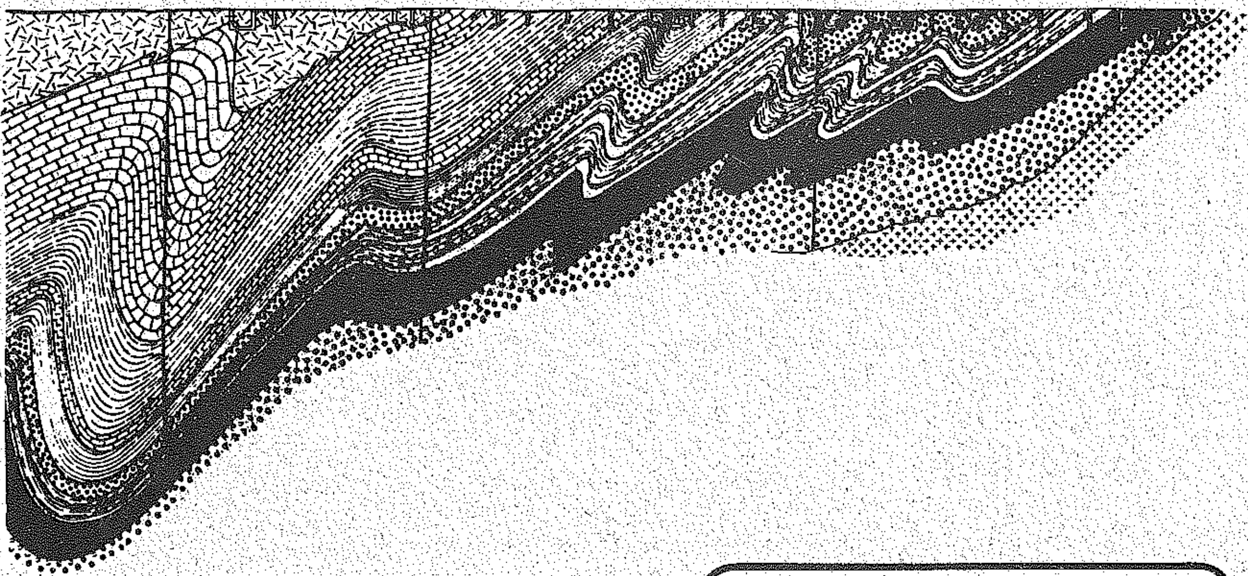
UNIVERSITY OF THE WITWATERSRAND

JOHANNESBURG



ECONOMIC GEOLOGY

RESEARCH UNIT

INFORMATION CIRCULAR # 9

UNIVERSITY OF THE WITWATERSRAND

JOHANNESBURG

LITHIUM- AND BERYLLIUM-BEARING PEGMATITES IN THE KARIBIB DISTRICT, SOUTH WEST AFRICA

by

C. ROERING

Research Fellow

and

T. W. GEVERS

Professor of Geology, University of the Witwatersrand

Economic Geology Research Unit

INFORMATION CIRCULAR No. 9

October, 1962

INFORMATION CIRCULAR No. 9

(For Restricted Distribution)

LITHIUM- AND BERYLLIUM-BEARING PEGMATITES IN THE KARIBIB DISTRICT, SOUTH WEST AFRICA

ABSTRACT

A detailed description is given of three of the major lithium- and beryllium-bearing pegmatites occurring in the Karibib District, South West Africa. A fairly systematic pattern of internal zoning is found which reflects the crystallization history of pegmatite magmas. The overall zonal pattern of the pegmatites from their contacts corewards is as follows:

1. Granitic zone of albite-perthite-quartz-muscovite.
2. Cleavelandite-quartz-muscovite with accessory beryl, frondellite and sometimes columbite-tantalite.
3. Lithium-bearing ore zones.
4. Cleavelandite-beryl-columbite-tantalite-cassiterite.
5. Quartzose core, either pure or mixed with adjacent mineral phases.

****

LITHIUM- AND BERYLLIUM-BEARING PEGMATITES IN THE KARIBIB DISTRICT, SOUTH WEST AFRICA

CONTENTS

CCNTENTS

CONTENTS

****

LITHIUM- AND BERYLLIUM-BEARING PEGMATITES IN THE KARIBIB DISTRICT, SOUTH WEST AFRICA

INTRODUCTION

A. ACKNOWLEDGEMENTS

Following on the earlier work of De Kock and Gevers, the Economic Geology Research Unit of the University of the Witwatersrand undertook an investigation of lithium- and beryllium-bearing pegmatites in the Karibib District, South West Africa, during 1959 and 1960. Financial subvention was provided by the South West African Administration to which the Unit and authors wish to express their indebtedness, as well as to Dr. F.C. Truter, Director of the Geological Survey, Pretoria, for sustained interest and help. They also wish to extend their thanks to the various owners of the pegmatite properties for permission of access and help in the field. In particular, they would like to thank Mr. Jack Levinson and South West African Lithium Mines Limited for unlimited co-operation in all aspects of the work. Thanks are also due to Mr. J. McIver, of the Geology Department, University of the Witwatersrand, for several feldspar determinations.

B. LOCATION OF AREA

The following important pegmatites were mapped in detail: Rubicon, Helicon, Karlsbrunn, Brockmann's pegmatite on Albrechtshöhe, Becker's pegmatite on Otjua, Kaliombo, Henckert's pegmatite on Dernburg, Van de Made's pegmatite in the Erongo Schlucht. Only the first three are described in this paper.

These pegmatites all lie within a radius of 20 miles from Karibib, approximately 120 miles by rail from Walvis Bay harbour.

C. SCOPE OF PRESENT PAPER

Parallel with this study, a regional investigation of the south-western portion of the Damara geosyncline, including the main area of economically mineralized pegmatites, was also undertaken by the Unit (Smith, 1961). A structural investigation of certain selected areas, undertaken to clarify the mode of emplacement of individual pegmatite bodies, has already been published by Roering (1961). A comprehensive detailed account of the complex economic pegmatites of the district is in preparation.

The present paper is concerned with reporting briefly the more pertinent field observations of selected, particularly interesting pegmatites, comparing these with trends observed in other pegmatite areas, and, finally, assessing the validity, or otherwise, of generalisations.

Due to the lack of analytical chemical facilities, detailed mineralogical work is, as yet, inadequate and relevant terminology must, of necessity be accepted in a broad sense. Thus "muscovite" merely indicates a grey platy mica, generally coarser than ¼ inch, while "lepidolite" refers to massive mauve or purple, generally fine-grained, mica. The term "grey or green lepidolite" applies to lithium-rich micas found at core margins. "Columbite" refers to a mineral in which, as far as is now known, the Nb content exceeds that of Ta. Where more precise mineralogical data are available, these are mentioned in the text.

The coarse, often "giant" structure of pegmatite minerals is, by definition, characteristic. Detailed field observations alone therefore, are able to provide a wealth of diagnostic data, impossible to achieve without a microscope in other rock types. Among many other important aspects they may serve to elucidate mineral relationships and crystallization trends within these complex bodies. Furthermore, certain systematic patterns of mineral zoning described in this paper should be of practical aid to prospecting and mining operations in this district.

D. PREVIOUS WORK

The first significant detailed mapping in and around the pegmatite region began in 1927 when the "Erongo Tin Fields" were investigated by Haughton, Frommurze and Gevers. In 1929 Gevers and Frommurze published the first account of the tin-bearing pegmatites. This work, supplemented by that of Schwellnus and Rousseau, was finally assembled into two geological maps (Sheet 71, Omaruru, 1939 and Sheet 72, Karibib, 1942).

The description accompanying the Karibib sheet reports the occurrence of lithium minerals such as amblygonite, lithia mica, and zinnwalidite at several localities.

After extending the mapping west- and southwards, Gevers in 1934 dealt with igneous rocks on a regional basis and allocated the economically important pegmatites to certain types of granite intrusive into the meta-sediments of the Damara System.

In 1932 De Kock made the first detailed study of lithium-bearing pegmatites of the Karibib District (Rubicon, Helicon and Karlsbrunn). He observed the occurrence of beryl in these pegmatites as well as other less common lithium minerals, e.g. cookeite, zinnwaldite and rubellite, and considered lepidolite always to be a replacement product of feldspar and, to a very slight degree, of topaz. In 1944 Nel published the results of a detailed mineralogical investigation of pollucite from Helicon, followed in 1946 by detailed accounts of petalite and amblygonite from Karlsbrunn.

