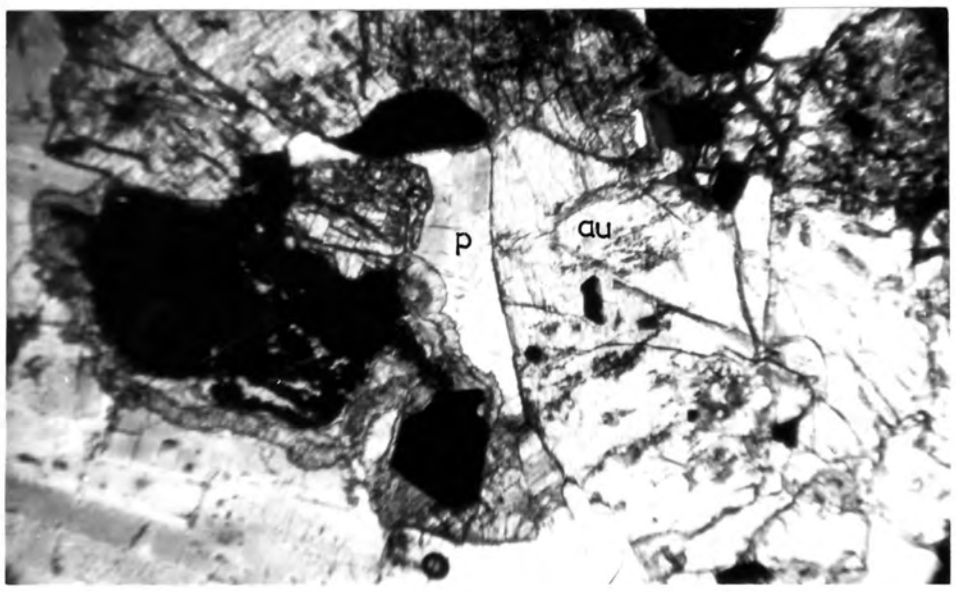


Plate XXXI. Dolerite from Joachimstal 107 in thin section, showing reaction rim around magnetite, and bent laths of plagioclase (p) and augite (au). X 35, crossed nicols.

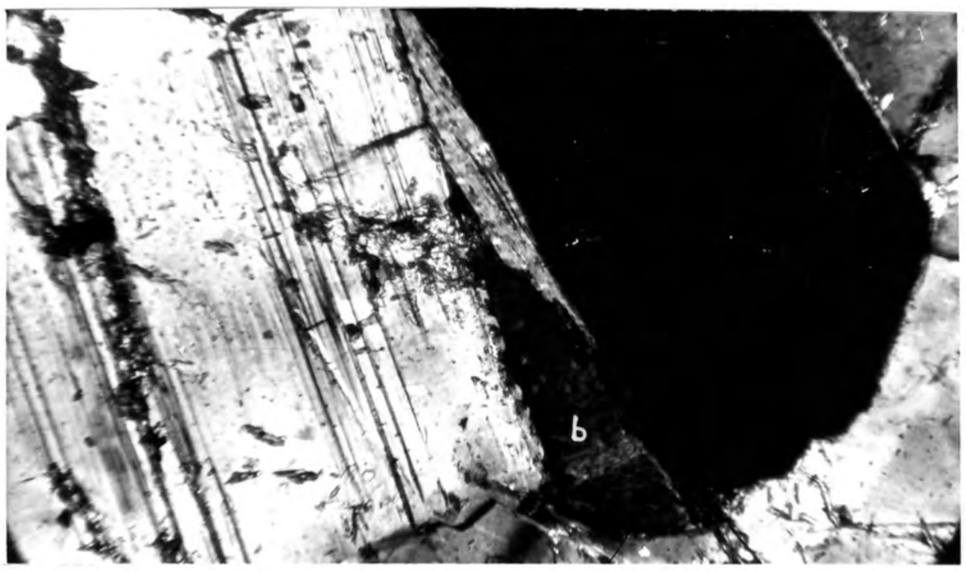


Plate XXXII. From the same slide as above, a grain of magnetite altering to biotite (b) around its edges. X 100, crossed nicols.

of the clouding is thought to be due to absorption, or to scattering, of light by the inclusions or by minute cavities within the crystal. Eales (1959, p. 94) considers the clouding of felspar from the Khale dolerite sheet in Botswana to be due to the scattering of light by numerous microscopic granules of a pale-green or colourless transparent mineral forming inclusions in the plagioclase. Opaque grains occurring within felspar laths have been identified by MacGregor, and by Poldervaart and Gilkey (1954, p. 78) as iron oxides and ferromagnesian minerals. Inclusions of this nature may mean that the brown clouding is an absorption phenomenon.

Plagioclase in the amphibolite at Chibuluma, Zambia (Thomson, 1969) exhibits clouding; the material causing this could not be identified, even under magnification of 800 (Thomson, p. 76). However, from a comparative study of these amphibolites and the Khale dolerite, Thomson concludes that scattering of light by minute inclusions, rather than by minute cavities, is responsible for the clouding.

Discussing the origin of clouding MacGregor, cited by Thomson (p. 79) suggests that exsolution of iron oxides from the felspar during thermal metamorphism is responsible. Poldervaart and Gilkey (1954, p. 87) feel that this could be responsible for mild discolourations, but that intense clouding is due to inclusions of extraneous material, chiefly iron oxides, that has diffused into the felspar after crystallisation of the latter. Sustained high temperatures, an aqueous pore fluid, as well as the presence of iron-bearing minerals in the original rock are, in the opinion of these authors, prerequisites for clouding to occur. On cooling, crystallisation of iron minerals inside and outside the felspar will lead to a reversal of the concentration gradient within the felspar. The consequent outward migration of iron results in the, seldom complete, clearing of the inclusions from the felspar.

Poldervaart and Gilkey (p. 88) state that clouding is not necessarily always attributable to thermal metamorphism, but may be found in rocks subjected to a high grade of regional metamorphism. Furthermore they state (p. 88) that a:

> "...... prolonged iron-rich deuteric phase in the basic intrusives, as might result from magmatic incorporation of water and pelitic material upon emplacement, may also produce clouding of pre-existing or newly-formed plagioclase which cannot then be attributed to later thermal or regional metamorphism".

Such a process could well have been responsible for the clouding of the felspar in the intrusion on Joachimstal 107. The absence of clouded felspars in the other basic intrusions of the area suggests, as has already been deduced by the present author from petrographic studies of other rocks in the area, that the regional metamorphism was not of sufficiently high grade to be responsible for this particular phenomenon.

Specimen 92, referred to above, resembles numbers 91, 93 and 94 in hand specimen, but is very much finer grained. Under the microscope, the rock is seen to be highly altered. No metamorphic foliation is developed, but all traces of the original sub-ophitic texture have been obliterated. The felspar is extensively altered to zoisite, while augite, hornblende and biotite have been replaced by a blue-green amphibole. Magnetite, no longer euhedral, occurs as scattered remnants and is associated with sphene. Traces of quartz and apatite are present. The volumetric composition of this specimen is also quoted in Table 13.

The author originally believed this, and adjacent intrusions, to be of Karroo age, but evidence obtained from the petrographic study of specimens collected suggests a different, probably considerably greater age for these rocks. Some points of note are:

1. Walker and Poldervaart (1949, p. 640) state that normal Karroo dolerites contain two or more pyroxenes, generally strongly zoned. Only one pyroxene, showing slight zoning, occurs on Joachimstal 107.
2. The presence of :
   (a) bent pyroxene and felspar laths in slide 94;
   (b) reaction rims in specimens 91, 93 and 94, and the highly altered nature of specimen 92;

   suggest that the intrusion has suffered considerably more alteration than is normal for dolerites of Karroo age. Since the area under consideration is not believed to have been involved in any orogenic movements younger than the Late Precambrian Damara episode, the intrusion must predate this period of metamorphism.

(ii) Goldene Aue 106

There are several occurrences of basic rocks on this farm.

Some 600 metres south (grid reference -18250/34760) of the Joachimstal intrusion described above is a small dike that can be followed for a short distance southwards before disappearing below the overburden. This dike has little surface expression and was noticed only because amphibolitic debris, found in the gully that debouches into the White Nossob River near the Joachimstal 107 farmhouse, was traced back to its origin.

The dike trends roughly parallel to the regional strike, and contains a variety of rock types. Specimen 57 is a massive, medium-grained dark rock in which epidote and amphibole can be made out with the hand lens. Under the microscope it bears a strong resemblance to specimen 50 from the eastern corner of Goldene Aue 106, described in the section on amphibolites. Colourless epidote, biaxial negative with a 2V angle approaching 90^{o}, and a blue-green, pleochroic amphibole with similar optical properties, make up the bulk of the slide. Iron oxides are present in trace amounts only, but sphene is abundant, occurring as large ragged, occasionally subidioblastic crystals up to 1mm across. Albite and quartz were noted in small amounts. Carbonate appears to have been introduced later; crystals reaching 1mm in size may enclose amphibole and sphene.

Number 61 is similar in hand specimen, but shows a faint metamorphic foliation. The amphibole forms occasional porphyroblasts up to 2mm in length. In thin section, only trace amounts of epidote were noted, amphibole, plagioclase and sphene being the dominant constituents. The visually estimated volumetric compositions of both specimens are quoted in Table 13.

Also from this dike are specimens 59 and 60. Both are coarse-grained, and may be termed basic pegmatites. In hand specimen No. 59 is seen to consist of fine-grained felspar and coarser amphibole. Specimen 60 is somewhat lighter in colour. A groundmass of roughly equal proportions of felspar and amphibole contains isolated, larger laths of amphibole, at times exceeding 2cm in length.

In thin section these specimens are considerably fresher in appearance than numbers 57 and 61. Felspar, determined as albite, forms laths up to 1.5mm wide and shows broad twinning. In slide 61 the crystals are mostly equant, of side 1mm, but isolated grains reach lengths of 5mm. A little clouding is apparent, and some of the longer laths are slightly bent. Otherwise, the rock shows no development of the limpid, usually untwinned plagioclase so typical of metamorphosed Damara amphibolites and greenschists. The felspar encloses shredded blue-green amphibole. In slide 60 sphene is almost idiomorphic; in slide 59 it forms elongated crystals 2.5mm in size, enclosing epidote. Apatite and biotite are present as accessories.

Specimen 58, from the northern side of the dike, is a fine-grained, green calcareous pelite that has suffered some metamorphism as a result of the dike emplacement. Grain size lies between 0.05 and 0.3mm, and carbonate is the chief constituent, followed by recrystallised albite and green amphibole in roughly equal proportions.

Finally, mention must be made of a narrow vein found between the northern side of the dike and the adjacent sediments. The vein, only 10-15cm wide, consists solely of very coarse carbonate and black, fibrous tourmaline. It is probably of deuteric origin. It should be noted that no tourmaline was found in any of the sections of the dike rocks investigated.

Another basic dike was found in the northeastern part of Goldene Aue 106, where it intrudes the dolomitic portion of the horizon described as the Straussenkuppe-Vierkuppenberg unit earlier in this chapter. This dike (grid reference -18980/38050), of average width 35 metres, was traced for some distance between the windpump in the centre of the farm and the White Nossob River.

There can be little doubt about the intrusive origin of this rock, since evidence of chilling was found against the dolomite along the margins of the feature. The dike weathers into rounded boulders with a brown, oxidised outer skin. Fresh surfaces show a very fine-grained matrix, containing numerous rounded, faintly green patches measuring 1 - 6mm across. The chilled portion is not exposed everywhere, and is highly weathered, making the collection of a fresh sample difficult. Unlike the central part of the dike, it forms angular, joint-bounded blocks.

Under the microscope specimen 46, from the centre of the intrusion, is seen to consist essentially of pale-green pleochroic amphibole, forming ragged laths up to 0.6mm long. Occasional brown tints were observed in this mineral. Interference colours are low in the first order. Plagioclase occurs interstitially with the amphibole as short, occasionally twinned laths, usually extensively replaced by epidote. The rounded patches noted in hand specimen possibly represent former felspar phenocrysts, and are now entirely altered to a mass of granular, faintly coloured epidote. Sphene is well developed, having formed by the alteration of ilmenite, remnants of which it encloses.

Specimen 47 from the chilled margin is similar to the above, but is of average grain size 0.2mm. It contains a more strongly coloured amphibole, pleochroic from blue-green to yellow. The formation of sphene is more complete than in specimen 46.

