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[illegible] INVESTIGATIONS IN THE [illegible] DISTRICT, SOUTH WEST AFRICA

by

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M.Sc. (Eng.) ([illegible])

Thesis submitted for the Degree of Doctor of Philosophy in the Faculty of Engineering, University of the Witwatersrand.

NOVEMBER, 1963.

Thesis C 21647

DECLARATION

I hereby declare that the dissertation entitled "Pegmatite Investigations of the Karibib District, South West Africa" is my own work and has not been submitted as a thesis for any other degree.

C. ROERING.

October 1963.

PEGMATITE INVESTIGATIONS IN THE KARIBIB DISTRICT, SOUTH WEST AFRICA

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ABSTRACT.

Several of the more important Li - and Be - bearing pegmatites of the Karibib District have been studied in detail with regard to their mode of emplacement, internal zoning and mineralogy.

It is shown that these complex pegmatites are related to late kinematic granites of the Damara-Otavi Orogeny. A "pegmatite series" is suggested relating the complexity of pegmatites very broadly with time and space in orogenic belts. Simple pegmatites are thought to be of local secretive origin forming at a fairly early stage in the metamorphism and are related to the first stages of mobilisation of granitic material. Complex pegmatites are genetically related to late tectonic granite plutons intruded into environments of moderate to high grade metamorphism. Similar mobilised granites emplaced into higher crustal levels in the form of high level granite plutons crystallized at a relatively quicker rate with the resulting effect of wide dispersion of unusual elements in the normal silicates forming granites and the wide dispersion of fluxing agents. The notable exception to this appears to be tin mineralisation found associated with high level orogenic granites as well as anorogenic granites.

The pegmatites of the Karibib District reveal a fairly uniform zonal arrangement which is often developed in a vertical dimension as well as the horisontal. The ideal arrangement of zones is as follows:-

(a) The outer pegmatite zone of variable thickness which is essentially a very coarse-grained granite consisting of larger perthite phenocrysts lying in a matrix of albite, quarts and muscovite. The inner portions of this zone may reveal a great enrichment of perthite, so much so, that it may grade into a giant perthite zone e.g. Rubicon main ore-body; Karlsbrunn close to the Li-bearing ore zones. This outer portion of the pegmatite may also reveal a subdivision into two distinct units: an outermost zone of albite-quartz-muscovite and an inner zone of albite-perthite-quarts-muscovite.

(b) This sequence of essentially granitic crystallisation is often abruptly broken by the appearance of a zone consisting essentially of cleavelandite with minor quarts and muscovite. This zone is characterized by the appearance of numerous accessory minerals often in economic quantities, e.g. beryl, columbite-tantalite frondelite, topas and apatite. The zone is generally of the order 1 - 5 feet depending on the original size of the pegmatite and the degree of fractionation. That it is not a late replacement unit is confirmed by observations at Rubicon where corroded crystals of beryl belonging to this zone are found lying in a matrix of lepidolite and albite which is the next unit to form. The lepidolite-albite zone in fact replaces the beryl-bearing zone. The striking symmetry alone of the Rubicon body testifies to this zone preceding in crystallisation sequence the Li-ore zones.

The significant fact about this zone is that it marks a distinct break in the crystallisation history of the pegmatite, i.e. it marks the change from crystallisation of essentially granitic components to the formation of late phase constituents, viz. Li-bearing and associated minerals. It possibly marks the break from magmatic crystallisation to late-magmatic conditions when pneumatogenic and even hydrothermal processes begin to operate.

(c) The next group of minerals to form are noticeably rich in Li and are frequently associated with sugary albite. The major minerals are petalite, lepidolite and albite, while minor amounts of amblygonite also occur. There is a definite spacial relationship and time sequence in the formation of these minerals. Petalite crystallizes first and collects in the upper part of this unit generally forming a hood. Amblygonite, albite, quartz, may occur at the same time. Immediately below this petalite hood, and at a somewhat later stage, fine-grained lepidolite crystallizes together with albite and minor quartz. The final phase to form at this general stage is sugary albite which collects at the bottom of the still non-crystalline portion of the magma chamber. The sugary albite phase is able to behave diapirically and can intrude, brecciate and replace any of the previously crystallized zonal constituents. Each successive stage here can assume corrosive relationships to previously consolidated units. No assessment is made as to the amount of replacement that may take place as the criterion commonly used for such diagnosis are somewhat subjective.