The zonal arrangement of minerals in pegmatites was briefly referred to by Gevers and Frommurze in 1929. The systematic arrangement of zones in North American pegmatites, as well as their theoretical implications, were fully reported in 1949 by Cameron et al. Cameron applied these concepts to some South West African pegmatites in 1955.

In 1961 Roering showed that a secretion - diffusion origin was not tenable for the complex pegmatites of the Karibib area and that tensional openings provided favourable loci for pegmatite emplacement. The most recent contribution has come from Smith (1962). He is of the opinion that the pegmatites were intimately related to the Damara orogeny and associated processes of metamorphism, granitization and mobilization. The pegmatite liquid is considered to have been a rather volatile fraction of mobilized magmatic material intruded into tensional zones.

The Geochronology Division of the Bernard Price Institute, in conjunction with the Council for Scientific and Industrial Research, has been engaged in a program of age determinations, mainly of pegmatite minerals from the Damara System (Burger, Nicolaysen and Rethemeyer, manuscript in preparation).

GEOLOGICAL SETTING

A. STRATIGRAPHY

The pegmatites under consideration all occur in rocks of the Damara System. The stratigraphic succession in Western Damaraland, according to Smith (1962), is as follows:-

	Stratigraphic Unit		Approximate Thickness (feet)
DAMARA SYSTEM	KHOMAS SCHIST SERIES		+ 10,000
	UPPER MARBLE SERIES		0 - 1,800
	CHUOS TILLITE		0 - 200
	LOWER MARBLE SERIES		0 - 600
	QUARTZITE SERIES	(KHAN FACIES	0 - 3,500
		(CHUOS FACIES	0 - 10,000
---------- UNCONFORMITY ----------			
ABBABIS SYSTEM			

B. LITHOLOGY

(a) Quartzite Series

The Chuos Facies consists mainly of red, often felspathic quartzites. Argillaceous and conglomeratic bands are locally developed. With metamorphism, micaceous and/or sillimanitic quartzites are formed. A basal conglomerate is occasionally present.

Grey-green, well-bedded calc-granulites with locally intercalated biotite schists and felspathic quartzite characterize the Khan Facies.

(b) Lower Marble Series (Not developed in the Karibib District)

The predominating rocks are white crystalline marbles with intercalations of biotite schist and quartzite. Within the latter, pebble horizons have a limited local distribution. At the base, amphibole-biotite schist is sporadically developed.

(c) Chuos Tillite

This is represented by a glacial boulder bed with granulitic schistose matrix, in places associated with thinly laminated biotite-schists.

(d) Upper Marble Series

This is composed mainly of massive blue and white dolomitic marbles with abundant chert bands. Calc-silicates are developed locally. As in the Lower Marble Series, amphibole-biotite schist may sometimes be found at the base.

(e) Khomas Schist Series

This is represented by thick groups of well foliated biotite schists alternating with biotite-quartz schists. Cordierite, garnet, andalusite, staurolite, actinolite, hornblende and sillimanite are often developed.

(f) Metamorphic and Igneous Rock Types

Apart from the normal meta-sediments described above, there occur various migmatites, gneisses and granites, mostly characteristic of their own stratigraphical environment. Acid red quartzo-felspathic granites and gneisses are developed mainly in the basal Quartzite Series and, therefore, outcrop mostly in the cores of anticlinal and elongated domical structures. More widespread biotite gneisses and granites, often porphyritic, on the other hand, have been generated within the Khomas Schists, filling synclines or elongated basins. South and southwest of Karibib the latter also include quartz diorites.

Later intrusive granites, either rich in biotite or deficient in this mineral, also occur, but are of limited size and restricted distribution. According to Smith (1962), the lithium- and beryllium-bearing pegmatites are associated with such bodies. Age determinations on uranium and thorium minerals, as well as lepidolite, have yielded values around 510 million years. (Nicolaysen, personal communication).

C. STRUCTURE

The Damara rocks are folded along axes dominantly trending N.E. - S.W. to form, in the main, a pattern of elongated basins and domes. Locally, areas of considerably greater structural complexity are to be found. Isoclinal folding, as well as deformation of pre-existing axial planes, are common. It is believed that in Western Damaraland an earlier phase of deformation produced N.W.-trending folds which were subjected to later more powerful stresses producing the dominant N.E. fold trend.

DESCRIPTION OF THE VARIOUS PEGMATITES

A. GENERAL STATEMENT

The lithium-bearing pegmatites are frequently situated within larger bodies of pegmatitic granite occurring as bosses, dykes and irregular masses. The latter consist essentially of a matrix of albite-quartz-muscovite containing large, often "giant", crystals of perthite or sometimes of graphic granite. The economically mineralised portions possibly represent volatile-rich fractions from these masses, enriched in silica, alumina, alkali metals, and other elements such as beryllium, columbium, tantalum and bismuth.

In this paper emphasis is placed on the economic and immediately adjacent zones. Through quarrying operations and, in some instances, underground development, these are best exposed.

B. THE RUBICON AREA

(a) The Main Ore-Body

(i) Locality

The Rubicon pegmatites are situated about fourteen miles S.E. of Karibib on the farm Okongava Ost. The main body, forming a prominent ridge, occurs at the base of a larger mass of late-tectonic coarse-grained pegmatitic granite. While along its footwall the basal pegmatite is intrusive into quartz diorite, in the hanging the upper mineralized zones grade into pegmatitic granite of progressively diminishing coarseness, the northern boundary of which is obscured by surface deposits (map, fig. 1).

(ii) Structure

The main ore-bodies are contained within an interrupted zone of lithium and beryllium mineralization stretching for a total length of approximately 3,200 feet in a N.W. - S.E. direction. The eastern section of this zone is the richest and has been quarried over a continuous strike length of 1,100 feet. Here the average thickness of the economically important zone is 100 - 150 feet (maps, fig. 1 and 2).

In detail the Rubicon ore-body is seen to have an "anticlinal" configuration caused by the upward coalescence of lithium-bearing zones occurring symmetrically about two quartzose core zones (section, fig. 2). The higher portion forms the main Rubicon ore-body, with a central quartz-rich core zone, while the northern "limb", with a less thick quartz core, provides subsidiary ore (fig. 2). From a central point in the pegmatite the "anticline" plunges at a low angle to the west and more steeply to the east. The dip of the main southern "limb" is 65° N.E. The hanging wall ore-body begins with a fairly steep dip where it coalesces with the former, but flattens with depth. This feature was particularly noticeable in the westernmost quarry (now mined out and waste filled) where a huge flat petalite zone rested on the quartz core, and which, in turn, was itself overlain by a flat-lying beryl zone. Here the dip is approximately 20° N.E.

(iii) Zoning of the Main Ore-Body

1. Outer Zones adjacent to the Economically Mineralized Zones.

The only good exposure of the pegmatite contact with the quartz-dioritic wall-rock is along its southern margin within the adit driven across the entire ore-body (fig. 1). Here a finer-grained <u>border zone</u>, not more than six inches thick, is made up essentially of perthite, quartz, and garnet, probably spessartite. The perthites are mostly $\frac{1}{4}$ - $\frac{1}{2}$ inch in size; locally larger crystals ($1\frac{1}{2}$ - 2 inches) are characteristically oriented with their longer axes perpendicular to the contact. This zone is followed inwards by another, <u>the wall zone</u>, variable in thickness, but generally only a few inches to two feet wide, consisting of albite, quartz, muscovite and garnet. The latter three minerals show a tendency to occur together within a more albite-rich matrix. A still higher degree of separation may produce distinct crescentic and arcuate banding, in which garnet, in particular, is enriched.