Detritus scattered over a considerable area in the vicinity of the kraal (grid reference -18960/36670) just south of the homestead on Goldene Aue 106 suggests that another dike is present here, although no outcrops were found. A thin section of the weathered specimen 45 is similar mineralogically to specimen 46. A metamorphic foliation is developed. A matrix of sub-parallel crystals of pale amphibole and plagioclase, 0.1 to 0.2mm in length, contains isolated porphyroblasts, up to 2mm long, of both these minerals. The slide shows one elongated zone of length 6mm, consisting of a cluster of highly epidotised felspar laths.

A similar rock, of which unfortunately no specimen was collected, forms a dike (grid reference -16900/39000) some 3km southsouthwest of the homestead. The effects of the emplacement of this dike on the adjacent dolomite horizon have been discussed elsewhere in this chapter.

Perhaps the most interesting feature amongst the basic rocks of the region, and one which unfortunately could not be studied in sufficient detail, lies some 800 metres northnorthwest of the homestead on Goldene Aue 106. As appears usual in this region of Damara rocks, the dike (grid reference -18740/35660) does not have any great surface expression, despite its considerable width of some 200 metres. Owing to the presence of silt, sand and calcrete overburden, the full lateral extent could not be determined. To the north, the dike possibly connects with the small intrusive feature situated along the boundary with Joachimstal 107 and already referred to above. To the south, after a hiatus of several hundred metres, surface rubble of a basic nature denotes the presence of similar rock (grid reference -18025/36920). This could well represent an extension of the main body.

In plan, the dike exhibits a curvature which, although not as pronounced, corresponds to that imposed on the surrounding sediments during the period of tectonism. In view of this difference in the degree of folding, it is suggested that emplacement of the dike occurred after the sediments had already suffered extensive folding. The dike cuts across the regional strike in this locality at a high angle, and appears to have been only slightly deformed during the closing stages of the Damara orogenic episode. Of interest in this connection is the occurrence , within the body of the dike near its eastern margin (grid reference -18740/35340), of a small antiformal structure with a southwesterly plunge, similar to those found in the pelitic sediments of the area covered by Map 3.

Features observed in the quartzites immediately to the east of the contact with this body, and attributed to a certain measure of contact metamorphism, have already been discussed.

The dike appears to be of composite origin. Generally medium- to coarse-grained, it shows local development of basic pegmatite, and has very fine-grained, obviously chilled portions suggestive of multiple intrusions near its centre. Detailed mapping of the dike, coupled with further petrological work, would no doubt be rewarding.

Specimens 38 and 39 from this basic body are both massive, medium-grained, grey-green rocks in which crystals of amphibole, 6-8mm long can be seen. In specimen 39 felspar laths can be recognised, while specimen 38 shows development of pale yellow epidote. When studied in thin section it appears that both represent basically similar rocks, except that specimen 38 is in a more advanced stage of alteration than No. 39. The latter, for which the approximate composition is quoted in Table 13, is a rock of initially doleritic composition. Amphibole and plagioclase are present in approximately equal amounts, and are the dominant constituents. The amphibole occurs as broad, green pleochroic laths, up to 5mm long, or as clusters of short, radiating fibres. The colour masks the interference colour, which is upper first order. The following data were obtained for this mineral by universal stage and immersion methods:

	N_z	N_y	N_x
Pleochroism:	Dark green	Light green	Colourless
Refractive index:	1.679	ND	1.667

$2V_x$ 56 - 59^o

Extinction angle 18^o

The amphibole is probably a green hornblende, derived from original pyroxene. Besides enclosing rounded crystals of sphene in the 0.05 to 0.2mm size, it shows well developed ophitic and poikilophytic texture. Plagioclase laths up to 1mm in length either penetrate the hornblende, or are entirely enclosed by it. Some of the felspar laths show signs of recrystallisation, with highly irregular boundaries towards the hornblende.

Elsewhere in the slide the plagioclase, identified as andesine, forms twinned crystals from 0.2 to 5mm in size. A colourless to pale-yellow, optically negative epidote occurs as isolated grains and clusters within the felspar laths, but may also form occasional larger crystals up to 1mm in length. Sphene, seen to be derived from ilmenite or titaniferous magnetite, is the only other conspicuous mineral noted. Apatite is present in trace amounts.

When compared with the foregoing, slide 38 has a similar amount of hornblende. The mineral now has a more ragged appearance, and contains numerous small inclusions of quartz, plagioclase and epidote. The original plagioclase has been almost entirely altered to an epidote-group member which, on account of its lack of colour and anomalous interference colour, should be termed clinozoisite, but which is optically negative. It forms granular, occasionally twinned crystals of high relief, 0.1 to 0.3mm across; these crystals are usually aggregated into large clusters. Isolated interstitial quartz, as well as a little carbonate, is present in the slide.

In thin section the rock shows considerable resemblance, both in texture and composition, to specimen 50. This fact supports the previously stated view that the horizon from which specimen 50 was collected represents a metamorphosed ortho-amphibolite, intercalated with the pelitic and psammitic sediments of the Damara System.

Specimen 36 comes from the fine-grained portion in the centre of the dike, and is considered to represent a later, rapidly chilled intrusion. In hand specimen the rock is massive, very fine-grained and dark-green in colour. With the hand lens isolated larger crystals of amphibole and iron oxides, as well as occasional felspar laths, can be made out.

The thin section shows green amphibole and felspar to predominate. The former, as fragments of average size 0.1mm, exhibits a sub-parallel arrangement, giving rise to a faint metamorphic foliation. Isolated flakes of chlorite, 0.6mm in length, are present. Two types of plagioclase were noted. Andesine occurs as stumpy, well-formed prisms, 0.15 to 0.25mm long and usually twinned. Albite is porphyroblastic, of limpid appearance and irregular shape, and may enclose amphibole. Both types of plagioclase, as well as the amphibole, form very isolated larger crystals up to 1.5mm long. Of interest is the occurrence of one rounded porphyroblast, 2mm across, with an albite core and a rim of microcline. It contains a cluster of amphibole crystals 0.1 to 0.5mm in size. This is the only evidence of potash felspar found in this rock. Sphene occurs throughout the slide as tiny rounded grains, while apatite and iron oxides are present as accessories.

Finally, specimen 40, collected from the western side of the dike, is possibly the most interesting of all the rocks as regards composition. It is sufficiently coarse-grained to warrant the term basic pegmatite, since it consists of felspar laths 5 to 10mm long, with interstitial amphibole and smaller, more equant felspar crystals. Iron oxides may also be seen with the naked eye.

The thin section shows broad felspar laths, 4 to 5mm in length and of random orientation, with interstitial quartz, amphibole and microcline. The plagioclase only very occasionally shows twinning on the Albite Law, although Carlsbad and pericline twins are common. From a suitable albite twin a maximum symmetrical extinction angle of 18^{o} was measured. This, together with a refractive index below that of balsam, and the optically biaxial positive character of the mineral, served to identify it as albite. It contains isolated needles of zircon. Some alteration is evident in the centres of the laths, where minute needles of clinozoisite occur in a sub-parallel arrangement.

The amphibole is the usual green variety of hornblende, and occurs as laths 0.1 to 2mm long, often containing inclusions of quartz. The latter also forms veinlets crossing the slide. Apatite is present as stout prisms, and as slender needles in excess of 1mm in length. Sphene forms granular aggregates, again occasionally larger than 1mm, and is obviously derived from the ilmenite still locally present as included relics.

The presence of microcline in the slide is rather unexpected. This mineral, visually estimated to make up some 6% by volume of the rock, forms equant grains in the size range 0.5 to 1.5mm, and exhibits the usual grid-iron twinning. The writer confesses to some doubt concerning the true nature of some of the untwinned felspar grains in this size range, tentatively identified as albite. These suspect grains show a peculiar mottling, locally resembling incipient perthite structure. Besides forming the discrete crystals mentioned above, the mineral positively identified as microcline occasionally forms partial rims to the albite laths, and may even locally begin to replace these. No myrmekite is present in the slide.

The source of the microcline poses a problem. Since the dike under consideration is almost certainly of composite origin, local contamination by sediments collected by the magma from depth during the period of emplacement, could be suggested as a source of potash. However, the adjacent Damara quartzites and schists are poor in microcline and biotite. Any later period of potash metasomatism would be assumed to have effected the entire dike, and not just selected portions. Furthermore such metasomatism would, according to J.W. Wiles (personal communication) convert any hornblende present to biotite before leading to the formation of microcline. Since no biotite is present in any of the specimens investigated, potash metasomatism must be ruled out.

It is suggested that the horizon from which specimen 40 was collected represents a potash-rich differentiate of the dike magma. According to Bowen's reaction series, plagioclase would be expected to crystallise before potash felspar. The rims of microcline on the albite may thus be explained. The presence of irregular, sutured crystal boundaries suggests that the rock has undergone a measure of recrystallisation. Partial resorption, as well as the replacement of albite by microcline, are the natural extensions of this process.

4. THE BUSCHMANNSKLIPPE FORMATION

Rocks of this formation, whose probable equivalence to the lower portions of the Nama System has already been discussed, occur in the southeast of the area mapped.

Corresponding in strike with the Nosib and Tsumis Formation sediments, the Buschmannsklippe rocks have, on Orochevley 216 and the farms to the south and southeast, been thrown into a series of anticlines with a gentle northeasterly plunge. Strike faulting has resulted in the shearing out of the southeastern limbs of these anticlines, together with the intervening synclinal portions of the folds (Dr. P. Richter, personal communication). Cross-bedded purple quartzites of the Tsumis Formation, overturned and steeply dipping, are exposed in the anticlinal core traversing Orochevley 216.

On this farm, shallow-water dolomitic limestones at the base of the Buschmannsklippe Formation overlie these Tsumis quartzites with a large angular unconformity. The range of hills running parallel to the southeastern boundary of Owinieikiro 213, and ending in the anticlinal nose of the Weissberg at the southern corner of Gemsbockvley 214, is composed of sheared white quartzites. Strike faulting in this vicinity has led to a portion of the Buschmannsklippe sediments being repeated several times in the northwestern limb of the anticline along the boundary between Owinieikiro 213 and Orochevley 216.

The quartzite of the Weissberg is overlain by a considerable thickness of pelitic and psammitic sediments, giving rise to the flat featureless terrain extending north and northeast as far as the White

Nossob River. Exposures are very poor over this stretch of country. On the northern side of the river, south of the fault with the Tsumis rocks on Okasewa NW 120 and Okasewa N 121, green shales may occasionally crop out.

Apart from reconnaissance mapping, no detailed work was carried out on the Buschmannsklippe rocks between Witvlei and Omitara.

IX. STRUCTURE

1. Introduction

During the early mapping of the area between Witvlei and Omitara, the present author followed the usage of the Geological Survey of South West Africa and tentatively placed the base of the Damara System at the base of the lowest recognisable Hakos dolomite unit. Subsequent work by the author has revealed the existence, if not of an angular unconformity between Nosib Formation and Damara System, then of an apparent overlap of the latter onto the former. This is especially noticeable north of the White Nossob River, and is thought to be due to one, or a combination of, the following factors:-

i) The existence of a slight discordance between Nosib Formation and Damara System;

ii) The effects of disharmonic folding in the Nosib Formation;

iii) The effects of strike faulting, resulting in the wedging-out of a certain thickness of strata north of the White Nossob River.

The pronounced folding of the Kamtsas quartzites on the farm Losberg 105 contrasts strongly with the essentially linear features of the overlying strata; a glance at Map 2 will confirm this. Accordingly, on evidence obtained from geological mapping, it became necessary to include the quartzite unit that forms the Okaheberg on Losberg 105 in the Damara System. Since this quartzite is a well defined horizon, it has been arbitrarily chosen to represent the lowermost member of the Damara System.

The possibly adverse influence of folding on the continuity and regularity of copper-bearing strata discovered in the area prompted the author to conduct a preliminary investigation into the regional structure. It is realised that the data collected is incomplete, and the interpretation of the results must be regarded as tentative. The scope of the investigation was severely limited by the poor exposures in the region. Accordingly, data were collected chiefly from the resistant, outcropping formations such as the quartzites, and represent, therefore, only a restricted sample of the whole structure. It follows from the nature of the rocks sampled that the ensuing treatment is largely restricted to bedding surfaces, and to linear features on these. Macrofolds outlined by the regional mapping were measured, and where possible the results obtained were compared with those from mesoscopic folds in the same locality. The sporadic nature of outcrops, such as the inselberge of quartzite in the Damara schists, made it virtually impossible to attempt a systematic subdivision of the area into structual domains. In many cases, the stereograms accompanying this chapter depict the structure in somewhat arbitrary domains whose boundaries are outcrop boundaries rather than structural boundaries.