During this entire process of complex diffusions and crystallisation, silica is apparently being concentrated in the residual fractions of the pegmatite magma.

(d) The next zone to form is a cleavelandite-rich rock confined to the quartz core margin. This cleavelandite is able to vein and brecciate and corrode the immediately adjacent lying lepidolite and is often associated with minerals such as beryl, columbite, tantalite, tourmaline, topaz and apatite. Amblygonite may also belong to this stage of mineralisation though in general it tends to be associated close in time with the petalite stage of mineralization.

(e) The final stage of the crystallisation sequence is the quartz core. Quartz veinlets emanating from the core have been observed to cut across adjacent lepidolite-rich and amblygonite-albite zones. Euhedral crystals of columbite and beryl at the core margin are completely surrounded by quartz. These observations may suggest that quartz, although concentrated in the centre of the dyke, probably existed in some unconsolidated state (e.g. a gel as Brotzen (1959) has suggested).

The development of a gas phase at certain stages of the pegmatites consolidation history possibly accounts for the vertical fractionation found in these pegmatites.

Finally details of the more important pegmatite minerals are given together with chemical analyses.

INTRODUCTION

Following on the earlier work of W. De Kock and T.W. 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.

The following important pegmatites were mapped in detail: Rubicon, Helicon, Karlabrunn, Brockmann's pegmatite on Albrechtshöhe, Becker's pegmatite on Otjua, Koliombo, Henckert's pegmatite on Dernburg, Van de Made's pegmatite in the Erongo Schlucht. The majority of these pegmatites lie within a radius of 20 miles from Karibib, approximately 120 miles by rail from Walvis Bay Harbour.

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).

The generation of pegmatites is a subject which has received great attention and given rise to a vast record of data as reflected by the enormous number of articles which have been published in the past and which continue to appear every year. (literature references given by Jahns, 1955).

With the somewhat limited time available the present investigation has been directed towards certain aspects of pegmatite genesis which, the author hopes, will contribute to a fuller understanding of the complex pegmatites of the Karibib District in particular, and which may also add to the knowledge of pegmatite genesis in general.

The present investigation is, therefore, concerned with the following aspects of pegmatite genesis:

(i) Are complex pegmatites a product of in situ crystallisation of pegmatite magmas emplaced into certain structurally controlled sites, or do they represent products of a secretion-diffusion origin?

(ii) If pegmatites crystallise from a magma, what can be deduced from field observations about their crystallisation history?

(iii) Can any rational statements be made about the source of such a pegmatite magma should it exist?

With regard to these aspects of pegmatite formation the author is indebted to D.A.M. Smith who has carried out a comprehensive geological investigation of that section of Damara geosyncline in which the complex economic pegmatites occur (Smith, 1961). This work is an integral part of the present investigation in that it gives the geological background to the development of the lithium- and beryllium-bearing pegmatites. In general the formation of pegmatites is closely related to the processes of metamorphism, granitisation and mobilisation associated with major orogenic events. They should be considered in terms of this environment, and for this reason the author has drawn heavily from Smith's work.

The present paper is subdivided into three major sections, viz:-

(i) Structural investigations with the aim of determining the mode of emplacement of selected pegmatite bodies.

(ii) Detailed description of individual pegmatites with particular reference to macroscopic textures, and inter-relationships of various zones.

(iii) Investigations of the major pegmatite minerals.

These three aspects are treated separately each with respective discussions and conclusions. The final chapter is devoted to a synthesis of all the data.

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 (sheets No. 71 Omaruru 1939, and No. 72 Karibib 1942).

The description accompanying the Karibib sheet reports the occurrence of lithium minerals such as amblygonite, lithia-mica, and sinnwalidite 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 more 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, sinnwaldite and rubellite, and considered lepidolite always to be a replacement product of feldspar and to a very slight degree of topas.

In 1944 H. Mel 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. This comprises the first section of the present paper.

A recent contribution has come from Smith (unpublished thesis 1961). He is of the opinion that the pegmatites are intimate-

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ly related to the Damara orogeny and associated processes of metamorphism, granitisation, and mobilisation. The pegmatite liquid is considered to be a rather volatile fraction of mobilised magmatic material intruded into tensional zones.