The bulk of the material making up the pegmatite adjacent to the interior economically mineralized zones can be characterised as albite-perthite-quartz-muscovite rock, in which microcline-perthite crystals, varying in size from several feet down to a few inches in diameter, lie in a groundmass of albite-quartz-muscovite of $\frac{1}{4}$ - 1 inch grain-size. The proportion of the two major constituents, perthite and albite, varies. On surface the microcline is flesh-coloured, while fresh underground specimens are white. Occasionally the perthite reveals a graphic-granite texture with quartz. The often highly idiomorphic perthite crystals are found in various stages of replacement by albite, quartz and muscovite (fig. 3). The amount of perthitic plagioclase varies from specimen to specimen, and this can be attributed directly to the replacement action of albite. If the albite were purely of exsolution origin it would be expected that the amount of albite would be relatively constant and not vary widely in a single crystal of microcline perthite. X-ray and universal stage determinations showed the An- content of the groundmass albite to be low, viz. 3 - 7%.

Black schorl tourmaline occurs as an accessory in this zone. Small branching veinlets cutting into microcline perthite, together with the corrosive habit of groundmass albite towards perthite, indicate that the latter largely crystallised before the groundmass constituents.

Large irregular masses of banded albite-rich rock within this zone cannot be regarded as forming a distinct separate zone, since they are intermittent and the banding is often at a large angle to the pegmatite contact. Thin layers, generally not exceeding $\frac{1}{4}$ inch of quartz and muscovite, the latter sometimes replaced by biotite or blue tourmaline, are separated by wider layers of sugary albite. Their presence poses a problem. Are they fragments of early crystallized material scattered within the pegmatite magma, or were they formed by replacement within the albite-perthite-quartz-muscovite zone? Alternatively, were locally varying physico-chemical factors within the crystallizing zone responsible, e.g. sudden local release of pressure with consequent rapid crystallization?

Certain variations in this zone are not recorded on the map (fig. 2). At the eastern end of the pegmatite, for example, local patches of quartz-muscovite or quartz-albite rock, are developed adjacent to the economic zones.

2. Perthite Zone

On the hangingwall side of the economically mineralized zone in the eastern part of the pegmatite there is a unit of pure, coarse perthite with individual crystals measuring 10 x 4 feet. Eastwards and westwards these crystals come to lie in an albite-quartz-muscovite matrix and the rock becomes identical with that already described.

3. Beryl Zone

In general, this occurs as a distinct unit at the contact between the lithium ore zones and enclosing albite-perthite-quartz-muscovite rock (fig. 2). It is best developed along the southern footwall margin of the lepidolite-bearing zones where it has an average thickness of 7 feet. The western half of the beryl footwall zone is apparently richer in beryl than the eastern. The uppermost hangingwall beryl zone has an average thickness of only 4 feet and is economically less important than the footwall zone.

When examined in detail the comparatively narrow beryl zone is complex due to the incorporation of minerals from adjacent zones. Generally, the mineral assemblage is characterised by cleavelandite-muscovite-quartz-beryl. Frondelite, $(MnF_2)_4(OH)_5(PO_4)_3$, (identification confirmed by X-ray, X-ray fluorescence and wet chemical methods) occurs as an accessory constituent and, on weathering, produces black manganese oxide stains which impart a useful diagnostic criterion to this zone.

The outer zone of albite-perthite-quartz-muscovite rock shows distinctive gradational changes towards the beryl zone. A characteristic feature of the transition is the appearance of cleavelandite. Small beryl crystals, 1 - 1½ inches in diameter and pale greenish or white in colour, also appear in the quartz-muscovite phase of the rock. Nucleation textures are almost the rule, a core or nucleus of perthite being surrounded by a rim, of varying thickness, of albite (generally cleavelandite) and subordinate quartz. The albite reveals spectacular corrosive relationships with the perthite and is followed by a rim of muscovite and quartz, giving the rock a rosette-like appearance (fig. 4). The perthite crystals appear to have acted as crystallization muclei for the albite, quartz and muscovite.

In the beryl zone itself cleavelandite dominates over all other constituents. Muscovite, also a major constituent, has a propensity for forming reniform nests, mostly ± 1 foot in diameter, which frequently develop radiating spines, approximately 3 - 5 inches in length. These spines project into the surrounding rock, mainly cleavelandite, and frequently have their tips made up of pink lepidolite.

10/...

Quartz is a subordinate constituent, generally occurring intergrown with muscovite.

Beryl, the main economic mineral of this zone, occurs in crystals generally 3 - 18 inches in diameter, though lengths of up to 30 inches have been observed. The colour is variable, being either pink, orange or green. Often only sparsely distributed, locally large, enriched pockets are developed. The crystal size appears to increase inwards towards the lithium-rich zones. In general the beryl tends to develop good crystal faces. A basal type of fracturing is sometimes found in which the fractures are "healed" by albite.

With the approach of the lithium-rich zones the mineral associations become complex. Thus, beryl has been found entirely surrounded by lepidolite-albite rock close to the contact. This suggests that the lepidolite-albite rock may have a replacement relationship to other minerals of the beryl zone. Petalite logs, sparsely scattered along the southern contact of the lepidolite zone, project into the beryl zone and continue into the lepidolite-rich zone itself. Either the logs crystallized before the beryl and lepidolite zones were formed (highly improbable if one envisages the pegmatite as crystallizing from the walls inwards in a systematic sequence), or the formation of the beryl zone was followed by the crystallization of lithium minerals (petalite first) which replaced parts of the beryl zone. For some physio-chemical reason (e.g. water vapour pressure, or the composition of the residual fraction reaching a critical state) petalite did not long remain a stable phase during crystallization. In its stead lepidolite and albite became the stable phases in the new environment, these minerals revealing marked corrosive relationships with petalite.

It would appear that the formation of the beryl zone occurred at a critical period in the pegmatite system, marking the change from bulk crystallization of essentially granitic components (albite-perthite-quartz-muscovite zone) to the crystallization of lithium-bearing components (lepidolite and petalite with their associated minerals).

4. Lithium-rich Ore Zones

These are treated as one unit in spite of the fact that, in the hangingwall of the core zone, petalite is the main lithium mineral occurring with subordinate amblygonite, while, in the footwall, lepidolite is the major lithium mineral (section, fig. 2). Viewed as zones of lithium mineralization only, the latter is symmetrically disposed

11/...

about the quartzose core zone, between the quartzose zone and the beryl zone. There are, however, distinct paragenetical differences in the zones so that they are best described separately.

(a) Petalite Zone

The exact boundary of this zone with others is irregular and mostly difficult to define. This is due to mineral mixing of the zones near their contacts and also to the fact that the core zone is not pure quartz but mixed with other phases (e.g. petalite, lepidolite, albite). The thickness is variable, averaging about 4 - 6 feet. Locally it swells to 12 feet, and in the extreme east thicknesses of 18 - 20 feet are approached. The thickness of this zone is greatly exaggerated in Fig. 2.

The composition of the zone is somewhat variable, ranging from massive, pure petalite, found in large quantity, to petalite mixed with albite, lepidolite, amblygonite, columbite and quartz.

Petalite usually occurs in platy crystals of variable size. Crystals up to 6 x 2 feet in size have been measured. The colour is generally white, but locally pink tones are developed where alteration is apparent. A drusy vug within the petalite zone, exposed in underground workings, was surrounded by a pink clay mineral (hectorite), pseudomorphic after petalite, which strongly suggests that the alteration is hydrothermal and not due to weathering.

Sugary albite and lepidolite are frequently encountered. They may occur independently or together, but invariably both reveal the same textural relationships to petalite. They may form the matrix of petalite crystals or take the form of pinching and swelling veins. The latter are dominantly parallel to the main petalite cleavage, but here and there they are also cross-cutting. These relationships indicate that part of the albite and lepidolite must certainly have crystallized after petalite. Quartz is subordinate in this assemblage. Amblygonite is an accessory, occurring as rounded masses, generally less than 18 inches in diameter. Columbite-tantalite also occurs in minor amounts. A crystal 3 x 2 inches has been observed in situ within petalite.

Petalite is also found in the footwall of the lepidolite zone where it developes as a discontinuous unit (fig. 1). The adjacent lepidolite-albite phase shows very clear corrosive contacts with the petalite, a fact which makes it desirable to know quantitatively how much lepidolite might have been derived from replacement of petalite.

This feature is particularly striking where lepidolite-albite entirely surrounds the petalite and where veins of the former penetrate the latter. Veining tends to be cleavage controlled, but in detail the individual veins vary greatly in width and shape and invariably can be traced back to their source in the matrix.