The linear trends of the southeastern portion of the area contrast with the large dome structure of the Kuduberg-Omatewaberg, which must accordingly be due to a different type, or period, of folding. That the region suffered at least two phases of deformation is suggested by the distinct grouping of fold axes measured into two sets, one having a southwesterly, the other a westerly to westnorthwesterly axial trend. The discovery, by the author, of folds of both groups developed together on a single bedding plane is regarded as strong evidence for cross-folding. Finally, a few mostly small folds, exhibit axes having a northeasterly trend. The origin of these features is problematical, but it is thought that they could be the local manifestations of an even later phase of deformation. The reasons for postulating several periods of folding are given more fully on pp 202-4.

All the structural data were plotted on the lower hemisphere of the equal-area (Schmidt) net, and contoured in the conventional manner (Whitten, 1966, pp. 21-24).

2. General : Elements of Structure

(a) Planar Structures

In the quartzites of the Nosib Formation and the Damara System bedding, S_o, is usually defined by the concentration of heavy-minerals on the planes of deposition. In the case of certain micaceous quartzites, recrystallisation of the platy minerals with metamorphism and folding has led to the original bedding surfaces becoming planes of fissility, the rock easily splitting along them to form flagstones. In the Hakos dolomites this original sedimentary layering is denoted by a regularly alternating colour sequence from white to blue-grey.

In some of the less competent phyllitic horizons interbedded with the quartzites and dolomites, compression has led to the formation, not of the bold, open concentric folds characteristic of the quartzites, but of similar folds which approach the isoclinal (Turner & Weiss, 1963, p. 114). Such folds, exhibited by very thin quartzitic or calcareous interbeds in these schists and phyllites, have been observed in trenches dug during the course of prospecting activities in the area. The original bedding surfaces S_0 of the schists have been transported into close parallelism with the axial planes of the isoclinal folds, which in turn correspond to the schistosity S_1 of the phyllites. These two contrasting fold styles are, according to C.W. Stowe (personal communication), usual in interbedded sediments of differing competence.

Minor crenulations, of wave length measuring a few millimetres, are developed on certain S planes, in some localities. In the eastern corner of the farm Joachimstal 107, a gully has exposed mesoscopic folds of S_0 in a sequence of graphitic schists and thin interbedded limestones. These folds have a very gentle southwesterly plunge, and the S_0 surfaces usually show one lineation. Occasionally, a second linear feature is present, cutting the first at an angle of some 50°. Both lineations take the form of minute folds; shear along the axial plane surfaces of these has, in the more prominent of the two sets of crenulations, resulted in the development of a crenulation cleavage S_1, axial planar to the fold in S_0. This cleavage is almost vertical, cuts the bedding at a high angle, and is easily discernible with the naked eye.

Elsewhere, as in the Duruchaus rocks underlying the Lower Member of the Kamtsas Quartzite on Losberg 105, immediately northeast of the Otjiwarumenduberg, the schistosity S_1 in the phyllites, dipping steeply to the northwest and, as already stated above, approximating to the transposed original bedding S_0, carries a crenulation with a steep northeasterly plunge. This crenulation can be seen, under the microscope, to give rise to an incipient cleavage S_3, cutting the schistosity S_1.

(b) Linear Features

These comprise minor fold axes, as well as the axes of crenulations on S surfaces. These crenulations may be responsible for the development of a crenulation cleavage. This intersects the S surface on which the crenulations are developed, the trace on this S plane of the intersection of these two surfaces being a line corresponding to the axial planes of the crenulations. The preferred orientation of pebbles in the conglomerate on Eintracht 118 also presents an example of a linear feature.

The above features will now be treated in somewhat greater detail:

(i) Minor fold closures have been observed at several localities in the area under consideration; many axes were measured during the detailed mapping of the eastern corner of Goldene Aue 106, and have been plotted on Map 3. Two dominant directions of plunge, one to the southwest and the other to the northeast, are apparent.

(ii) Crenulations, the parallel axes of which give rise to a lineation on S planes, have not been observed in the quartzites of the Nosib Formation. They are, however, in evidence in the Duruchaus phyllites, where they give rise to the microscopically discernible cleavage S_3 already mentioned above.

Nearly all the Damara rocks of the region are lineated. In the area covered by Map 3, the lineation in the quartzites and limestones has a westerly plunge roughly corresponding to that of the major and minor fold axes of the region. In the graphitic schists found in the eastern corner of Joachimstal 107 two lineations, l_1 and l_2, trending to the southwest and west respectively, are present. They are due to the intersection with S_0 of axial plane cleavages S_1 and S_2 respectively; only the former is visibly penetrative.

Two similar lineations are found in the quartzites of the Quartzite Hill, near the northwestern boundary of Joachimstal 107. The dominant lineation l_1, in the form of a crenulation resembling mullion structure, ranges in wave length from several millimetres to 2-3cm. It appears to be penetrative, though not visibly so, in that the rock splits easily into slabs bounded by the bedding S_0 and an incipient cleavage S_1, normal to the bedding and apparently axial planar to the dominant crenulations. The second linear feature is not well developed at this locality. Cutting across the dominant crenulation, it takes the form of minute striae 1-2mm in wave length, resembling slickensiding and visible only when viwed obliquely along the bedding planes.

(iii) The pebble conglomerate extending northeastwards from Eintracht 118 to Spandau 149 shows the pebbles to pitch steeply in the plane of foliation. Measurements indicate that the average direction of plunge of the long axes of these pebbles approximates to that of the anticlinal nose of the Kuduberg-Omatewaberg massif.

(c) Folds

(i) Major Folds

The central portion of the region, considered as a

Plate XXXIII. Folded graphitic schists in the eastern corner of Joachimstal 107, showing development of two sets of lineations on the bedding planes.

Plate XXXIV. Locality as above. Folding in an interbedded sequence of schist and limestone, exposed in a small gully.

broad strip trending northeastwards from the southwestern corner of the area mapped, is dominated by by the competent quartzites of the Nosib Formation and the lower part of the Damara System. These rocks form prominent relief, and are conspicuously folded. Although these concentric folds may appear large and open when considered in a purely local context, they are still relatively tight when viewed in a regional setting. Accordingly, this strip of country, with its westsouthwesterly fold direction, presents a linear aspect that contrasts strongly with the westerly trend of the Kuduberg-Omatewaberg unit in the northern part of the region. In that area, the dome-and-basin structure suggests a different style, and probably period, of folding from that found elsewhere in the area mapped.

Although fold axes throughout the region generally have a moderate southwesterly to westerly plunge, at two localities, namely on the farms Dorka 206 and Otjiwarumendu 119, large folds with axes plunging to the northeast were noted.

(ii) Minor Folds

Folds on a scale ranging from several centimetres to several metres have been observed at isolated localities, especially in the better exposed terrain along the White Nossob River. On Goldene Aue 106 two types were noted in narrow limestone and quartzite interbeds in the schists:

(a) Almost isoclinal folds, with axes plunging southwestwards at moderate angles. A non-penetrative lineation l_1, roughly parallel to the fold axis, is present. It appears as the

Plate XXXV. Minor northeasterly-plunging folds in Hakos limestone, Vierkuppenberg, Eintracht 118.

Plate XXXVI. Fold structures in a thin quartzite band in Damara schists exposed in a gully on Goldene Aue 106.

axes of minute crenulations on the bedding surfaces S_o.

(b) More open, inclined folds, with axes plunging northeastwards at shallow to moderate angles. The northwestern limb of these folds is usually steep to vertical, whilst the southeastern limb has a very gentle dip.

In the graphitic schists found in the eastern corner of Joachimstal 107 similar inclined folds as described in (b) above, but with southwesterly plunging axes, were observed in S_o.

On Costa 207 folds in the bedding planes of dolomite, on a scale of 5-10cm, display a moderate northeasterly plunge; the axial plane here is almost vertical.

Finally, trenching operations in the Duruchaus phyllites on Losberg 105, close to the boundary with Christiadore 104, have exposed almost isoclinal folds of the bedding planes S_o in quartzitic interbeds in the phyllites. The axial planes dip at approximately 60^o to the northwest, while the fold axes plunge westwards at some 30^o. In the same locality, small folds in S_1 were observed, plunging almost due north at 50^o to 75^o, and corresponding on a larger scale to the crenulations already mentioned (p. 193)

3. Stereographic Analysis

(a) Symbols Employed

In this account, bedding planes have been given the symbol S_o; axial plane cleavages of the first and subsequent deformationshave been labelled S_1, S_2, etc. Lineations, due to the intersection of two S surfaces, are designated l_1, l_2 etc., where l_1 is an S_o/S_1 intersection.

The terminology is summarised below:

Folded Surface	Axial Plane of Fold	Fold Axis	Chronological Phase of Folding
S_o	S_1	B^{S1}_{So}	F_1 i.e. Quartzite Hill
S_o	S_2	B^{S2}_{So}	F_2 i.e. Kuduberg
S_o	S_3	B^{S3}_{So}	F_3 i.e. Rotberg
S_1	S_3	B^{S3}_{S1}	F_3 i.e. Duruchaus Phyllites

(b) Southwesterly- and Westerly-plunging Folds

As already mentioned, these are the dominant folds in the greater part of the region. Figure 4 gives tectonic data for the Kamtsas Member in three localities, covering the entire exposed strike of some 30 km. in the area mapped. As deduced from a study of Map 2, the axial plane traces of the three folds depicted vary in trend from approximately westsouthwest for figures 4(a) and 4(b) to westnorthwest for Figure 4(c). The axial planes are,in all cases very close to the vertical, and the folds are thus of the normal, or upright type. Proceeding southwestwards across the region it is evident from Figure 4 that, not only do the axial planes trend more westerly, but the axial plunges steepen somewhat.

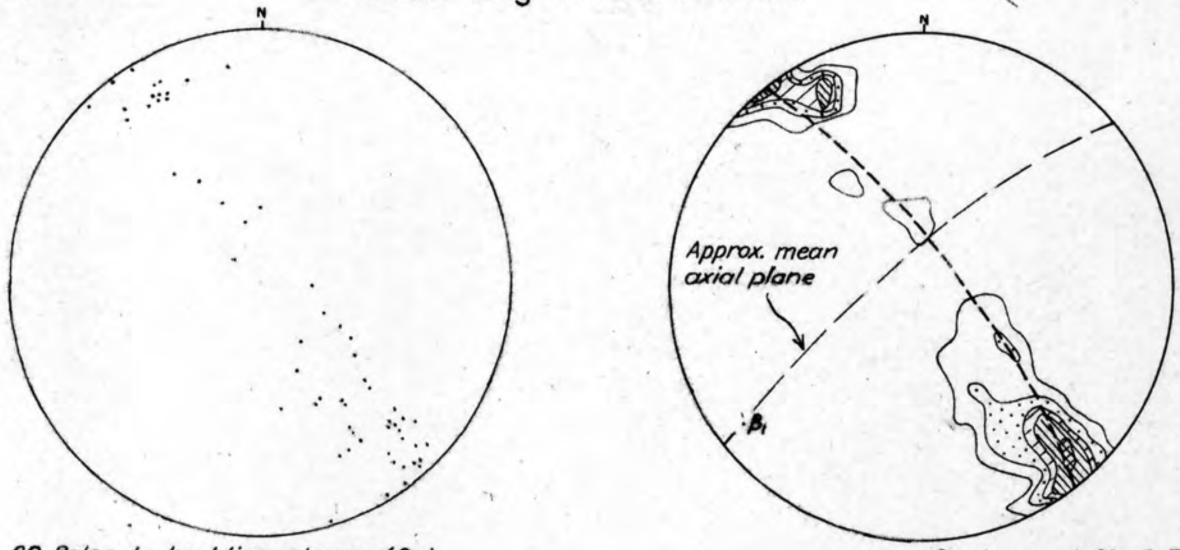
As already stated (p.196), minor folds in quartzitic and calcareous interbeds in the Duruchaus phyllites below the Kamtsas Member were investigated; measurements of these features revealed hinges with trends of 233 - 252° and westerly plunges of 33 - 34°. Axial planes of these folds dip to the northwest at some 60°. These figures show fair correspondence with those obtained from the macrofolds of the vicinity, as plotted in figures 4(a) and 4(b).