In 1963 Haaring and Gevers published a description of the Rubicon, Helicon and Karlsbrunn pegmatites. This data has been included in the second part of this paper.

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

GEOLOGICAL SETTING

A. STRATIGRAPHY

The pegmatites under consideration all occur in rocks of the Damara System. The stratigraphic column of the latter was initially outlined by Gevers and Frommurze (1928 - 34). Recent work by Smith (1961) has modified their conclusions not so much in regard to stratigraphy but in the interpretation of the metamorphic rocks, gneisses, and granites.

The stratigraphic succession in Western Damaraland, according to Smith is as follows:-

STRATIGRAPHICAL UNIT		APPROXIMATE THICKNESS
Damara System	KHOMAS SCHIST SERIES	+ 10,000 FT
	UPPER KAREBLE SERIES	0- 1,800 FT
	CHUOS TILLITE	0-200 FT
	LOWER KAREBLE SERIES	0-600 FT
QUARTZITE SERIES	KHAN FACIES	0- 3,500 FT
	CHUOS FACIES	0- 10,000 FT
----- ------- UNCONFORMITY ----------		
ARCHAEAN SYSTEM		

B. LITHOLOGY

(a) Quartzite Series

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

Grey-green well-bedded calc-granulites with locally interpolated biotite schists and felspathic quartzite characterise the Khan Facies.

V ...

(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

A glacial boulder bed with granulitic schistose matrix. in places associated with thinly laminated biotite-schists.

(d) Upper Marble Series

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

A thick group of well foliated biotite schists alternating with biotite-quarts 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-feldspathic granites and gneisses are developed mainly in the basal Quartzite Series and therefore outcrop mostly in the cores of anticlinal and elongate domical structures. More widespread biotite gneisses and granites, often porphyritic, on the other hand have been generated within the Khomas Schists filling synclines or elongate basins. South and southwest of Karibib the latter also include quarts 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, 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 elongate 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 is 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.

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MODE OF EMPLACEMENT OF CERTAIN Li- AND Be-PEGMATITES INVESTIGATED

A. GENERAL STATEMENT

This section is confined to one particular aspect of the study of pegmatites, viz. the mode of emplacement of the complex Li- and Be-pegmatite type. It was considered that an investigation of this problem would lay a solid foundation for the subsequent sections dealing with the genesis of these pegmatites. Furthermore, if it were established that certain structural conditions favoured their emplacement, knowledge of the genesis of such conditions could possibly assist in the locating of further occurrences of presently undiscovered ore-bodies.

In order to establish the mode of emplacement, the following two points are considered to be of major importance:

(i) Have the pegmatites formed from a local secretion-diffusion mechanism, or have they crystallized from a pegmatite magma?

(ii) What were the structural conditions that influenced pegmatite emplacement?

All possible relationships of the pegmatite to the wall rock, and the character of the wall rock itself were used to answer the first question.

The structural environment of the pegmatites was determined from the relationships of the pegmatites to the regional structure and to smaller structures (e.g. lineations, foliations, bedding).

In the Albrechtshöhe-Koliombo area the smaller structures as indicated above were treated statistically and then used in the interpretation of the tectonic history.

The following three areas were selected for the study of the structural environment of the pegmatites:-

(i) The Karlsbrunn pegmatite (PLATE I).

(ii) Pegmatites of the Albrechtshöhe-Koliombo area (PLATE I the rectangular area in the north east).

(iii) Brockmann's pegmatite on Tsaobismund 58. This body is not shown on PLATE I but occurs approximately 45 miles southwest of Karibib.

The mapped area of PLATE II represents approximately ten square miles. Within this area 1,125 small structural features were recorded (lineations, foliations, axial plane cleavages).

B. THEORETICAL CONSIDERATIONS

(a) Brief Review of Theories on Genesis of Pegmatites

No attempt will be made to give a complete review of the present theories on pegmatite genesis. The reader is referred to a comprehensive account by Jahns (1955) on the present state of knowledge on pegmatite genesis, which is accompanied by an extensive list of references on the subject.

Two theories on the origin of pegmatites are currently most acceptable. The first is the magmatic theory which envisages a pegmatitic phase to represent segregations from parent igneous masses. The pegmatites may be found within the mother pluton or may be injected into the surrounding rock. This residual pegmatite phase is considered to consist of a silicate and aluminium silicate system rich in volatile constituents. The gross composition differs little from that of ordinary igneous rocks. (Jahns op. cit.)