(b) Lepidolite Zone

The maps (figs. 1 and 2) show differentiation of the lepidolite-bearing unit into two zones. That immediately adjacent to the quartzose core is of very much higher grade and has yielded large quantities of usable ore, while the outer, underlying zone is much more diluted with admixed minerals, mainly albite. There is much variation in the proportions of lepidolite and fine-grained albite. From almost pure lepidolite, present in bodies of considerable size in the high-grade zone, there exist all transitions to a rock in the low-grade zone, composed mostly of sugary albite speckled with only minor amounts of lepidolite.

The dilution of lepidolite by albite takes place in several ways. The most common is a completely even distribution of one phase in the other. Other varieties are well-banded, showing albite-rich layers alternating with lepidolite-rich layers. Distinct veining of lepidolite by albite is also encountered. Less common are cross cutting veinlets of quartz and cleavelandite. In these veinlets crystals of white beryl $\frac{1}{4}$ - $\frac{1}{2}$ inch in diameter can sometimes be found. Near the core-zone criss-crossing cleavelandite veinlets can be traced back to a source in the core.

It is difficult to establish the genetical relationship of sugary albite to lepidolite in these rocks. Even distribution might indicate simultaneous precipitation, or there might have been effective permeation of one phase by the other. Veining of purer lepidolite masses by sugary albite (with varying concentrations of admixed lepidolite) indicates the albite, in these circumstances, to be later. Locally veining may be so heavy as to produce a breccia of purer lepidolite masses lying in albite-diluted material.

A rather common feature is the presence of rounded clots of extremely fine-grained pure albite in which individual grains can be distinguished microscopically only. In size the clots vary from $\frac{1}{2}$ - 3 inches in diameter, and locally may impart a "conglomeratic" appearance to the rock. Their rounded nature, as well as their ultra-fine-grained character, must have some significance. Are they a

13/...

result of a sudden release of pressure? They could have been isolated spots in the crystallizing mush where a sudden pressure release combined with supersaturation of albite, allowed the rapid, and almost in situ, precipitation of albite.

Quartz occurs either as grains and blobs distributed fairly homogeneously through the lepidolite-albite rock or, more commonly, as scattered irregular masses up to 1 - 2 feet in size. Cleavelandite is frequent along the margins of such quartz bodies, sometimes associated with crystals of white beryl (1 - 2 inch diameter), blue tourmaline, and/or amblygonite. Amblygonite is scattered throughout the lepidolite zone, but in smaller amounts than in the petalite zone. It occurs in oval bodies up to 2 - 3 feet in length and 18 inches wide. One pocket found near the base of the low-grade lepidolite zone yielded 5 - 6 tons of amblygonite.

The mineral association of the lepidolite zone, therefore, is lepidolite-albite-quartz-amblygonite-petalite. The latter may be residual from a replaced petalite zone.

5. The Core Zone

Only in the northern subsidiary hangingwall ore-body is the core zone developed as pure massive quartz. In the main, southern ore-body the predominating quartz is mixed with lesser amounts of lepidolite, albite, petalite and amblygonite. A little white beryl has also been observed. The purer albite aggregates are cleavelandite.

The complexity of this zone can be ascribed to a mixing of the final quartz fraction with the adjacent lepidolite-albite and petalite-rich zones. In the Rubicon pegmatite the final highly siliceous fluid was apparently less voluminous than in many other pegmatites of this region, or, owing to its great size, more widely and, therefore, more diffusely distributed.

(b) The Hangingwall Ore-Body

For the structural position of this subsidiary northern ore-body reference should be made to the initial account and to Fig. 2. Its mineral zoning is essentially a replica of the main ore-body, except for the development of a milky-white pure quartz core. As exposed in the workings, the thickness of the latter varies from a few to twenty feet.

14/...

Lithium mineralization is developed both above and below this shallow dipping core. However, all zones are noticeably erratic, pinching and swelling unpredictably. In general, massive petalite overlies the quartz core and occurs together with minor albite-lepidolite, quartz and muscovite. Occasionally native bismuth, with its various oxidation products, is found close to the quartz-petalite contact. The lithium-bearing zone underlying the quartz core consists of massive petalite only in a few limited exposures in the western part of the mineralized area; elsewhere it is represented mainly by lepidolite-albite rock, locally also containing petalite. The ratio of lepidolite to albite is very variable; in general, the latter is more abundant than in the main ore-body.

Locally the quartz-core and ore zones may pinch out together or independently, so that the upper petalite may come to rest directly on the lower lepidolite-albite rock. Along the contact of the petalite zone with the overlying albite-perthite-quartz-muscovite zone, beryl is found locally (fig. 2). In the westernmost quarry, beryl was enriched and an economic zone similar to that of the footwall beryl zone of the main ore-body was developed, the mineral assemblage being cleavelandite-muscovite-quartz-beryl. At some localities, beryl has been found at the footwall contact of the lepidolite-albite and the albite-perthite-quartz-muscovite pegmatite zones (fig. 2). At one place in the "crest" of the anticline, where this footwall beryl zone swings sharply over in the core of the structure near the centre of the pegmatite, beryl was very much enriched (fig. 1 - extreme western beryl zone shown on map).

(c) Other Ore-Bodies

Sporadic lithium and beryllium mineralization occurs over a strike length of 2,100 feet within the northwestward extension of the main Rubicon pegmatite. Similar ores are also found over a distance of 800 feet within a parallel pegmatite some 700 feet to the south of the main ore-body. These mineralized bodies are essentially similar and can be characterized as having outer pegmatitic phases of albite-perthite-quartz-muscovite and inner core zones with a highly irregular distribution of lepidolite, petalite, sugary albite, amblygonite, and quartz. Locally different minerals dominate. As a whole, the ores must be regarded as non-fractionated Li-ore zones around a quartz core. The inner core zones are of variable thickness, being generally about 6 - 15 feet wide, but locally swelling out to 30 feet, and in places pinching out altogether. A 2 - 3 feet wide beryl zone characterised by cleavelandite, muscovite, quartz, beryl and columbite-tantalite, is usually developed at the contact of the two units.

The basic pattern, therefore, is essentially similar to that of the main Rubicon ore-body, except for the non-fractionated core zone. Given a longer cooling time these narrow dike-like bodies might possibly have segregated into lithium ores surrounding a quartz-rich core.

(d) Summary of Zonal Structure

The ore-bodies, therefore, reveal a symmetrical pattern which can be idealized in the following succession of zones:-

(i) outer pegmatite zone: albite-perthite-quartz-muscovite

(ii) beryl zone: cleavelandite-muscovite-quartz-beryl-frondelite

(iii) lithium ore zones: in the hangingwall, petalite-rich; in the footwall, lepidolite-rich

(iv) quartz-rich core zone:

The reason for the virtual restriction of massive petalite to the hangingwall, and lepidolite to the footwall, of the core zone is not clear, unless it is assumed that petalite crystallized first, and the volatiles collected in the residual system until conditions were reached when hydrous silicates crystallized which were themselves corrosive to the petalite. This residual system was probably trapped below the petalite zone (e.g. "hooded" zone of the North American investigators). Helicon II, not described in this paper, shows a similar feature. Here the core zone at one locality consists of massive petalite followed down dip by a lepidolite-rich zone.

C. THE HELICON I AREA

(a) Locality

This pegmatite is located approximately 13 miles ESE. of Karibib on the noreastern corner of the farm Okongava Ost.

(b) Structure

The ore body has a simple structure consisting of an elongated lens which strikes east-west and can be followed for a distance of 1,300 feet. It dips 60 - 70° to the north. Where worked the average width of pegmatite is 200 feet. Banded biotite-quartz schist, alternating with marble layers, makes up the surrounding wall-rock. These formations strike E-W and dip to the south at angles of 45° - 55°. Flattening of the dip of the quartz core and the lepidolite ore-bodies on the northwestern wall of the main quarry suggests that the pegmatite "roofed over", i.e. changed upwards from a steeply dipping body to a flatter-lying one above the present level of erosion.

(c) Zoning of the Ore-Body

Zoning is described from outer zones inwards towards the quartz core (see fig. 5).

(i) Albite-Quartz-Muscovite (Perthite) Zone

Data from this zone were not gathered from continuous outcrops, but from various cuttings and prospect pits scattered about the main quarry. An underground adit suggests that it can be regarded as a single unit, but showing irregular small-scale variations.