1979

Figure 4

Tectonic Data from the Kamtsas Member

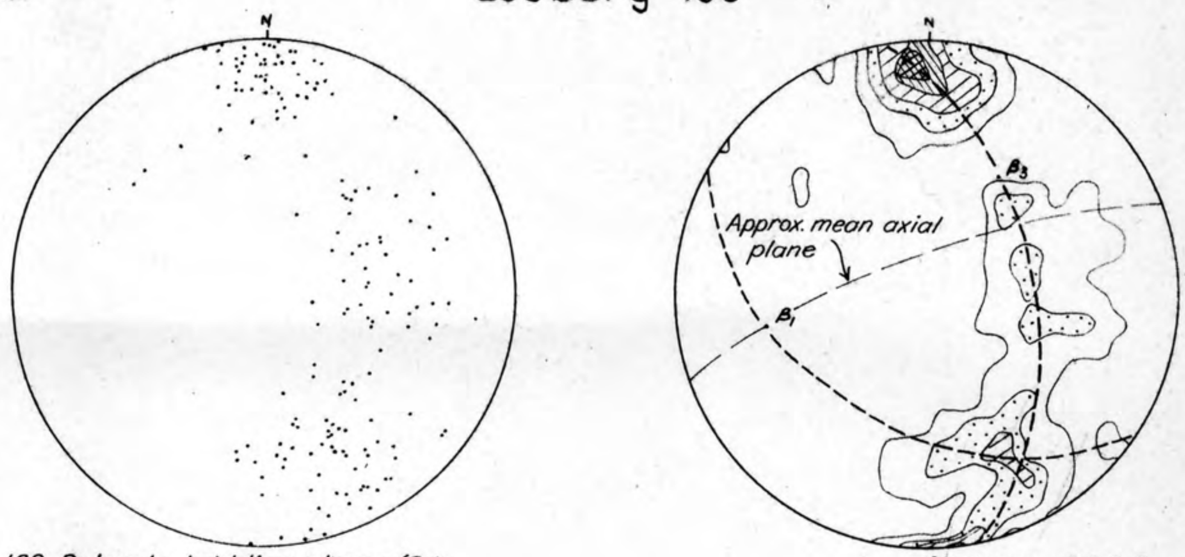
a. Rotberg Anticlinorium



60 Poles to bedding planes (So)

Contours at 2½, 5, 7½, 10 and 15%

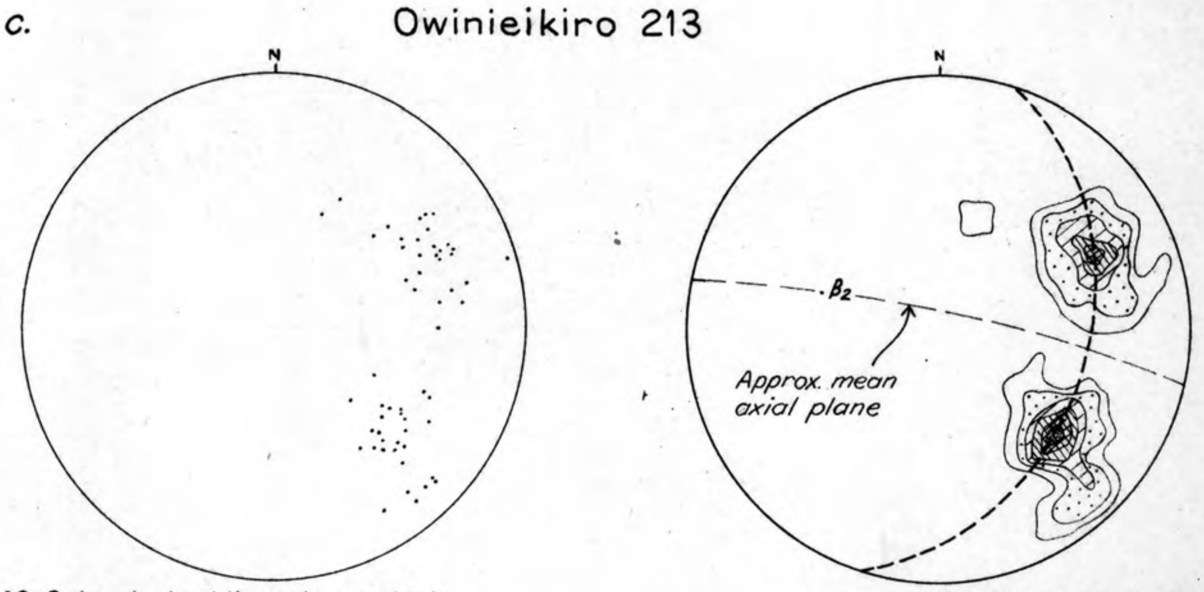
b. Losberg 105



168 Poles to bedding planes (So)

Contours at 1, 3, 5, 7 and 9%

c. Owinieikiro 213



43 Poles to bedding planes (So)

Contours at 2, 5, 10, 15, 20 and 25%

EXPLANATION

· Poles to bedding planes (So)

Mention must be made of the cross-girdle depicted in Figure 4(b). This cross-girdle is very vague, and its orientation is by no means certain. However, it is noteworthy that the beta axis defined by this girdle, of trend and plunge $030^{o}/44^{o}$, approximates to the axes of small folds in S_1 with a northerly plunge, noted locally in the Duruchaus phyllites on Losberg 105 (p.196). This probably represents evidence for F_3 folding, the hinge being a B_{S1}^{S3} axis.

Figures 5, 6, and 7 give further structural data, this time from certain of the better exposed members of the Damara System. Again, almost vertical axial planes are apparent; plunges here show no systematic steepening towards the west of the region.

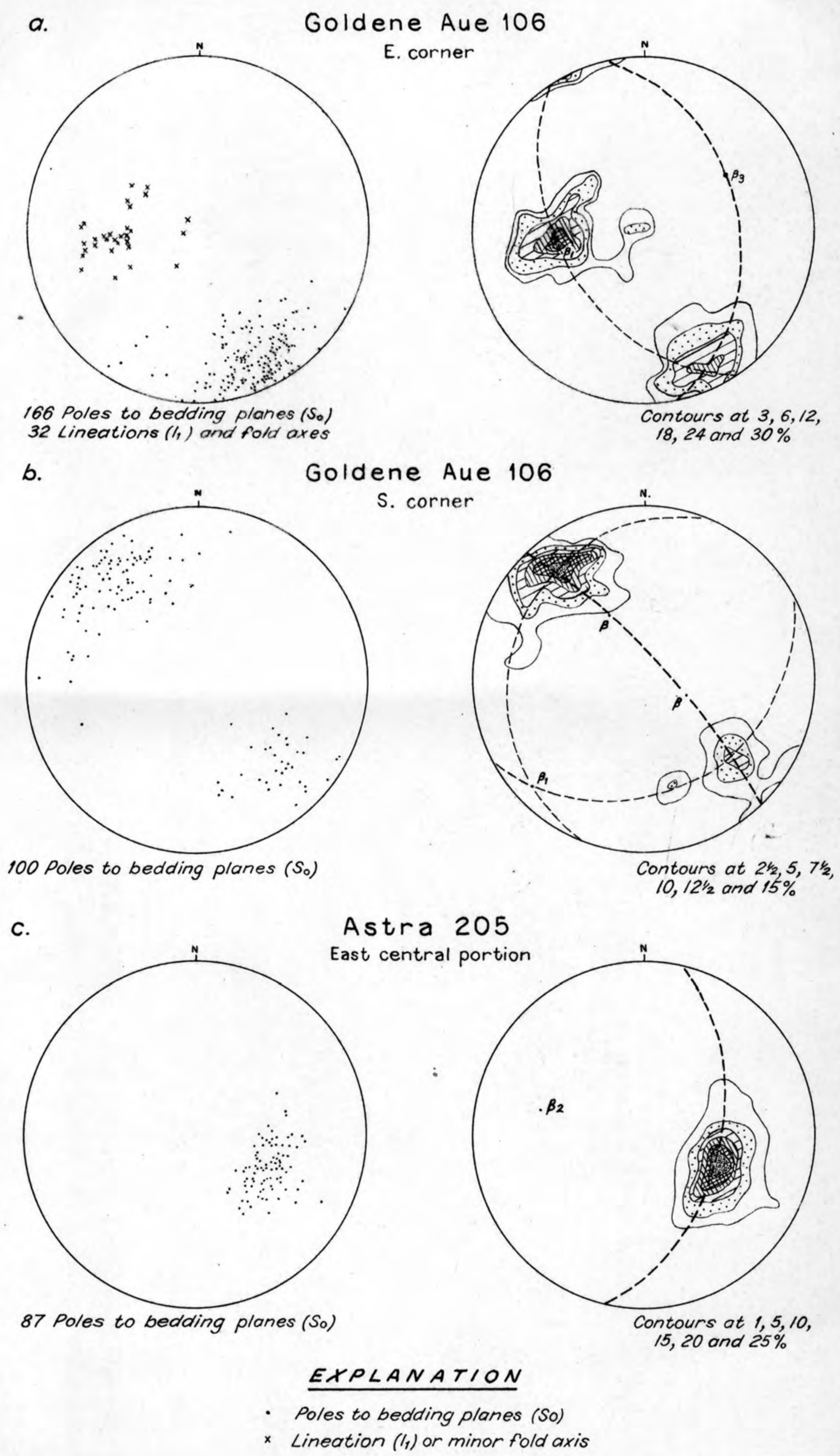
In Figure 5(a) the limited spread of pi poles would have made the construction of an accurate girdle very difficult. However, also plotted are several lineations and the axes of some minor folds; the lineations are So/S_1 intersection lineations l_1, whose maxima must closely approximate to the mean strike and plunge for beta, which here has a value of $259^{o}/48^{o}$.

The significance of the cross-girdle in figure 5(a) will be discussed further below (p.204).

The uneven grouping of points in Figure 5(b) clearly shows the asymmetry of the outcrop in a small syncline occurring in a quartzite horizon in the extreme south of the farm Goldene Aue 106. The northwestern flank of the syncline forms a hill with good outcrops, whereas the southeastern flank is but poorly exposed. Besides the principle pi girdle, it has been possible to define a further two girdles on the stereogram; their significance will now be discussed.

Figure 5

Structural Geometry of some Damara Folds



Three ill-defined minor folds were observed on the limbs of the syncline. One such fold has a trend and plunge of 225°/30°. These figures correspond closely to the values of 227°/10° obtained from the stereogram for the synclinal axis, and suggest this fold to be truly intrafolial.

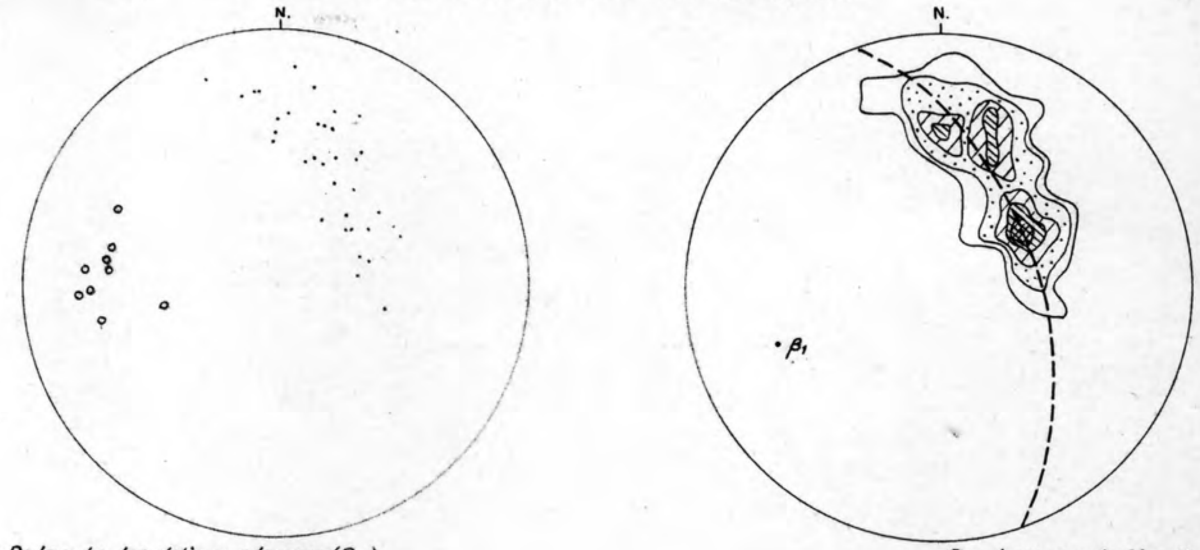
The other two folds, for which poor exposures precluded the taking of sufficient readings for a structural analysis, are situated on opposite limbs of the syncline. They have axial trends and plunges approximating to 138°/70° and 310°/60°. The axial planes could not be defined with any accuracy, but seem to be nearly vertical. In figure 5(b) the two cross-girdles are interpreted as having beta axes with trends and plunges of 109°/68° and 331°/55° respectively. The fairly close correspondence of these values with the figures quoted above for these two minor folds suggests that these features are present on the flanks of the syncline in greater numbers than was recognised in the field. The structural data plotted in figure 5(b) probably includes measurements on several of these folds whose genetic origin is doubtful. However, if they are assumed to be slump structures, it is improbable that readings resulting in such clearly defined girdles would have been obtained.