Crystallisation is imagined to have taken place in situ from the pegmatite magma. There are differing opinions as to whether the pegmatite crystallized under open or closed system conditions. (Jahns, op. cit.). Cameron, Jahns, McNair, and Page (1949) have proposed that the pegmatite may have crystallized in a "restricted system" which implies that nothing is added to the system from its source after its emplacement, but that material is allowed to escape from it during crystallization.

The second theory on pegmatite genesis, called the metamorphic-metasomatic theory, is one in which diffusion is essential (Ramberg, 1956). A main feature of this hypothesis is the supposition of an energy gradient, generally a pressure gradient, along which ions, atoms or molecules may diffuse. These particles migrate and become fixed in tensional (often dilating) openings to form pegmatites.

In the dilation, or diffusion-secretion type of pegmatite, the composition of the pegmatite does not have to be the same as the nearest host-rock. The differences in the mobilities of various constituents are supposed to give rise to a most effective differentiation during the formation of the pegmatite (Ramberg, 1956). The same author admits, however, that pegmatites may also gain substance from more distant sources, such as the mobile constituents of granitization which will become fixed in the pegmatites.

Non-dilation replacement pegmatites can also be added to the metamorphic-metasomatic group. Here the alteration of the wall-rock to a pegmatitic rock is considered to have started along a joint (Ramberg, 1952). Replacement of the wall-rock by some media supposedly takes place, assimilating the quartzo-feldspathic material of the wall-rock and driving out the calco-ferromagnesian constituents which then border the pegmatite in the form of a "basic front" of hornblende and/or biotite.

Subtle differences between a pegmatite formed from a magma which has reacted with and metasomatised part of the wall-rock, and a pegmatite formed solely by the replacement of the wall-rock from a joint are indeed difficult to distinguish!

Ramberg has developed his theory mainly from a study of pegmatites in West Greenland which, judging from his descriptions, do not represent economically mineralized bodies. They are found in deeply eroded roots of two Precambrian orogens in which gneisses and other metamorphic rocks are present. The rather simple type of quartz-feldspathic pegmatites with minor accessories found in these regions are possibly characteristic of this metamorphic environment.

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in which secretion types of pegmatites do seem to have formed.

The complex pegmatites (e.g. Li and Be-bearing types) are possibly of a different nature, and their genesis need not necessarily be the same as that of the pegmatites of West Greenland.

To summarize, the emplacement of pegmatites may occur as a result of the following processes:-

(i) Injection of a pegmatite magma.

(ii) Secretion from the surrounding rocks.

(iii) Concretionary growth where pegmatites grow by pushing apart the country rock in a manner similar to the growth of porphyro-blasts. According to Ramberg (1952), such pegmatites developed as crystallising bodies in crystalline surroundings.

(iv) Replacement.

(b) Definitions and Methods Used in Determining the Tectonic Environment of the Pegmatites

Ideally, structural data on the country rock, obtained from measurements on as many scales as possible should be used as a means of determining the conditions that influenced the localisation of the relevant pegmatite. If, however, the relationship of the macroscopic structure is sufficiently conclusive it would seem unnecessary to seek confirmatory evidence in a study of related mesoscopic and microscopic structures. (For definitions of macro-, meso- and microscopic scales see Weiss, 1958). Thus, in the present investigation one of the pegmatite areas (Karlsbrunn) was studied on a macroscopic scale only. Conditions in the Albrechtshöhe-Koliosbo area are similar to those at Karlsbrunn, but it was decided to attempt to unravel the tectonic history by employing statistical analysis of mesoscopic structural features in addition to the assessment of the macroscopic structural data. The same applies to the Tsaobismund 58 area.

Statistical analysis of structural geometry involves the measurement and recording of small structural features such as lineations, foliations and axial plane cleavages (for definitions see below). These are then plotted on a Schmidt-type stereographic projection and treated statistically.

The interpretation of such projections has become a rather specialised branch of geology and the reader is referred to an excellent introduction to the subject - "Structural Analysis of the Basement System at Turoka, Kenya", by Weiss (1958). For further information on this subject, including the principles involved in the interpretation, reference should be made to papers by Weiss (1959) and Ramsay (1960, 1962a, 1962b).