The essential rock-type is albite-quartz-muscovite. Albite is very commonly of cleavelanditic type which tends to occur independently, while quartz and muscovite are intimately associated. Locally quartz-muscovite intergrowths reveal a characteristic "conglomeratic" type of texture, with $\frac{1}{2}$ - $1\frac{1}{2}$ inch rounded quartz nodules lying in a finer-grained matrix of muscovite and quartz. Such masses reach several feet in size, but are not common. Near the mineralized zone rounded aggregates (1 - 3 feet in diameter), rich in muscovite, may be developed. These have a core of stellate and sheet mica, with subordinate quartz surrounded by a zone of cleavelandite, several inches in thickness. The muscovite of the core often projects into the cleavelandite. The latter, in turn, is surrounded by muscovite-quartz aggregates. Such "rosette" structures are similar to those described from Rubicon where the nucleus, however, is perthite. In both pegmatites, these textures are developed close to the edge of the lithium-bearing zone. Lobate and arc-like masses of quartz and muscovite, concentrated into distinct bands, are found in the same position. The muscovite is frequently stained black by oxidation of a manganese-bearing mineral, such as frondelite which has not as yet been found in situ.

Only once was perthite found in situ, in the form of crystals 1 - 2 feet long and occurring as "phenocrysts" in a finer-grained ($\frac{1}{4}$ - $\frac{3}{4}$ inch average grain size) matrix of albite-quartz-muscovite. More numerous fragments, however, were seen on dumps derived from the albite-quartz-muscovite assemblage. In contrast to Rubicon, this pegmatite is noticeably deficient in perthite. This might have been due to a more effective replacement by albite, or conditions in the pegmatite system might not have been favourable to the formation of perthite, which was, instead, incorporated in the muscovite of the outer zone and in the lepidolite of the inner zone. Albite, the major constituent, is evenly distributed throughout the zone and is hardly ever intergrown with other phases. Muscovite-albite intergrowths are absent. Very rarely quartz and albite are found together, the quartz tending to occur as rounded bodies in an albite matrix.

Beryl occurs as a rather rare accessory with a sporadic and uncontrolled distribution over the whole zone. Crystals up to 4 inches in diameter and 6 inches in length have been found. Locally, a bluish tourmaline also constitutes an accessory. It tends to occur as fine-grained nests or sheaves up to 2 inches and more in size. Isolated grains, $\frac{1}{4}$ - $\frac{1}{8}$ inch in diameter, are developed sporadically. Columbite is found as a rare constituent of the zone, occurring as small plates not more than 2 - 3 inches in length.

(ii) Lepidolite Zone

At maximum development, the lepidolite-bearing zone attains a thickness of 70 - 80 feet and has been followed downwards for vertical distances of 60 feet and more. It does not consist entirely of extractable ore due to varying degrees of dilution, mainly by albite. Eastwards, where the quartz core widens considerably, there is a noticeable increase in the amount of sugary albite accompanying the fine-grained lepidolite (fig. 5). The zone virtually pinches out in this direction, only small lens-like bodies up to 10 feet in width of sugary albite rock with minor lepidolite occurring adjacent to the quartz core. The high-grade ore occurs in the west. If any structural trend is present, the ore zones may possibly plunge westwards in the same way as the quartz core.

The exact contact of this zone with the quartz core is virtually impossible to depict on a map, large rounded masses of grey and purple lithium mica lying marginally in the quartz core as irregular blobs. The latter are invariably bordered by a 1 - 3 foot rim of cleavelandite which also veins and brecciates the lepidolite masses.

Beryl is intimately associated with this cleavelandite. The contact of the lepidolite zone and the albite-quartz-muscovite-(perthite) unit is less irregular, but also transitional over a distance of 1 - 2 feet.

In detail, the zone is highly complex, due to variations in the relative proportions of lepidolite, sugary albite and quartz. Rock-types vary from unusually pure massive, very fine-grained lepidolite to sugary albite with only sparsely distributed lepidolite flakes. High-grade ore occurs in massive lenses and more irregular blocks up to several feet in diameter. These are surrounded by and veined by sugary albite with varying amounts of lepidolite (fig. 6). Sugary albite becomes less important towards the quartz core where cleavelandite is the common type. The latter may also occur away from the core but is then also generally associated with quartz.

Quartz is either developed as evenly disseminated grains in the different rock-types or as larger segragated masses, which are irregular in shape and may vary in size from a few inches to several feet. Such quartz masses are not common, but show some very interesting mineral associations:

(i) columbite-tantalite in crystals up to 3 inches in dimension

(ii) whitish beryl crystals, generally small and never much greater than 3 inches in diameter

(iii) lumps of amblygonite generally 2 - 4 inches in size, but sometimes larger

(iv) blue and pink tourmaline generally $\frac{1}{4}$ - $\frac{1}{2}$ inch in diameter and of variable length.

Almost invariably these minerals are found at the margins of quartz bodies, usually together with cleavelandite. This feature conforms with the overall pattern of pegmatite mineralization of this region in which amblygonite, beryl and columbite-tantalite are found in economic quantities mostly on the main quartz-core margin. While quartz blobs within the lepidolite ore may locally contain these minerals in excess of, or at least equal to, the amount of quartz (on two dimensional exposures), at the normal quartz core margin they form only a very small proportion of the total core rock.

Variations in rock-type are numerous. In addition to high-grade, practically pure lepidolite, some types are speckled with small concentrations of albite $\frac{1}{8}$ inch or less in diameter. Larger aggregates also occur, such as the rounded inclusions $\frac{1}{4}$ - 3 inches in diameter of microgranular albite, found at Rubicon. Stellate forms of albite are also found the "stars", not exceeding $\frac{1}{2}$ inch in diameter. A curious feature is the occurrence of fine-grained albite pseudomorphic after larger grains $1\frac{1}{2}$ inches wide and 9 inches long. These masses appear to have fairly regular crystal outlines and, yet, are composed of fine-grained albite. This is probably a replacement feature of some pre-existing unknown phase.

The time relationships of sugary albite to lepidolite can be studied well at Helicon. Banded aggregates of alternating lepidolite-rich and albite-rich layers are common and often entirely surrounded by sugary albite. The banding bears no relationship to the dip of the pegmatite and is sometimes folded, thus suggesting movement within this zone before complete consolidation. These folded structures often grade into a phase richer in sugary albite which completely surrounds them.

Some of the structures are highly confusing (figs. 7 and 8). The undulating vein of lepidolite, with subordinate quartz and albite, lying in an albite-rich rock with scattered irregular masses of greater lepidolite concentration (fig. 7) may be later than the albite. Rounded involute and convolute structures (fig. 8) suggest some form of rotation and distortion of plastic material during the period preceeding complete consolidation of the lepidolite zone. Here again the relatively late age of sugary albite is quite clear from the veining and brecciation of the lepidolite-rich masses.

In the eastern part of the pegmatite the lepidolite ore becomes noticeably albitic. Sugary albite, weakly speckled with lepidolite flakes, eventually dominates. Streaks, bands, and lumps of lepidolite-rich rock progressively decrease in abundance. Blobs of quartz-cleavelandite continue to be present in the albite-rich rock.

Regarding mineral sequence it would appear that in the rhythmically banded and even-textured rocks, containing both components, lepidolite and albite are contemporaneous. In isolated instances, e.g. the vein of Fig. 7, lepidolite may be later. But far more commonly, albite is later, as shown by the frequent exposures in which albite definitely cross-cuts, brecciates and corrodes the lepidolite-rich masses. On a small scale, this is demonstrated by veins of albite traversing lepidolite. On a larger scale, the whole lepidolite ore may appear as a brecciated rock in which purer lepidolite masses lie in albite. The contacts between the rock-types vary from sharp to transitional. It should be mentioned that a small local patch of petalite was encountered in this zone during mining operations.