For the small synclinal hill in the Straussenkuppe-Vierkuppenberg unit on Astra 205, situated 1.5 km. southwest of the corner Joachimstal 107/Goldene Aue 106/Astra 205, figure 5(c) gives a value of 283°/37° for the beta axis. On the flanks of this hill five smaller fold structures, similar to those found on Goldene Aue 106, were noted. For three of these, axial trends and plunges

Figure 6

Tectonic Data from the Damara Quartzites on Joachimstal 107, Büschow 108 and Omatewa 113

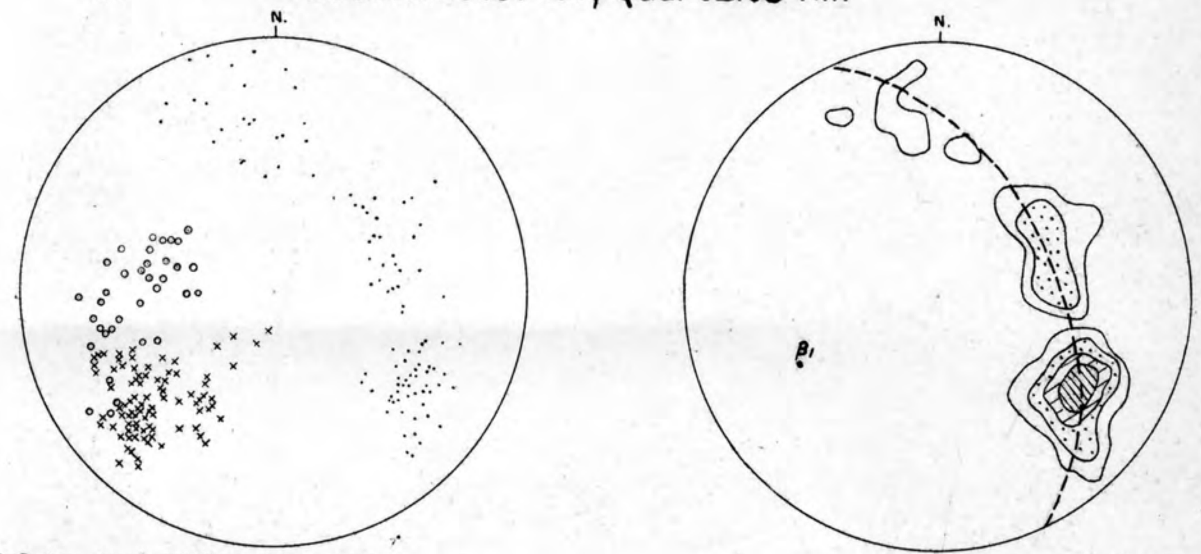
a. **Joachimstal 107 Homestead**



36 Poles to bedding planes (S_0)
9 Lineations (l_2)

Contours at 2½, 5, 7½, 10, and 12½%

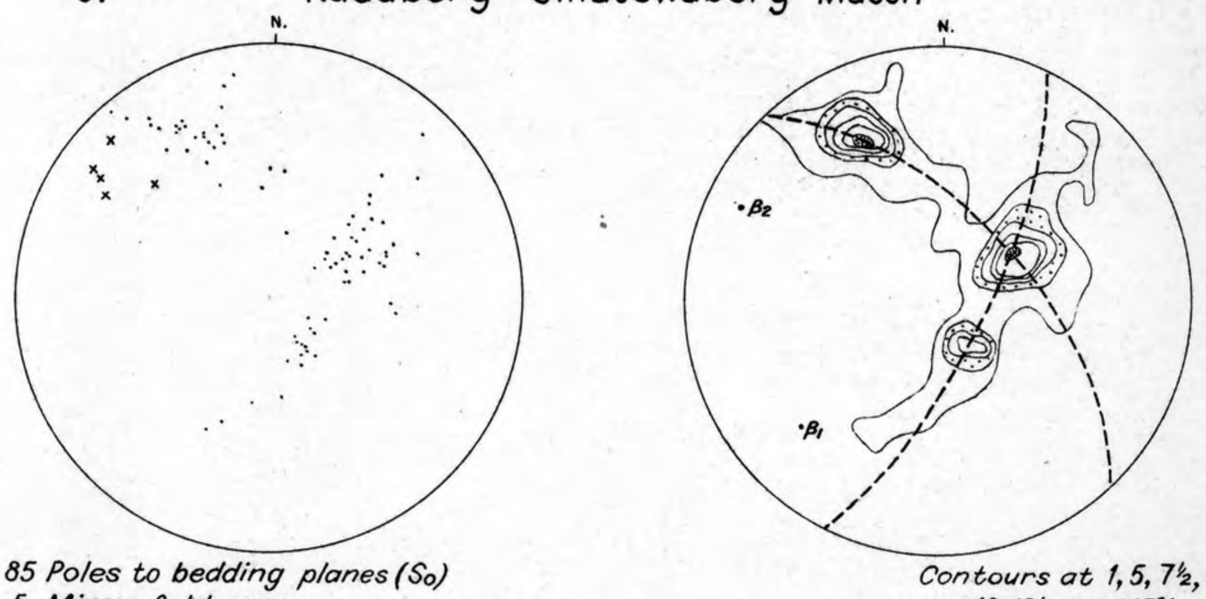
b. **Joachimstal 107, Quartzite Hill**



100 Poles to bedding planes (S_0)
92 Lineations (l_1)
37 Lineations (l_2)

Contours at 2½, 5, 10, 15, 20 and 25%

c. **Kuduberg - Omatewaberg Massif**



85 Poles to bedding planes (S_0)
5 Minor fold axes

Contours at 1, 5, 7½, 10, 12½ and 15%

EXPLANATION

· *Poles to bedding planes (S_0)*
× *Lineation (l_1) or minor fold axis*
○ *Lineation (l_2) or minor fold axis*

obtained stereographically were: $270^{\circ}/52^{\circ}$, $271/46^{\circ}$ and $258^{\circ}/31^{\circ}$. These folds are probably of the intrafolial variety but the other two, with corresponding values of $074^{\circ}/46^{\circ}$ and $343^{\circ}/62^{\circ}$ respectively, do not fall into this category, and the author feels unable to offer an explanation for their origin.

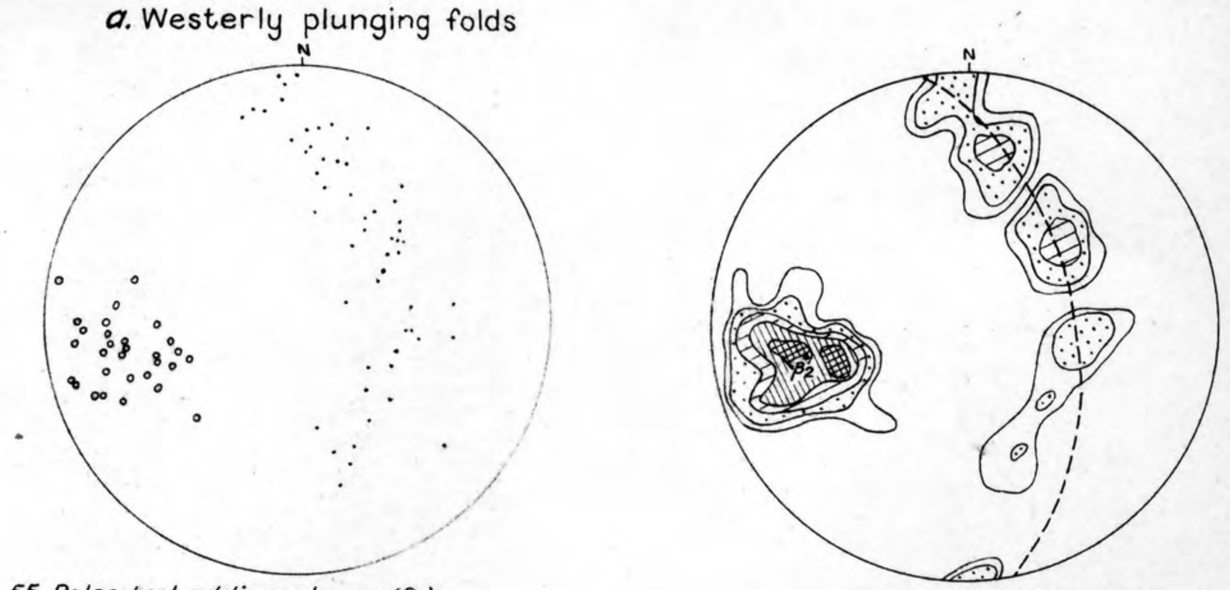
Figure 6 depicts structural data from Damara quartzite horizons in the west and northwest of the region mapped. The l_2 lineations plotted in Figure 6(a), in which is represented data from the vicinity of the ruined farmhouse on Joachimstal 107, are S_0/S_2 intersection lineations, thought to be due to a later phase of deformation. In Figure 6 (b) the mean beta axis is seen to lie close to the maximum of the l_1 lineations which are thus, as already mentioned (p.194), probably due to the intersection of S_0 with a (non-penetrative) S_1 or axial plane cleavage. The l_2 lineations probably represent the traces on S_0 of S_2, a cleavage axial planar to folds of a later deformation with more westerly trending axes.

Figure 6(c) is interesting in that it contains two well defined pi girdles. Data were collected from the nose of the Kuduberg-Omatewaberg anticline on Büschow 108 and Joachimstal 107, and from the northern flank of this massif on the boundary of Omatewa 113 with Altenstein 115. What are considered to be the earlier folds, corresponding to those measured elsewhere in the region, have an axial trend and plunge of $224^{\circ}/29^{\circ}$. The second girdle gives a value for beta of $294^{\circ}/17^{\circ}$; these last figures approximate to those obtained from figures 4(c) and 5(c). The maxima of l_2 (S_0/S_2 intersection) lineations in Figures 6(a) and 6(b) also approximate to these