The present paper makes use of several terms which are defined as follows:-

Foliation: "A visible set, or sets, of parallel surfaces of inhomogeneity defined either by lithological variation or preferred dimensional orientation of minerals or by both". (Weiss, 1958).

Lineation: There are three main types of lineation according to Weiss (op. cit.):-

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1. "Lineations caused by folding on a microscopic scale of a fabric surface. This structure is homologous with folding on a larger scale."

2. "Lineations caused by elongation of fabric elements such as individual grains, groups of grains, small heterogeneous inclusions, etc."

3. "Lineations caused by mutually inclined sets of fabric surfaces. A parallel lineation occurs in each set of surfaces."

Similar Folding: The basis of similar folding is the presence of cleavage or schistosity surfaces along which movement has taken place. These are often inclined to and penetrate the main bedding, foliation or form surfaces. The most important mechanism of similar folding is one of flattening and in particular, differential flattening (Ramsay 1962b). A characteristic, geometrical feature of similar folds is that the individual thickness of bedding surfaces is variable, being thickest at the hinge of the fold and thinning out on the limbs, while the thickness measured along a line parallel to the axial plane remains constant.

The interpretation of the statistical data in the present paper is based on the principles involved in the process of superposed folding. Ascertaining the effect of folding earlier lineations and establishing what positions they adopt in space, was considered to be of less importance than determining the attitude of lineations superposed on pre-existing structures. The principles involved in the former process are presented by Weiss (1959) and Ramsay (1960). The second, somewhat simpler case is discussed below as it has a direct bearing on the Albrechtshöhe-Kolombo area.

When lineations formed by similar folding (axial plane cleavage acting as slip surfaces) are superimposed on an existing structure (such as an unsymmetrical arrangement of foliation planes), the only ideal parameter constant in the new set of lineations would be the axial plane cleavage slip surfaces; the lineations formed by the intersection of these surfaces with the unsymmetrical arrangement of pre-existing foliation surfaces would either be axial plane cleavage foliation intersections or small folds formed by slip on the fairly uniformly oriented plane surfaces. In either case, the only constant parameter would be the axial plane containing all the lineations. On a stereographic plot the superposed lineations would then fall on a great circle.

In nature, conditions would not be ideal. There would be a distinct spread in the lineations on either side of the axial plane of the superposed folds because the axial plane cleavage slip surfaces are not statistically parallel and show a small, but significant divergence from the axial plane (De Sitter, 1956). In the case of isoclinal folding, this spread would be minimised and the ideal conditions would be approached. Such conditions are, therefore, to be expected in the Albrechtshöhe-Kolombo area where isoclinal folding is prominent.

It is of interest to note that for ideal conditions the superposed lineations will always lie on a great circle, irrespective of what the pre-existing structure was. Thus, the orientation of the applied force necessary to give rise to these superposed lineations, is represented by the pole to the great circle containing these lineations, or, in other words, the pole to the average uniform slip surface.

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There are other types of similar folds (e.g. chevron folds) in which the cleavage direction is an oblique shear direction (de Sitter, 1956). The same author states, however, that, in his general experience, slaty and fracture cleavage are both roughly parallel to the axial plane of the fold. Thus schistosity which would represent a more advanced stage of the two preceding types of cleavage, would thus also tend to be in a similar orientation.

Another point of consequence is that the lineations referred to above would only apply to the intersection of axial plane cleavage and foliation, and micro- and small-folds developed by slip folding on essentially parallel surfaces. These lineations are thus also governed by the original geometrical attitude of the beds (folia) prior to the super-position of the later lineations.

Preferred orientation of minerals indicates lineations governed to a greater degree by the ideal kinematic axes, which could therefore have a different vector direction. Lineations controlled by the original attitude of the foliation may be anywhere in the a - b plane, while mineral orientations may be parallel to the a or b axis. (For a definition of tectonic axes see De Sitter 1956, Weiss, 1958). If there were minerals that grew with their elongation parallel to the directed compressive force, these lineations would then lie parallel to the c - axis. It is therefore essential to realise what type of lineation is being measured.