(iii) Footwall Beryl Zone

Beryl is found on the footwall (south) side of the quartz core. It is generally of whitish colour and is associated with cleavelandite. The lepidolite ore changes in nature close to the quartz core. As already described, large masses up to several feet in diameter occur in the marginal portion in the quartz core. They are generally bordered by an irregular rim of cleavelandite which tends to vein and brecciate the lepidolite. This cleavelandite often has a radiating texture, splaying out from the lepidolite and ending in abruptly rounded surfaces which are convex to the quartz core. Beryl is found within this cleavelandite as well as in that surrounding quartz blobs within the adjacent lepidolite. Generally, some crystal faces are developed; occasionally perfect hexagonal crystals are found. The size is variable. Diameters of 1 - 2 feet were observed. Smaller individuals, 3 - 5 inches in diameter by 5 - 8 inches in length, are more common.

This zone can, therefore, be characterised as cleavelandite-beryl-bearing, the cleavelandite certainly post-dating the massive lepidolite.

(iv) Hangingwall Mineralized Zones

Immediately overlying the quartz core there occurs an interrupted unit of mineralization which is differentiated down dip into three distinctive zones:

(a) amblygonite zone on the core margin followed downwards by:

(b) a "barren zone" passing in depth into:

(c) a beryl-columbite zone.

Lying on the core margin, at the same elevation as the amblygonite zone, is a pollucite unit.

1. Amblygonite Zone

This zone had virtually been mined out at the time the pegmatite was mapped. Only at one locality was there still ore in situ. Various indications of the characteristics of the mineralization could be gained from the sidewalls of the workings.

The amblygonite is associated with quartz, sugary albite, cleavelandite and lepidolite. The zone extends over a horizontal distance of 500 - 600 feet. Near surface it is 7 - 8 feet wide, but thins in depth before becoming barren. It has been mined to depths of 30 - 50 feet. The lower limit is almost horizontal in the east, but from the centre westwards there is a tendency for the ore to plunge to the west. On the southern side of the amblygonite zone large rounded and lens-like lumps of amblygonite were found embedded in the margin of the quartz core. The size of individuals varied from 6 - 9 inches to 5 feet in diameter.

The main constituents of this zone are sugary albite, cleavelandite and quartz, the distribution of which is irregular and complex. Sugary albite may occur in large masses continuous over tens of feet; elsewhere only in small isolated patches. It mostly has a pale pink colour due to small amounts of evenly dispersed lepidolite. Less often, lepidolite is concentrated into nests several inches in size. Quartz, is present in small amounts and invariably associates itself with the lepidolite. The cleavelandite is mostly found adjacent to the quartz core, but may be lacking altogether in this position. It also occurs in the overlying albite-quartz-muscovite rock from which it persists downwards into the amblygonite-bearing zone, where it is commonly associated with quartz. Cleavelandite has a "conglomeratic" texture with rounded quartz blobs ($\frac{1}{4}$ - $\frac{3}{4}$ inch average size) lying in a cleavelandite matrix. It is impossible to state with certainty which of the constituent minerals are inherent to this zone and which might have formed by later replacement.

Columbite and beryl may appear on the core margin of this zone, but are uncommon constituents.

2. Pollucite Zone

Pollucite occurs only at one locality within this pegmatite, viz. on the quartz core margin adjacent to the amblygonite zone. Judging from the workings, the total amount of ore extracted must have been several cubic yards. Since the ore is mined out completely, its relationship to the amblygonite zone is not known in detail. In the available exposures pollucite can be seen to occur only in the marginal quartz core. On broken surfaces the pollucite looks very similar to the white beryl found in the same pegmatite. It occurs as subhedral masses, commonly cut by numerous thin pink veinlets which never continue into the quartz. These veinlets consist of lepidolite and a clay mineral (Nel, 1944).

In detail the contact with the quartz is somewhat irregular and a certain amount of mixing of the two components is found. On occasions, however, the contact is sharp with a set of straight edges tending to intersect at high angles (fig. 9). Since the veining of pollucite by lepidolite indicates later formation of lepidolite, the lepidolite-albite phase may well post-date also the amblygonite. Assuming younger units to form core-wards, the sequence would be amblygonite, pollucite, lepidolite, albite.

3. Barren Zone

For 10 - 30 feet further down dip, this zone, 5 - 10 feet wide, is barren. Large masses of sugary albite, identical in mode of occurrence with that higher up, continue and contain irregularly scattered small bodies of quartz up to several inches in diameter. The most common rock type developed is the 'conglomeratic' cleavelandite-quartz mixture already described. Muscovite is also present, frequently as a matrix to rounded quartz blobs. The main minerals are, therefore, albite (mainly cleavelandite), quartz and muscovite. Again sugary albite (speckled with lepidolite) may be of later age than the normal albite-quartz-muscovite rock.

4. Beryl-Columbite-Tantalite Zone

Down dip, below the barren zone, a spectacular enrichment of beryl and columbite-tantalite is found. The zone is approximately 15 inches thick and lies directly on the quartz core contact. In most cases, both minerals are found in quartz on the cleavelandite-quartz core border. The relative proportion of the two minerals varies from place to place. The columbite crystals reach sizes of 6 - 8 inches in diameter. The beryl crystals are mostly of the same order of magnitude, but some are even larger. The felspar, intimately associated with the beryl and columbite-tantalite, is cleavelandite. In the hangingwall of the zone a sugary albite is found similar to that higher up in this zone. As a whole the zone is somewhat erratic, pinching out and swelling. Locally it is extremely rich.

23/...

The Helicon pegmatite shows several interesting features. Beryl is found directly in the core margin and not further out at the outer contact of the lithium-bearing units, as at Rubicon. Although lithium-bearing minerals tend to be symmetrically disposed about the quartz core, this zoning becomes more complex in depth, the hangingwall amblygonite zone giving way, below a barren area, to a beryl-columbite-tantalite zone. Sugary albite, with minor lepidolite, is ubiquitous in the entire hangingwall zone adjacent to the quartz core, but may post-date the other minerals in the various units. The main lithium mineralization (lepidolite-albite) is found in the footwall below the quartz core. Here it seems certain that some albite post-dates the formation of lepidolite. The assymmetry of the zoning is the most prominent feature of the pegmatites described so far.

D. THE KARLSBRUNN AREA

(a) Locality

The Karlsbrunn pegmatite is situated approximately 4 miles SSW. of the railway siding Albrechtshöhe on the main line from Windhoek to Walvis Bay.

(b) Structure

This pegmatite forms a highly irregular outcrop pattern (fig. 10). It is intrusive into dolomitic marble of the Marble Series, which contain a spectacular development of tremolite. In a north-westerly direction the pegmatite can be followed for a distance of 1,100 feet, while at right angles to this the outcrop, widths vary between 100 - 500 feet. The flat-lying quartz core forms a prominent krantz below which the ground slopes to the east.

The detailed structure of this pegmatite is extremely complex (fig. 10). There are four basic units:

(i) The Western quarries high up on the hillside, where petalite, amblygonite and beryl are mined. The Jooste beryl workings (beryl-rich zone in fig. 10) give a good idea of the attitude of the mineralization in this area. These exploit a beryl-rich zone which is 70 foot long, 8 foot wide, and dips vertically down to the maximum depth obtained (25 - 30 feet). The other pegmatite zones in this area are essentially parallel, have a N.18°W. strike, and dip steeply or vertically.

(ii) About 450 feet to the NE of the Jooste beryl quarry there occurs a more or less continuous zone of quartz, grey and pink lithium-bearing micas and sugary albite. This mixed mineralization occupies a core zone that can be traced for a distance of 120 feet and it is surrounded by an irregular zone of cleavelandite-quartz-muscovite and beryl. This, in turn, is enveloped by an albite-quartz-muscovite phase with ubiquitously scattered perthite crystals. The core zone and the western contact of the pegmatite have a N.20°W. strike and dip vertically.

(iii) The quartz core, often underlain by lepidolite, is essentially flat-lying.

(iv) To the SE. and NW. there are offshoot portions of the pegmatite, the central zones being essentially steeply dipping and made up of lepidolite, quartz, petalite, etc.

The probable structure of the entire pegmatite is shown in the section of Fig. 10. The steeply dipping western portion represents the roof zone of an otherwise flat-lying pegmatite now largely eroded away.