Figure 7

Fold Structures on Diana 117

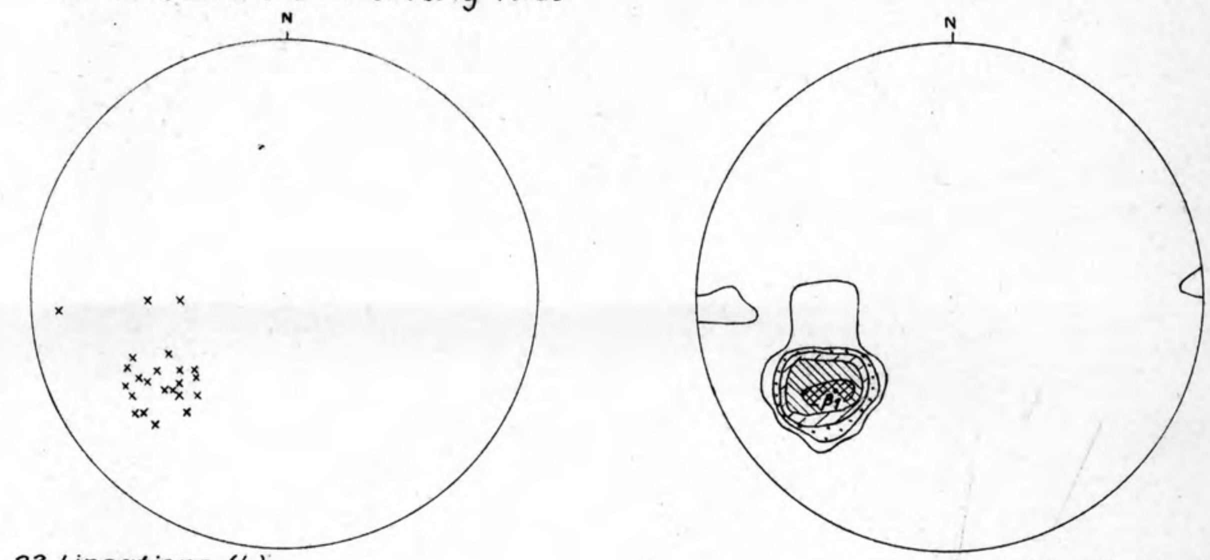
a. Westerly plunging folds



55 Poles to bedding planes (So)
22 Lineations (l2) 8 Fold axes

Contours at 2½, 5, 10, 15 and 20%

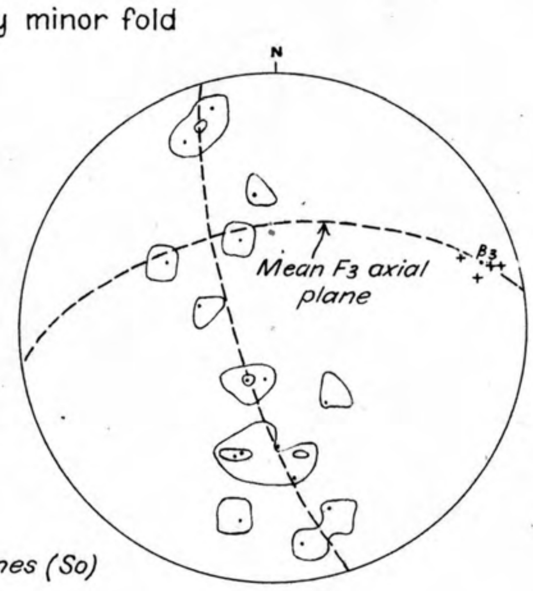
b. Lineations on Westerly folds



23 Lineations (l1)

Contours at 2½, 5, 10, 15 and 20%

c. Easterly minor fold



16 Poles to bedding planes (So)
4 Lineations (l3)
Contours at 6 and 12%

EXPLANATION

- · *Poles to bedding planes (So)*
- × *Lineations (l1)*
- ∘ *Lineation (l2) or minor fold axis*
- \+ *Lineation (l3)*

values.

Small folds in a quartzite horizon some 2km north-west of the homestead on Diana 117 have hinges which also exhibit a westerly rather than southwesterly trend (Figure 7(a)). In this locality the l_2 lineations are due to a visibly penetrative axial plane cleavage S_2 intersecting the bedding S_0.

(c) <u>Northeasterly-Plunging Structures</u>

Although mesoscopic folds with northeasterly-plunging axes were occasionally observed in the area here being considered, only two macrofolds having a similar attitude were noted. These latter include the Rotberg on Otjiwarumendu 119 and the small synclinal hill on the boundary between Dorka 206 and Costa 207; Figures 8(a) and 8(c) respectively refer. In the field, the southeastern limb of the fold depicted in Figure 8(c) was found to be overturned. Accordingly, the axial plane must have a very steep northwesterly dip.

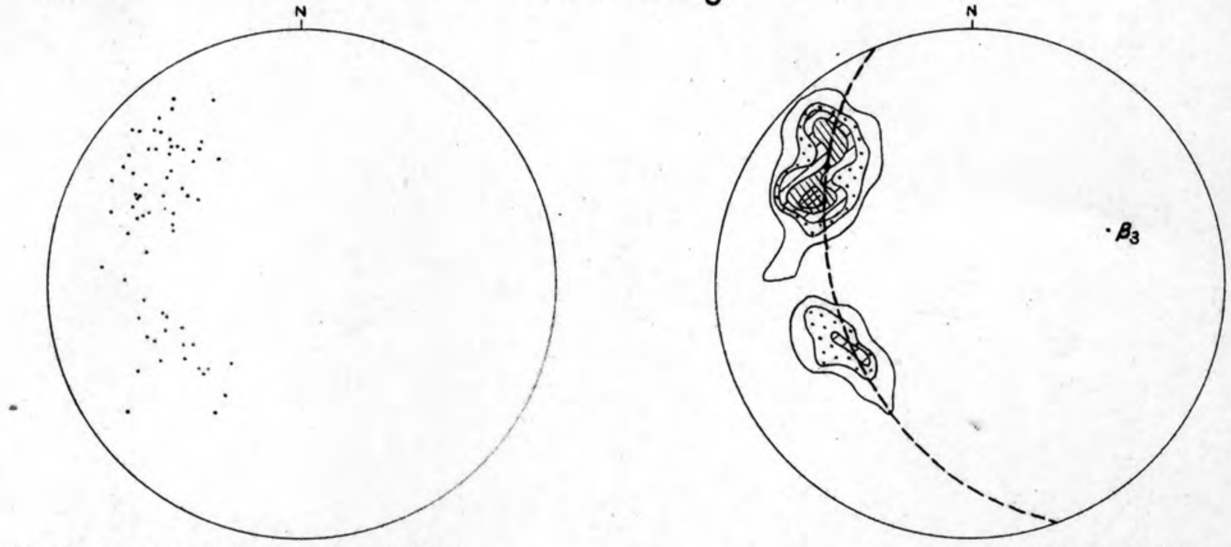
Figure 8(b) depicts data from some of the mesoscopic northeasterly-plunging folds on Goldene Aue 106; measurements were made in the area covered by Map 3. It is of interest that the mean axial trend and plunge of $057^{\circ}/40^{\circ}$ obtained from this figure agrees exactly with the value for the pole of the cross-girdle shown in Figure 5(a). The implications of this are discussed below.

Finally, in Figure 7(c) are quoted data from the northern bank of the White Nossob River on Diana 117 where, some 2 km northwest of the homestead, an ill-defined anticline with a shallow easterly plunge was discovered in quartzites. Only a very few measurements could be taken; fortunately, these included four lineations and

Figure 8

Structural Geometry of some North-Easterly-Plunging Folds

a. **Rotberg**

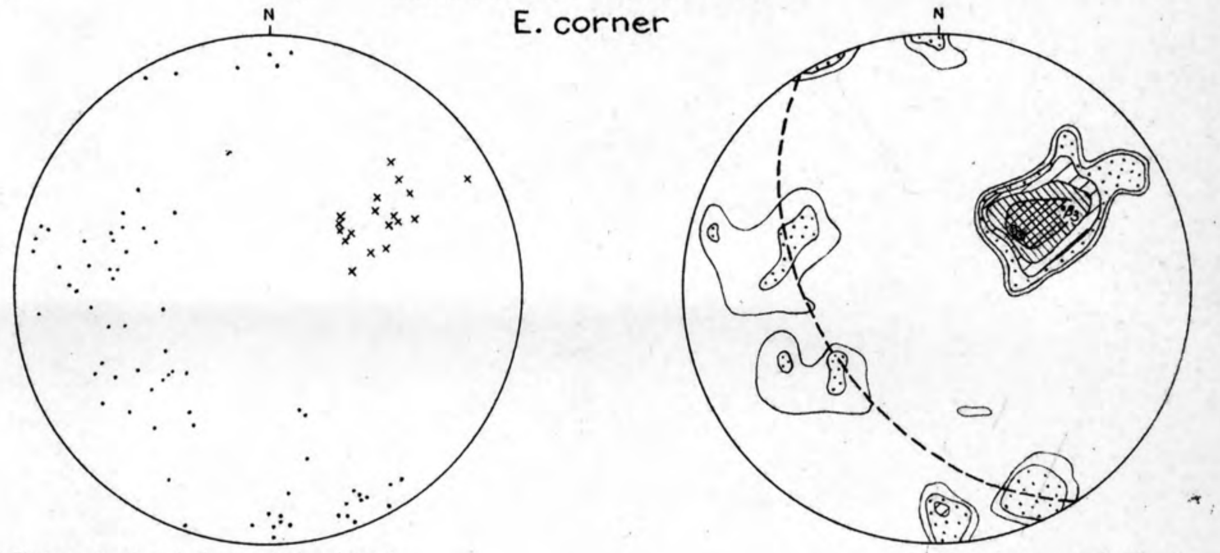


66 Poles to bedding planes (So)

Contours at 3, 6, 9, 12 and 15%

b. **Goldene Aue 106**

E. corner

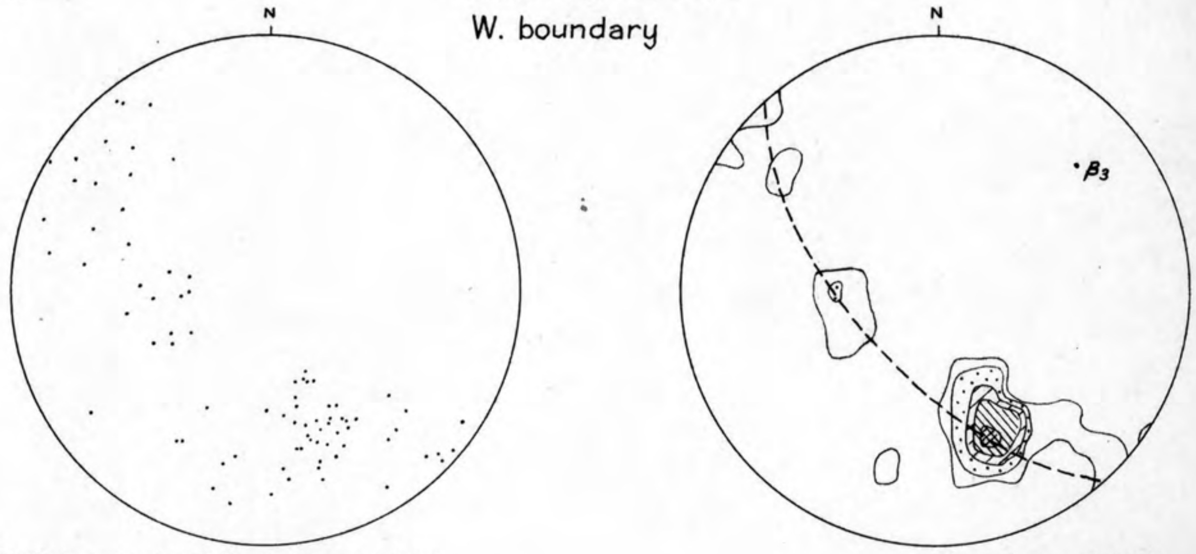


71 Poles to bedding planes (So)
18 Fold axes

Contours at 2½, 5, 10, 15, 20 and 25%

c. **Dorka 206**

W. boundary



78 Poles to bedding planes (So)

Contours at 3, 6, 9, 12 and 15%

EXPLANATION

· *Poles to bedding planes (So)*

× *Minor fold axes*

and the axial plane. A plot of the readings obtained gives a beta value of $073^{\circ}/13^{\circ}$, with an axial plane of strike 081°, dipping 56°N.

4. Structural History

As already stated, this structural analysis is intended as a general, preliminary treatment of the subject in this region. The poor exposures serve to limit the data that may be collected and hence also the evidence that may be obtained from such data. Postulation of several phases must rest largely on other evidence, which is given below:

(i) The failure to locate, in sediments of the Nosib Formation, any evidence for a phase of folding predating that of the Damara System, such as would have been expected from a study of the structures on Map 2, leads the author to suggest that, if such an earlier (Nosib) deformation existed, the early phase of the later (Damara) folding must have been coaxial with it.

(ii) The distinct grouping of the dominant folds of the region into two sets, having axial trends lying between:

(a) 224° and 260° (Figures 4(a), 4(b), 5(a), 5(b), 6.).

(b) 283° and 294° (Figures 4(c), 5(c) and 6).

is worthy of comment. In this connection, mention must be made of the following evidence for cross-folding. On the southern bank of the White Nossob River, in the sharp bend (grid reference -13600/29900) 2 km below the boundary between

Osombahe 112 and Omatewa 113, a bedding plane in talc schist exposed by the river shows two sets of folds to be developed. One set, of wave length 10-15cm, has an axial trend and plunge of $226^{o}/25^{o}$; the other, smaller folds, of wave length 5cm, cross the above set and have axes trending 275^{o} and plunging westwards at 48^{o}. It will be seen that, on the basis of their attitude, the larger folds fall into group (a) above while the smaller ones correspond to those cited in group (b).

It is felt that the existence of two sets of folds on a single S surface is strongly suggestive of polyphase deformation. The present author suggests that the folds of group (a) represent examples of the early, major period of Damara deformation, F_1, which is probably co-axial with a possible earlier Nosib deformation. A late-orogenic pulse, F_2, is thought to be responsible for the attitude of the folds cited in group (b).