This premise that superimposed lineations (formed by similar folding along axial plane cleavage slip surfaces) are controlled by, and lie close to, the axial plane of the superposed folds, forms the basis of the interpretation used in establishing the structural history of the Albrechtshöhe-Kollombo area (page 12).

The minor structures that have been made use of in the present investigation are small folds, bedding-cleavage intersections, bedding and cleavage (schistosity). Lineations were measured where they were well developed and the banded limestone-biotite schist shown on PLATE II was particularly useful in this respect in that it characteristically reveals a profusion of minor folds and lineations.

C. INTERPRETATION OF FIELD OBSERVATIONS

(a) Geological Environment of the Lithium- and Beryllium-bearing Pegmatites

The Li- and Be-pegmatites of the Karibib District, and Brockmann's pegmatite, are considered to be associated with the period of Damara metamorphism and Salem granite formation (Smith, 1961).

These pegmatites occur in rocks of varying character (PLATE I). They are known to lie in Damara marbles (e.g. Helicon II on Okongava Ost) and in Damara quartzite, e.g. Brockmann's pegmatite on Tsaobismund 58, and Henckert's pegmatite on Dernburg (see Plate I). (Brockmann's pegmatite is not situated within this area). The main S-shaped pegmatite in the Albrechtshöhe-Kollombo area transects the Damara marbles, a transition zone between the marbles and the Khomas Schists, and finally the Khomas Schists (PLATE II).

It would thus seem that the mineralised pegmatites bear no significant chemical relationship to their wall rocks. The pegmatite composition is characterised by silica, alumina, alkalis, Be, Ta, Cb, P, B, F and remains fairly constant in spite of the fact that the pegmatites are found in rocks of varying stratigraphical position and type (quartzite, marble, banded limestone-biotite schists).

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Furthermore, some of these bodies occur in, and are completely surrounded by carbonate rocks (Damara Marble Series), e.g. Helicon II on Okongava, Berggera pegmatites on Koliorbo, and Karlsbrunn. (See PLATES I and II).

It is considered unlikely that dolomitic marbles would constitute a substantial source of silica, alumina and some of the unusual elements indicated above, which are necessary to produce a pegmatite by a secretion-diffusion mechanism.

On the basis of these data, it seems justifiable to assume a magmatic source for this type of pegmatite. The discussion of the structural conditions which might have controlled the emplacement of the pegmatites will be based on the assumption that these bodies were derived from a magma.

(b) Specific Examples of Pegmatite Emplacement

(i) The Karlsbrunn Pegmatite (PLATES I and III)

This is a lithium pegmatite with beryl and columbite occurring in the Damara Marble Series. The main pegmatite body has a "phacolithic shape" (i.e. in the sense of its shape only; it has not been folded and shows no signs of internal deformation), part of the pegmatite being almost vertical while the remainder is practically horisontal. A smaller body occurs just northeast of this and has the shape of a vertical lens. The vertical dyke-like portions of the pegmatite are those that have been considered in this study. The strike and dip of the main vertical portion of the pegmatite is suggested by the Jooste beryl quarry. The latter, a vertical narrow cut, defines the strike and dip of a very rich beryl zone which has been mined out. The cut is approximately 70 feet long, 8 feet wide, and at present 20 - 30 feet deep. The floor is filled with rubble so it is possible that the workings continued even deeper. The strike and dip of this beryl zone is taken to represent the strike and dip of a wide dyke displaying typical zoning. The strike is north-south (magnetic).

Another vertical dyke-like portion of the pegmatite, underlying the flat part, is found some 450 feet to the northeast of the Jooste beryl quarry. Here the central part of the pegmatite consists of a continuous zone of mixed quartz, grey and pink lepidolite, petalite and albite. This central core zone has an average width of 10 feet, is vertical over and exposed height of 30 -40 feet and can be traced for a distance of 120 feet. The strike of the mineralised zone is north-south (magnetic) and the remainder of the pegmatite can be taken to have a similar attitude. The observable eastern contact of this pegmatite with the limestone is steep, the strike being essentially parallel to that of the mineralised zone.

These two vertical portions of the structurally complex pegmatite are considered significant. The remaining part of the pegmatite is essentially flat, lying fairly conformable with the foliation. The wallrock roof cover is eroded away so that the exact control of the flat lying portion of the pegmatite is impossible to ascertain.