(c) Zoning of the Main Ore-Body

(i) The Outer Zone

This is exposed at scattered localities, mainly adjacent to the lithium-bearing ore zones. The rock is characterised by giant perthite crystals (e.g. 20 x 4 feet down to smaller individuals 1 foot x 5 inches) which lie in a matrix of albite-quartz-muscovite, the latter three minerals varying in relative proportions. As at Rubicon, the perthite crystals are frequently enveloped by radially-oriented cleavelandite to form rosette structures. Muscovite also behaves in a similar manner, growing out as radial spines from more or less evenly-spaced reniform nests on perthite surfaces. The perthite must have crystallized very early in the sequence to act as nuclei for cleavelandite and muscovite. Albite from the surrounding matrix corrodes the perthite crystals marginally and penetrates them in thin veinlets and films. The groundmass surrounding these perthite crystals shows characteristics already described from the other pegmatites. Quartz and muscovite have a habit of occurring as separate concentrations often with a "conglomeratic" texture. It is striking how these two minerals always tend to be intimately associated while albite is much more rarely intergrown with quartz. Near to the lithium-bearing zones the albite is distinctly of cleavelanditic type. It tends to occur on its own or together with quartz. With the cleavelandite in this zonal position small beryl crystals (1 inch diameter) and columbite are sometimes found.

As a generalisation, it can be said that the amount of perthite seems to increase towards the lithium-bearing zones where it may make up 30 - 40% of the rock. Further away from the lithium zones, muscovite and quartz increase while perthite decreases. Here the quartz and muscovite are very often intergrown in a manner simulating graphic granite. The quartz "pencils" are mostly rather coarse, $\frac{1}{8}$ - $\frac{1}{2}$ inch in diameter. If the K content is essentially similar throughout, then in the outer zones, due to a relatively higher partial pressure of H_2O, muscovite may represent the stable K-bearing phase, while later in the crystallization sequence microcline perthite may have become the stable phase.

Nests of bluish-green tourmaline 2 - 3 inches in diameter, form the characteristic accessory of the zone.

The Jooste Beryl Quarry is sited on a high concentration of small beryl crystals, $\frac{1}{2}$ - 1 inch in diameter, within this zone. The associated minerals are essentially the same as those already described, viz. albite-quartz-muscovite with perthite becoming prominent corewards. Beryl appears to have been enriched where perthite becomes abundant.

The outer pegmatite unit may thus be divided into two zones; an inner zone rich in microcline perthite, and an outer zone with a considerably lesser content of this mineral.

(ii) Petalite-Amblygonite Zone

This zone has mostly been extracted; visible exposures at the time of mapping were confined to the marginal portions, in which a certain amount of mixing with adjacent zones has taken place. In the southern section the petalite overlies the large, main quartz core, which appears to peter out northwards causing the petalite to lie cirectly on the lepidolite zone. In the line of section (fig. 10) a subsidiary quartz lens occurs above the petalite.

Petalite is by far the most important constituent of this zone. It occurs as large crystals up to 4 x 8 feet in size. The matrix around these crystals is highly variable and it is difficult to establish definitely what phases were present at the time of petalite formation. Locally, quartz forms the matrix, sometimes developing as large independent units up to 6 feet in length. More common is sugary albite with evenly scattered flakes of pink and grey lepidolite sometimes accompanied by quartz. Apart from forming the matrix, this material is also found as independent irregular masses and veinlets within the petalite which pinch and swell and behave in a corrosive manner (fig. 11).

Amblygonite is found fairly evenly spread throughout the whole zone. Individual masses have sizes of 4 x 2 feet and 3 x 1 feet. When occurring together with quartz, amblygonite tends to form smaller lumps only several inches in diameter. Beryl has also been extracted from this zone, but was not observed in situ. Remnants on sorting dumps are dull white. Individual crystals appear to have been fairly large. Other minerals found in this zone are columbite-tantalite, observed in petalite; a dark blue manganian apatite; and 2 - 3 inch diameter nests of bright green alkali-bearing tourmaline.

The characteristic mineral assemblage of this zone appears to be petalite-amblygonite-quartz-albite-beryl.

(iii) Lepidolite Zone

High-grade lepidolite ore is only found below the quartz core. That lying closest to the core is generally purest, being relatively free from albite dilution. It may be either mauve or grey, the two types occurring independently or mixed. If albite is present, it tends to be cleavelanditic which may vein and replace much of the lepidolite, dividing large masses into smaller ones. The remainder of the lepidolite unit tends to be more variable, due to varying degrees of albite dilution. The latter occurs in different ways: homogeneous mixtures, concentration into nests, or aggregates with a stellate texture, or bands of variable thickness. The banding is often highly complex. Sometimes it is folded. One set of bands may be completely cut off by obliquely trending sets. These structures indicate movement in a plastic or semi-consolidated state. Fig. 12 shows that banding may result not only from rhythmic precipitation of lepidolite and albite, but also by veining and replacement of lepidolite-rich masses by sugary albite extending from peculiar dome structures, to be described later.

As a result of the emplacement of these albite domes and associated brecciation and replacement of the lepidolite zone, the ore has a highly complex nature. Further diversification of the mineralogy is caused by the presence of quartz bodies of variable size which, without exception, show a marginal development of cleavelandite containing rubellite, topaz and amblygonite.

(iv) Core Margin Zone

The best example of this is found where the lower margin of the flat massive quartz core is exposed in a stream-bed. Here irregular bodies up to more than 3 foot in diameter of massive grey lepidolite occur immediately below the quartz. Their margins, usually containing albite, are locally enriched in cassiterite occurring as euhedral crystals $1/32 - \frac{1}{4}$ inch in size. Blue apatite of the same size occurs together with cassiterite. Beryl, in small $\frac{1}{2} - \frac{3}{4}$ inch crystals, is distributed in these albitic margins (fig. 13). Fragments of 5 inch diameter found on the mountain-side indicate also larger crystals to be present.

This type of mineralization along the lower quartz core margin is very local and was seen only in its southern reaches over a strike length of 40 - 50 feet. The alluvial cassiterite formerly recovered from sands lower down in the stream obviously was derived from this zone of the pegmatite.

(v) Core Zone

This consists of massive milky white quartz, containing, in places, druses with beautiful quartz crystals.

(d) <u>Development of Albite Domes</u>

The albite-rich domes found at Karlsbrunn are unique and the features exhibited by them contribute greatly to the interpretation of the complex pegmatites of the Karibib District. They occur mainly in the uppermost part of the lepidolite zone below the main massive quartz core. Where the latter peters out several also penetrate into the overlying petalite.

The salient features of the domes are:

28/...

(i) They are typically dome-shaped with broad tops and limbs varying in dip from 60° to vertical. This is interpreted as being due to upward movement of the albite-rich material. The pegmatites have not undergone any post-crystallization deformation and, therefore, the horizontal attitude of the quartz core and the overall configuration of the pegmatite are primary features. Eight major domical surfaces have been encountered with diameters of 12 - 15 feet on present exposures. Small domes, 18 - 24 inches in diameter, are also developed.

(ii) The domes never project into the main quartz core or subsidiary lens. The horizontal disposition of the quartz core has, therefore, acted as a barrier to upward movement. The domes cut through the lepidolite and petalite zones. They have also been observed to cut across the outer pegmatite phase. In the latter case, actual fragments of the albite-quartz-muscovite rock were observed in the sugary albite-rich rock of the dome. They are, therefore, late in the crystallization sequence, post-dating all other zones.

(iii) The composition of the rock is fairly uniform, and consists of fine-grained saccharoidal albite with a small amount of evenly disseminated lepidolite. Near the top of some domes the lepidolite may be concentrated into diffuse bands which are symmetrical with the dome contour (fig. 14). The average thickness of these bands is 2 inches.

Clots, streaks and stringers of lepidolite generally containing small amounts of albite, occur within the albite rock in very minor amounts. In the upper portions of the domes their dimensions are generally $\frac{1}{2}$ - $\frac{1}{4}$ inch; but at lower levels larger fragments of lepidolite have been found. These foreigh bodies represent highly modified blocks of lepidolite ore incorporated by the albite material during its upward ascent into and through the lepidolite zone. In Fig. 12 the process of brecciation and veining by albite is quite evident.

Quartz in clots up to several inches in diameter is rare within the domes. Fig. 14 represents an excellent example of such a dome showing the following structural and mineralogical arrangement downwards from the overlying quartz core (5) which marginally encloses blocks of lepidolite.