Plotting of all beta axes from both the above groups on to one diagram indicates that these axes lie approximately on a small circle, centred on the W point of the stereogram. This would suggest that an original, uniformly orientated set of $B^{S_1}_{S_o}$ axes has probably been dispersed by flexural-slip about an almost horizontal E-W trending axis during a later period of folding. However, no such sub-horizontal axes have been observed in the field, so that the dispersal of the beta axes is probably not due to this process. Accordingly, the above statements should be treated with reserve.

(iii) The origin of the folds having northeasterly-plunging axes is problematical. Apart from the two macroscopic folds mentioned above, these features are usually small, and of relatively localised occurrence. Hence, it was initially thought that they could have originated in response to local stresses set up during the main deformation.

In the area covered by Map 3, folds with both southwesterly- and northeasterly-plunging axes occur in the same folded surface. Unfortunately, the attitude of the axial planes of these two sets of folds was not determined, but their close association in a single S surface appears to be consistent with two, rather than one, episodes of deformation.

As evidence for this may be cited the cross-girdle defined by the 1% and 3% contours in Figure 4(b), suggesting a fold axis of trend and plunge $030^{\circ}/44^{\circ}$. A similar girdle in Figure 5(a), defined by the 12% and 18% contour lines, gives a beta axis of trend and plunge $057^{\circ}/40^{\circ}$. This last value coincides exactly with that obtained from a plot of bedding planes and fold axes of minor northeasterly-trending folds on Goldene Aue 106, depicted in Figure 8(b). Both these cross-girdles, although not very accurately defined, must be assumed to be due to the deformation of the earlier southwesterly-plunging features by one or more later phases of deformation, tentatively designated F_3.

Working in the Nama sediments of the Vanrhynsdorp region in the Cape Province, Kröner (1969, pp 138-149) found similar cross-girdles in his structural diagrams. In the field, he was able to relate these cross-girdles to folds which differed in orientation from the major features of the region and which, incidentally, were also of different ages.

5. Conclusions

(i) Field mapping has shown an angular unconformity, or perhaps an overlap, to exist between the Nosib Formation and the Damara System between Witvlei and Omitara. This suggests the possibility that the Nosib sediments were involved in orogenic movements before the Damara System was deposited.

(ii) No evidence for a post-Nosib-pre-Damara period of deformation could be found; it may be that the early Damara deformation produced folds co-axial with those of a pre-Damara deformative phase.

(iii) Evidence is given to show the existence of two periods of Damara deformation. The earlier F_1 phase resulted in relatively tight folds whose axes trend between southwest and westsouthwest. Later cross-folding F_2 gave rise to more open structures such as the Kuduberg-Omatewaberg massif, and has axes of more shallow plunge, trending from west to westnorthwest.

(iv) Although it could not be proved conclusively, there is evidence for at least one further period of cross-warping, F_3. Small folds on Goldene Aue 106 have northeasterly axial trends, whilst the Duruchaus phyllites on Losberg 105 show evidence of $B_{S_1}^{S_3}$ folding with northerly-plunging axes.

X. DEPOSITION AND METAMORPHISM OF NOSIB FORMATION AND DAMARA SYSTEM

ABSTRACT

The Nosib Formation of central South West Africa appears to have been deposited in the hinge zone between the developing Damara trough and the stable craton to the south. It is composed essentially of shallow-water deposits, in which the proportion of pelites increases with increasing distance from Dordabis. The Damara System was deposited in deeper water under less stable conditions, and shows a certain cyclicity, fine pelites alternating with quartzite-dolomite units. The entire area investigated falls within Eskola's "greenschist" facies of regional metamorphism, and shows a steady rise in grade towards the northwest. Basic igneous rocks of the region show signs of retrograde metamorphism.

In keeping with the remainder of this work, which sets out to be a first general account of the geology of a relatively small tract of country, the author feels that a detailed treatment of deposition and metamorphism is not warranted under the circumstances. Rather, this chapter is intended to summarise, and in certain instances to amplify, points mentioned in various places of the text. In order to reach valid conclusions regarding mode and conditions of deposition of any sedimentary assemblage, an area considerably greater than the 900 sq. kilometres here being considered would need to be investigated. A further prerequisite would be systematic sampling of considerable density. Nevertheless, the comments below should serve as pointers for further work on this subject.

(a) Deposition

From his studies of the region around Rehoboth and Dordabis, Schalk (1966) came to the conclusion that the Nosib Formation is of terrestrial origin, and was deposited in a basin representing a hinge zone between trough and shelf. At its approximate centre, around

Dordabis, this narrow linear zone appears to have consisted essentially of landlocked, isolated basins which locally received sediment from all sides (Schalk), although the regional palaeoslope was towards the north. The arenaceous Kamtsas Member, which at Dordabis makes up the greater part of the Nosib Formation, usually begins with a talus breccia of all pre-Kamtsas rocks. Deposition must have taken place on an uneven floor, possibly representing an inselberg landscape. Features such as clay pellets, local conglomerate lenses and heavy-mineral banding suggests that littoral conditions prevailed. Slumping is common, and for this Pettijohn (1957, p. 598) postulates sea floor slopes of 1.5 - 3° as being essential. Cross-bedding is virtually ubiquitous and its large scale is, according to Bailey (in Pettijohn, p. 593) due to deposition above wave base level. Finally, the presence of ripple marks also suggests a very shallow-water environment.

The features listed above, with the exception of the clay pellets and conglomerate lenses, have also been observed by the present author in the Kamtsas Member between Witvlei and Omitara. A parallel may therefore be drawn with the Dordabis region.

To the southwest and northeast of Dordabis, the Nosib basin appears to have come under progressively greater marine influence. Whereas in the area of the Kamtsas Mountains only one marine transgression occurred, resulting in deposition of the Witkoei Beds, the pelites make up the bulk of the Nosib Formation to the southwest at Duruchaus, and to the northeast at Losberg 105. In the area between Witvlei and Omitara, the geological record is incomplete owing to the faulting-out of the basal portion of the Nosib Formation. However, the lenticular nature of the Kamtsas Member and the great development of the (Duruchaus) phyllites indicate that here marine conditions prevailed, and that the area was far from the source of the arenaceous sediments.

Structurally, the author envisages a similar history for the Nosib Formation in the area under consideration as has been postulated for the Dordabis region by Schalk. Folding and dislocation occurred before onset of the Damara sedimentation, possibly at the beginning of subsidence of the main Damara trough. A glance at the accompanying Map 2 confirms this.

According to Martin (1965, p. 38) the early period of geosynclinal subsidence is characterised by very unstable conditions. The extremely varied lithology of the lower portion of the Damara System, with its rapid alternation of quartzites, phyllites and dolomites, bears out this observation. That the water must have been deeper than in Nosib times is suggested by the absence of ripple marks, by the small-scale cross-bedding occasionally present in the quartzitic interbeds, and by the preponderance of pelites over psammites. However, the environment must still be classified as sublittoral i.e. extending from the low-tide mark to a depth of 600 feet (Krumbein & Sloss 1963, p. 260). According to Twenhofel, cited in Krumbein & Sloss (p. 261) 80% of all sediments in the geologic column were deposited in this zone.

Petrological studies carried out by the author on Nosib and Damara quartzites, normally indistinguishable in hand specimen, indicate certain differences between the two. The Nosib quartzites have a felspar content ranging from 13-21%, an average lying close to 19%. Relatively coarse material, possibly derived from a granitic source, must have been rapidly buried in a subsiding basin. The Damara quartzites investigated, on the other hand, contain at most only 17% of felspar, an average being close to 10%. They also contain up to 16.7% of mica. This probably represents an original clay fraction, and suggests a different origin from that of the Nosib arenites. However, deposition and burial must have been as rapid as in the case of the Nosib sediments, since any winnowing by currents would have resulted in the removal of the fine clay fraction.

The common Damara lithological association quartzite-dolomite, with its shallow-water, possibly evaporitic connotations, has been discussed in detail in Chapter VIII. From this one must conclude that periods of slow deposition, resulting in fine pelitic material being deposited in relatively deep water, alternated with periods during which coarse clastics, possibly derived from nearby geanticlinal ridges, were being rapidly poured into the trough. The transition between these two cycles would have been characterised by quiescent, restricted-circulation lagoonal environments, possibly accompanied by local evaporitic conditions. The Damara dolomites would have originated during these periods. It follows that the Nosib and Damara periods of deposition are characterised by significant differences in tectonic and environmental parameters.

(b) Metamorphism

The mineralogical assemblage encountered in the various lithological groups of the region under consideration has already been treated in some detail. Petrological studies by the author reveal that the area falls wholly within Eskola's "greenschist" facies of regional metamorphism. According to Turner and Verhoogen (1960, p. 533) the association quartz-albite-epidote is diagnostic of this facies which has, on the basis of mineralogical changes observed in pelites at the biotite and almandine isograds, been further subdivided. Three sub-facies, defined by the following assemblages, are recognised.

1. Quartz-albite-muscovite-chlorite;
2. Quartz-albite-epidote-biotite;
3. Quartz-albite-epidote-almandine.

For the greenschist facies the temperatures have been estimated at 300-500°C, and pressures of 3-8kb are thought to have prevailed (Turner & Verhoogen, p. 534).

The quartz-albite-muscovite-chlorite subfacies is usually characterised by aluminous chlorites, such as prochlorite, while muscovite is the principal white mica. Increasing grade of metamorphism leads, in rocks of suitable composition, to the formation of biotite, i.e.

$$\text{Muscovite} + \text{chlorite} \rightleftharpoons \text{biotite} + \text{chlorite}$$

It is of note that both muscovite and Mg-rich chlorite can coexist with biotite until the temperatures given for the greenschist facies are surpassed. The distinction between the greenschist and the higher almandine-amphibolite facies lies in the composition of the plagioclase, and is easily determined under the microscope. The greenschist facies is characterised by a plagioclase containing 0-7% of the An component. In the almandine-amphibolite facies, on the other hand, the plagioclase is usually oligoclase or andesine; Winkler (1967, p. 103) gives a minimum value of 15% for the An component.

The whole of the Nosib Formation, together with the lowermost portion of the Hakos Series, may be considered to fall into the quartz-albite-muscovite-chlorite subfacies. The pelitic rocks, such as the phyllites of the Duruchaus Member and the Damara schists, are characterised by the assemblage quartz-muscovite/sericite-chlorite; albite, epidote, and tourmaline are accessories. The quartzo-felspathic rocks, such as the Kamtsas Member and the thin quartzitic interbeds in the Damara System, contain chiefly quartz with smaller proportions of albite and white mica. The K felspar content of these rocks, varying between 0 and 14.6%, is unusual, according to the criteria of Turner and Verhoogen (p.536).

Specimen 68, from an exposure (grid reference -22900/39650) in a gully on the southern bank of the White Nossob River, is the first to show development of biotite from chlorite, and hence ushers in the quartz-albite-epidote-biotite subfacies. A little higher in the succession, pelites collected from the area covered by Map 3 contain abundant biotite. The composition of specimens 54 and 55 from this area is quoted in Table 11, while Table 12 gives the mode of specimen 50, thought to be of igneous derivation. The dolomite horizons found on Joachimstal 107 usually carry tremolite, which is characteristic of calcareous rocks throughout the greenschist facies.

The highest zone of the greenschist facies, namely the quartz-albite-epidote-almandine subfacies, is represented by specimens of amphibolite from the northeastern corner of Büschow 108 and the southwestern portion of Omatewa 113. The presence of garnet in specimen 12 initially suggested that the almandine-amphibolite facies might locally be developed, However, petrological examination of the slide showed the plagioclase to be albite. Furthermore, chlorite occurs in the rock together with quartz. This, according to Winkler (p. 103) is no longer possible above the greenschist facies.

The petrology and metamorphism of the basic igneous rocks of Joachimstal 107 and Goldene Aue 106 have been discussed fully in Chapter VIII. These rocks have undergone partial retrograde metamorphism, bringing their mineralogical composition into equilibrium with the surrounding Damara tectonites.

XI. SUPERFICIAL DEPOSITS

Generally, the solid geology of the area is masked by one or more types of Tertiary to Recent material, which may be classified as below:

(a) River gravels and silt;
(b) Quartzite rubble;
(c) Vein quartz rubble;
(d) Calcrete;
(e) Kalahari sand.

These will now be examined in some detail.

(a) River gravels and silt

As already mentioned, the White Nossob River in the area mapped has formed numerous incised meanders, and it is in the inside bends of promontories thus formed, that considerable deposits of gravel occur. Pebbles are poorly sorted, varying in size from 2 - 15cm, and are usually somewhat flattened ellipsoids. The chief rock type represented is a white sugary quartzite, often limonite-stained, and possibly derived from the higher Damara beds traversed by the river in its upper reaches. Pebbles of vein quartz have also been noted. From gravel pits along the route of the new tar road linking Windhoek with Gobabis, these deposits are known to reach thicknesses in excess of 2 metres.