The Karlsbrunn pegmatite is located close to a major fault (PLATE III), striking approximately NW.35E. At two localities on this fault the displacement was determined. The fault cuts across a closed antiklinal structure. The displacement of the northern contact of the Damara Quartzite Series and the Marble Series indicates that the eastern side of the fault underwent a relative movement to the north. The dip of the metasediments is to the north at this locality.

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The displacement on the southern side of the anticline was found to be the same, viz. to the north, in spite of the fact that the beds dip southwards. Two useful markers could be used in establishing this fact: the Chuos Tillite, which is developed locally, and an amphiblitic horizon occurring in the succession above the tillite.

It could thus be established that the absolute displacement on the fault must have been essentially horizontal. The fault, therefore, probably represents a wrench fault as defined by Anderson (1951). It is of left lateral type, i.e. the relative movement is counter-clockwise.

Ideally, the major horizontal compressive force required to produce such a wrench fault would be approximately 30° counter-clockwise from the fault. (Moody and Hill, 1956). Tensional openings should theoretically always lie in the same direction as the major compressive force. The angles formed by the strike of the vertical dyke-like portions of the Karlsbrunn pegmatite and the strike of the wrench fault are approximately 35°. The only small angular difference between the ideal direction required to produce the wrench fault and the actual direction of the vertical dyke-like portions of the Karlsbrunn pegmatite suggests that these portions of the pegmatite occupy true tensional openings.

On the immediate west of the Karlsbrunn wrench fault, near the southern Quartzite-Marble Series contact, narrow 1 - 3 foot wide pegmatite dykes have the following two pronounced orientations:-

Strike	Dip
360° (N - S)	80° West
260°	70° North

The northerly strike belongs to the same system as the Karlsbrunn vertical dyke-like portions. The other direction is more or less at right angles to this, and is found also in the Albrechtshöhe-Kollombo area which has been subjected to the same stress conditions. The explanation is given in the next section (page 19).

A similar parallel fault occurs approximately two miles to the east of the Karlsbrunn wrench. The relative movement on this fault could not be determined with the same degree of certainty as at Karlsbrunn. However, the faults are considered to be similar as regards attitude, displacement and time of formation because:-

- They are parallel to each other.
- Dolomitic limestone fragments cemented by chert-like material occur in both.
- The apparent displacement of a calc-silicate horizon at one locality on the eastern fault suggests a movement in the same direction as the Karlsbrunn wrench. (See PLATE II).
- Pegmatite emplacement is closely connected with this period of faulting. This has already been described in the case of the western Karlsbrunn wrench fault. The eastern fault zone has pegmatite mineralisation developed although in a manner identical with that at Karlsbrunn (see page 19).

The Karlsbrunn pegmatite illustrates two important features:

1. It occurs in dolomitic marbles and a secretion-diffusion hypothesis involving enrichment of elements and compounds such as silica, alumina, alkalis, Be, B, P, F, Ta, Cb, Sn, is therefore highly unlikely.

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2. The vertical dyke-like portions of the Karlsbrunn pegmatite can be related to tensional openings caused in conjunction with a period of wrench faulting occurring in the area.

(ii) The Pegmatites of the Albrechtshöhe-Kolicombo Area

1. General Geology

A regional geological map has been compiled by Smith and is included to show the location of the Albrechtshöhe-Kolicombo area, as well as some of the other pegmatites of the Karibib District (PLATE I and II). (Smith, 1961).

This area was selected for two reasons:-

— It is one of the few areas that contains pegmatites of the same group (late tectonic). This pegmatite group is known to carry economic minerals, e.g. beryl, lithium minerals, tantalite-columbite, and tourmaline. Earlier syn- or pre-tectonic, pegmatites occurring in this area are generally simple quartz-feldspar - mica types with minor accessories;

— The area lends itself to detailed structural analysis, i.e. statistical assessment of lineations and foliations.

Most of the area is underlain by tightly folded (virtually isoclinal) Damara marbles (PLATE II). The marbles occasionally contain calc-silicate horizons which facilitate easy macroscopic determination of foliations and lineations (micro- and small folds). At two localities lineations measured in the calc-silicate horizons revealed that there was no dominant statistical orientation over outcrops of a few square feet, thus suggesting that flow had taken place.