1. highly altered petalite-quartz masses in which the petalite is largely altered to clay minerals, which are enclosed in,

2. albite together with scattered lumps of massive, purple, fine-grained lepidolite veined by albite and varying in size from 5 - 6 feet down to fragments less than 1 inch across; quartz is scattered throughout the albite which is distinctly finer in grain than that of the domes and is not visibly connected with it.

3. a unit made up mainly of quartz; banding due to intercalated layers of fine-grained lepidolite-albite is quite conspicuous and conforms with the domical shape; as shown by Fig. 15 the banding is nothing like as regular and smooth as that found in the albite domes; the marked irregularities in width and continuity rather suggest replacement processes; a $1\frac{1}{2}$ - 3 inch crystal of beryl was found in one quartz band; columbite occurs as very small crystals in the lepidolite-albite bands.

4. the major portion of the dome is composed of fine- and even-grained albite, with sparsely-disseminated flakes of lepidolite, also concentrated into concentric bands of varying, mostly narrow, width.

The concentric quartz capping (3) in this particular example is by no means characteristic, being absent in most other domes. In part this may be due to incomplete exposure. The symmetrical shape of the capping suggests a genetical relationship. Volatiles escaping from the dome, possibly during its rapid crystallization, may have been charged with silica and replaced the surrounding rock. Support for such a mechanism of possibly volatile phases released from the domes, is shown in other examples by the enrichment of columbite-tantalite on the upper surfaces. The columbite-tantalite grains are of the size order $\frac{1}{2}$ - $\frac{3}{4}$ inch. They may be evenly spread over the dome surface or occur in clusters. This concentration on the upper surfaces of domes would be in keeping with the maximum concentration of volatile phases in such structures. The beryl described above may be related to a similar process.

The origin of these dome shaped structures poses a fascinating genetical problem. Some light is thrown on their origin by the features depicted in Fig. 16. Here a 2 foot diameter dome occurs in banded lepidolite-albite ore. This small dome has obviously forced its way upwards into banded lepidolite-albite rock. The fact that the latter is of different nature on either side of the dome may indicate some form of displacement. It has been noted that these banded rocks are in places not only folded, but one set of bands may be completely cut off by an obliquely trending set. Furthermore, brecciation of massive lepidolite by sugary albite is a common feature. Noteworthy, too, is the fact that the columnar albite core of the small dome has far less disseminated albite than the surrounding rock.

The domed column could represent material pushed up in a semi-consolidated plastic condition from a lower banded zone into material already more consolidated and already capable of fracturing and displacement. The domes must undoubtedly have been formed at the close of the lepidolite-albite stage. That the emplacement and crystallization of sugary albite continued beyond that of much of the lepidolite has already been described in detail from all three pegmatites. It is also known from other pegmatite areas, e.g. North Mtoko, Southern Rhodesia, that late stage crystallization and mineralization <u>after</u> the consolidation of the quartz core may be much in evidence. Of the minerals occurring in quantity this applies particularly to lepidolite and albite, as well as to beryl and columbite-tantalite.

At Karlsbrunn the final albite (+ minor lepidolite) stage is developed in particularly unique form. The domes intrude upwards. In part, this is no doubt due to the flat-lying position of the greater part of the pegmatite. Gravitational pressure of overlying, already consolidated portions of the pegmatite, including the quartz core, on underlying still liquid late-stage fractions, in itself could cause buckling and dome formation. In addition, the residual albitic fraction would be highly charged with volatiles (H_2O etc), thus lowering its specific gravity and imparting an upward migrating tendency. The pressure of the residual fraction probably increased until it equalled and then exceeded the confining pressure. Under these conditions rapid crystallization from an undercooled liquid, or a liquid saturated or super saturated with albite could take place. That "mineralizers" were still active is demonstrated by the symmetrical concentrically disposed quartz-rich cappings of some of the domes (3 in fig. 14), the occurrence of beryl and columbite-tantalite within the capping, and particularly by the widespread concentration of columbite-tantalite on dome crests.

SUMMARY

A. IDEALIZED MINERAL ZONING PATTERN

An idealised model, constructed from all three pegmatites described, exhibits the following zoned mineral combinations, from the

31/...

outer units corewards:

(i) albite-perthite-quartz-muscovite; this zone may be subdivided into two units: albite-quartz-muscovite; albite-perthite-quartz-muscovite.

(ii) cleavelandite-quartz-muscovite with accessory beryl, frondelite, and sometimes, columbite-tantalite.

(iii) lithium ore zones; these show distinct variations, but are symmetrically disposed about a quartz core; should there be a pronounced dip on the ore body petalite ores are found on the hangingwall or upper part of the lithium ores, while lepidolite ores are found below the petalite zone or on the footwall side of a quartz core; two units are generally developed:

(1) petalite-quartz-albite-amblygonite-columbite-tantalite,

(2) lepidolite-albite-quartz-amblygonite;

in this lithium ore unit a definite sequence of mineralization can be established; viz. petalite → lepidolite → albite.

(iv) cleavelandite-beryl-columbite-tantalite-cassiterite.

(v) quartzose core, either pure or mixed with adjacent mineral phases; the age relationships of the quartz core appear to be variable; its boundary against adjacent zones may be sharp and apophyses of quartz from the core may cut through the adjacent lepidolite-albite zone; elsewhere the quartz core may enclose marginally minerals of adjacent zones; the albite domes at Karlsbrunn definitely appear to have originated after the consolidation of the quartz core and complex late stage, post-core mineralization is in evidence.

B. GRADE OF ORE

The petalite at Rubicon and Karlsbrunn has an average Li_2O content of 4.6%. Pure, high-grade lepidolite may contain 4.2% Li_2O,

32/...

but the grade of ores actually mined depends largely on the admixture of diluting agents, mainly albite.

Amblygonite usually contains 7 - 8% Li_2O. Beryl from the Karibib District usually runs at 11 - 12% BeO.

****

LIST OF REFERENCES

Burger, A.J., Nicolaysen, L.O., Rethermeyer, — Paper in preparation titled: "On the Probable Early Paleozoic Age of Granitic and Metamorphic Rocks from the Damara Orogen, South West Africa".

Cameron, E.N., Jahns, R.H., McNair, A.H., Page, L.R. 1949 "Internal Structure of Granitic Pegmatites". Monograph 2. Economic Geol. Publishing Co.

Cameron, E.N. 1955 "Concepts of the Internal Structure of Granitic Pegmatites and their applications to certain Pegmatites of South West Africa". Trans. Geol. Soc. S.A. pp. 45 - 70.

De Kock, W.P. 1932 "The Lepidolite Deposits of South West Africa". Trans. Geol. Soc. S.A. pp. 97 - 114.

Frommurze, H.F., Gevers, T.W., Rossouw, P.J. 1942 "The Geology and Mineral Deposits of the Karibib Area, South West Africa". Explanation of Sheet No. 79.

Gevers, T.W., and Frommurze, H.F. 1929 "The Tin-bearing Pegmatites of the Erongo Area, South West Africa". Trans. Geol. Soc. S.A. pp. 111 - 149.

Gevers, T.W. 1934 "Untersuchungen des Grundgebirges in Westlichen Damaraland". Neues Jahrb. f. Min. u Pet.

Haughton, S.H., Frommurze, H.F., Gevers, T.W., Schwellnus, C.M. Rossouw, P.J. 1939 "The Geology and Mineral Deposits of the Omaruru Area, South West Africa". Explanation of Sheet No. 71.

Nel, H.J. 1944 "Pollucite from Karibib, South West Africa". American Mineral. pp. 443 - 451

Nel, H.J. "Petalite and Amblygonite from Karibib, South West Africa". American Min. pp. 51 - 57.

Roering C. 1961 "The Mode of Emplacement of Certain Li- and Be-bearing Pegmatites in the Karibib District, South West Africa". Economic Geology Research Unit Information Circular No. 4.

Smith, D.A.M. 1961 "The Geology of the Area around the Khan and Swakop Rivers in South West Africa". Unpublished Ph.D. thesis. University of the Witwatersrand.

Smith, D.A.M. 1962 "Metamorphism, Granitization Structure and Metamorphism between the Khan and Swakop Rivers, South West Africa". Economic Geology Research Unit Information Circular No. 8.

****