On the outside bends of the meanders, below the base of the gravels on the opposite bank, are to be found deposits of grey micaceous silt, again reaching thicknesses of 2 to 3 metres, lying directly on an eroded surface of Damara schists. It appears that these fine-grained sediments initially formed an older valley floor into which the river cut during a later

Plate XXXVII. Erosion gully in the White Nossob valley on Goldene Aue 106, showing Damara schists overlain by several metres of micaceous silt.

period of uplift. Excavations for the foundations of the new road bridge across the White Nossob River between Eintracht 118 and Losberg 105 have shown the bedrock in the river to lie beneath some 10 metres of sand and silt.

(b) Quartzite rubble

Because of the arid nature of the country there are few well developed water courses, most drainage features from higher ground either becoming dissipated in the plains, or ending in small pans which contain deposits of silt and clay. Between the plains and the hills, where these latter are composed of quartzite, are to be found extensive areas underlain by rubble. The generally well-bedded and jointed quartzite breaks into angular blocks by mechanical weathering; these blocks then move down the slope by gravity, aided by game and cattle. This movement was obviously more pronounced in earlier wetter periods, since the extent of these deposits, as evidenced by trenching in connection with the recent prospecting activities in the area, can only be attributed to sheet wash. Thicknesses of 0.5 metres are common, the rubble showing a poor degree of sorting and little rounding, with fragments ranging in size from 2 - 20cm. Locally, former stream channels, also boulder-filled, are incised well below the general base of the rubble sheet, sometimes reaching depths in excess of 3 metres below the present surface. The rubble usually rests directly on the steeply dipping phyllites and schists adjacent to the quartzite ridges.

On Losberg 105, fairly extensive pediments composed of quartzite talus are developed on the lower slopes of the ridges.

It is noteworthy that no similar deposits have been observed in the vicinity of the dolomite ridges in the area mapped. However, the two granite domes of the Dachsberge on Sandflats 123 show some pediment development.

(c) Vein quartz rubble

In areas where the phyllites and schists of the Damara System are exposed, such as along the White Nossob River, the usually thin residual micaceous soil is covered by and mixed with rubble consisting almost entirely of sub-rounded to rounded fragments of white vein quartz in the 1 - 5cm size range. This material is derived from the weathering of the ubiquitous quartz veins which characterise the area under consideration, and which appear to represent both fault fillings in the numerous zones of dislocation as well as later secretion veins. Away from the river the red Kalahari sand, mentioned below, blankets this type of deposit.

(d) Calcrete

The development of calcrete, or surface limestone, has not been studied, but appears to be a function of the carbonate content of the underlying rock, coupled with its mode of weathering in the predominantly arid climate. Development of this type of deposit is especially noticeable over the more calcareous members of the Damara schists, as well as over the thin limestone bands interbedded with these.

It will be seen from the large-scale plan (Map 3) of a portion of the farm Goldene Aue 106 that, on the eroded slopes immediately adjacent to the White Nossob

River, rock is exposed at surface, or is covered by thin soil only. Away from the river the outcrop disappears beneath a capping of calcrete 1 - 2 metres thick. This forms a plateau with a well defined edge, and gives rise to a low scarp overlooking the river valley. Small tributaries of the White Nossob River are actively cutting into this calcrete capping, which in consequence presents a complex outline on the side facing the river. With increasing distance from the river this calcrete "plateau" becomes overlain by Kalahari sand.

(e) Kalahari sand

Away from the major drainage feature of the region, the White Nossob River, the only outcrops to be found are along the ranges of hills composed of quartzite and dolomite, and in the "inselberge" dotted over the plains. The remainder of the surface is covered by a blanket of red to grey Kalahari sand. When compared with the area southeast of Rehoboth, readily recognisable dune features are absent, although on Joachimstal 107 a concentric series of low mounds has been noted, trending from northwest through west to southwest and thus following approximately the outline of the Kuduberg. Generally, the cover probably averages only 2 - 3 metres in thickness; in areas of topographic lows existing prior to deposition of the sand, greater thicknesses undoubtedly occur, but no data are available. Poldervaart (mentioned in Boocock & Van Straten, 1962), working in the Central Kalahari Basin of Botswana, has distinguished sands of several ages and provenances, and it is therefore likely that variations in age and source would also be found on further investigation in the area under review.

Of interest are the large accumulations of sand piled against the northwestern flanks of the hills in the area. This sand must have been brought in by wind whose prevailing direction was other than those of the present time; a northerly to northwesterly palaeowind direction is indicated.

XII. ECONOMIC GEOLOGY

Economic interest in the area is centred on numerous small occurrences of copper mineralisation. Prospecting activities by two mining companies, Fedswa Prospekteerders (Edms) Bpk and Anglovaal South West Africa (Pty) Limited, commenced late in 1967, and are still in progress at the time of writing (1971).

Owing to the poor exposures, the cheapest and quickest prospecting technique used is geochemical soil sampling. Screening of the samples, in certain cases to -270 mesh, has been shown to make the method more sensitive by removing the coarser quartz particles; the copper minerals are usually associated with the clay fraction of the soil. A relatively new prospecting tool extensively used by Anglovaal is Geobotany. Mapping of plant distributions has shown the presence of vegetation "anomalies" - these often coincide with zones of high mineral concentration. From these zones certain botanical indicator species have been recognised. Furthermore, once it has been established which species, in a certain area, show a preferential uptake of the element being prospected for, selective sampling of these species will give results which show close correlation with those obtained by soil sampling. Also, since certain plants have long, deep-reaching tap roots, recognition and sampling of these species should obviate the need for auger sampling in areas of deep, wind-blown overburden. Any abnormal concentration of elements occurring below the overburden will be shown by analysis of stems and leaves of the plants, which will have taken up these elements in solution. Results obtained to date in this connection have been encouraging.

Any metal "anomalies" defined by the above methods are usually investigated by trenching, and then by wagon-drilling. Diamond drilling is used in the final assessment of any deposit that has been found to show sufficient promise by the other prospecting techniques mentioned.

Despite the fact that encouraging surface indications were found at several localities between Witvlei and Omitara, intensive exploration has revealed that the deposits are small and very localised. Sedimentological and structural control of the mineralisation is very evident; lensing and faulting out of ore horizons are common. No detailed investigation into the origin of the copper mineralisation was carried out, However, from observations of drill core, and of mineralised strata exposed in trenches, the present writer feels that differences exist between the deposits in the "Tsumis" rocks and those of the Nosib Formation and the Damara System.

In the strata lying southeast of the thrust fault on Christiadore 104 and Otjiwarumendu 119, the mineralisation is essentially strata-bound, and resembles the syngenetic ores of the Zambian Copperbelt with which the author has had several years of experience. In the schists of the Damara System, on the other hand, mineralisation appears to be associated with the many shear zones and faults that trend parallel to the regional strike. It appears that the copper, possibly of syngenetic origin and originally uniformly distributed throughout the sediments, was remobilised during metamorphism to become redeposited and concentrated along certain favourable horizons. A certain affinity of the copper mineralisation for the narrow limestone units interbedded with the chlorite-mica schists was noted. In these limestones, oxide copper occurs as blebs, and in vugs. In the adjacent schists partings of oxide mineralisation are found on the cleavage planes. Blebs of oxide copper also occur in the quartz veins traversing the region; these localised occurrences, of no economic importance, often give rise to considerable geochemical soil anomalies.

The more important zones of mineralisation known from the area under consideration will now be discussed briefly:

(i) Christiadore 104. Malachite was discovered in the conglomerate lenses of the "Tsumis" rocks, especially in the vicinity of the farmhouse (grid reference -27970/43660). Grade and strike length of the deposit are deemed insufficient to warrant further work.

(ii) Okasewa NW 120. Fedswa has been actively drilling a sizeable deposit, marked both by outcrop and by vegetation anomalies, located in the extreme southwestern corner of the farm, astride the main road between Witvlei and Omitara. A fault truncates the northeastern end of the mineralised zone, which extends for over one kilometre. The mineralisation, in the form of copper oxides and sulphides, appears to be of syngenetic origin, being concentrated along the bedding planes of the more shaly members of the "Tsumis" rocks. The area is tightly folded, with steep dips. Lateral correlation of strata from drillhole to drillhole is fraught with difficulties, and is often impossible owing to facies changes. Lensing-out of the deposit at relatively shallow depths is indicated. Assay values are fairly good, but widths are erratic.

(iii) Eintracht 118. On the promontory on the northern side of the White Nossob River, immediately south of the new road bridge over the river, rocks showing copper mineralisation crop out (grid reference -24300/39450) for a strike distance of over one kilometre. The deposit is probably connected with the large shear zone shown on Map 2. Extensions to the strike of the deposit, as well as parallel minor zones of mineralisation, were revealed by soil-sampling traverses carried out across the river on the farm Losberg 105. Geochemical anomalies could be traces as far southwestwards as the Okaheberg.

The Eintracht section of the deposit appears the most promising, but has not been investigated in any detail. On Losberg 105, adjacent to the White Nossob River, trenching on surface showings of malachite revealed the rock below the surface to have become almost completely replaced by calcrete, with concomitant leaching of the copper. Wagon-drilling results were extremely poor, and could in most cases not be correlated with surface findings.

(iv) Goldene Aue 106. Copper mineralisation in quartz-chlorite-biotite schists and associated limestone bands occurs in the extreme eastern corner (grid reference -20900/38800) of the farm. Details of the geology are given in the large-scale Map 3. As in the case on Eintracht 118, this deposit appears to be connected with the adjacent shear zone (see Map 2). Values and widths are disappointing, although wagon-drilling showed some continuity of the ore horizon at depth.

The strike of the deposit is considerable, and was traced northeastwards along the northern bank (grid reference -21950/38000) of the White Nossob on Eintracht 118. To the southwest, approximately 500 metres from the river, the outcrop disappears beneath the cover of Kalahari sand.

(v) Losberg 105. The Duruchaus phyllites below the Lower Kamtsas Member, approximately 1 km southeast of the White Nossob River (grid reference -25000/42500) contain a zone of relatively high-grade copper mineralisation. The horizon constitutes a tightly isoclinally folded band, 2 - 3 metres thick, of quartzites and limestones with thin phyllitic interbeds. The whole forms an anticlinorium lying along the axis of the Otjiwarumenduberg anticline, a short distance to the southwest. The copper appears to have been introduced subsequent to the folding of the rock, and is concentrated in the more phyllitic portions. Insufficient wagon-drilling was carried out for this description to be expanded further. The deposit, with a strike length of some 1200 metres, is of interest in that it forms a relatively narrow, compact, outcropping horizon, set in soft phyllites which are seldom exposed and which are far less metamorphosed than the ore horizon. The economic importance of this deposit has yet to be ascertained.

Reference has been made elsewhere to the unsuccessful search for gold on Astra 205.

Were it not for the poor communications and great distances from the larger centres of the territory, the deposits of high-grade marble occurring in the area and described more fully above, could no doubt be exploited. The same may be said for the platy quartzites of the Quartzite Hill on Joachimstal 107; closer proximity to Windhoek would make this a valuable source of flagstones

XIII. CONCLUSIONS

The tract of country described in this work is of extremely varied geology, and it is hoped that the above account has brought out, and has emphasized the need, for further investigation of the many aspects which still await clarification. The points that immediately come to mind are:

i) The relationship between the Nosib Formation and the undifferentiated quartzites occurring in the central portion of Owinieikiro 213;

ii) The possible equivalence of Nosib and Tsumis Formations;

iii) The detailed structural history of the area, including the relationship and boundary between Nosib and Damara beds;

iv) The exact nature of the pebble conglomerate on Eintracht 118, leading perhaps to an acceptable subdivision of the Damara System in this area.

It is felt that, probably on account of its relatively poor exposures, this particular portion of South West Africa has up to now been neglected geologically. However, the present work has brought out the considerable differences in lithology and stratigraphy that exist between rocks of this area and Nosib and Damara strata elsewhere in South West Africa. Accordingly, further studies in this region would serve to amplify and make more complete the present understanding of this widespread sedimentary assemblage.

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MAP 1

Geological Map of SOUTH WEST AFRICA

Scale 1 : 5 000 000

KILOMETRES 100 0 100 200 300 400 500 600 700 KILOMETRES

Modified after Haughton (1968)