Overlying the marbles is a very distinctive banded unit made up of narrow alternating layers of dolomitic marble and quartz-biotite schist. Individual layers are of the order 1/4 - 3/4 ins. in width. This rock type forms a transitional zone between the Damara marbles and Khomas schists proper. In this area the latter are composed dominantly of foliated black biotite rich schists.

2. Pegmatites

Several pegmatites occur within this areas, the majority of which are barren. Mineralised bodies show no signs of internal deformation and distinctly cross-cut the structure. They are, therefore, late tectonic (see page 22). The characteristics of this group of pegmatites are discussed below.

Attention is drawn to the central "S"-shaped pegmatite body (PLATE II). The greater part of the pegmatite is made up of pink microcline perthite crystals of varying size (up to 2 - 3 feet) lying in a groundmass of intergrown quartz-muscovite. Albite is scattered throughout the latter in varying amounts, as well as rare crystals of beryl. Distributed within this uniform feldspar-quartz-muscovite material are small local accumulations rich in Li-mica and bodies of massive dominantly albite rock.

Small quartz blows are sometimes irregularly developed in the main "S"-shaped pegmatite body without any major symmetry; they are generally 1 - 3 feet in width and may be followed over

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distances of 20 - 30 feet. On their margins, or intermingled with the quarts, minerals such as pink lepidolite, amblygonite, beryl, tourmaline and columbite may occur. Albite accompanying these ore minerals is characteristically developed in platy aggregates.

A large concentration of Li-mineralisation is found in the northeastern extremity of the "S"-shaped pegmatite (Brockmann's Property in PLATE II). This ore body is rich in lepidolite and ambly-gonite and also contains minor amounts of beryl and tantalo-columbite.

This "S"-shaped pegmatite is thus mineralised only at local, irregularly dispersed centres, the maximum concentration of economic minerals occurring at the northeastern extremity. In this section the whole pegmatite dyke is regarded as a single unit. Another mineralised pegmatite on Koliombo is that of Berger. This also contains Li- and Be-minerals.

The other pegmatites indicated on the map (PLATE II) are essentially of the microcline-albite-quarts-muscovite-type, which locally may develop a quarts core and minor lithium, beryllium, tourmaline mineralisation.

The similarity of mineralogy and general character of the majority of pegmatites in this area suggest that they belong to one single phase of pegmatite intrusion. Genetically they may be considered as a group consisting of the common reddish pegmatite type with its typical microcline-albite-quarts-muscovite assemblage, with local differentiates of Li, Be and associated mineralisation.

This group of pegmatites is considered to be late tectonic (see pages 18to 22). There are, however, a few narrow, simple quartz feldspar pegmatites and quartz veins in this area (fig. 1), which are folded together with the foliation. This relationship strongly suggests that they are pre- or syntectonic. Such pegmatites do not give rise to Li- and Be-ores.

Of the different types of pegmatites of varying ages, only the complex group are considered in this text.

3. Structural Geology

Statistical analysis was employed as the means of interpretation of the structural geometry in the Albrechtshöhe-Koliombo area. This involved measurement of lineations and foliations in the field. Observations were made at 600 points. At each point the geometrical attitude of the above features were recorded if developed. On PLATE IV, the orientations measured at each point have been recorded. If two obviously different directions were observed at one point, both directions have been plotted.

The nature of the structure varies appreciably over relatively short distances within the area and to facilitate description, the district has been divided into sub-areas. The projections have been plotted on the upper hemisphere.

Three distinct phases of folding have been recognised in the Albrechtshöhe-Koliombo area and these give rise to three definite sets of lineations - L_1, L_2 and L_3 in order of decreasing age. The evidence for postulating three periods of folding is given in the discussion of the data collected for all the sub-areas.

Sub-Area I

This sub-area shows a certain degree of simplicity and

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thus a higher degree of homogeneity than other more complex sub-areas. As can be seen from the maps (PLATE II and IV), the area represents a fairly uniform synclinal structure plunging gently to the east-southeast. Lineations in the area are not as symmetrical however, as would be expected from the simple macro-structure (fig.4). From the lineation plot the concentration of points defining the fold axis shows a spread, but would appear to have a maximum at 300° dipping at 16° east-south-east.

In the field the main set of lineations (L_1) is clearly folded by later sets which plunge in approximately south-easterly (L_2) and south-westerly (L_3) directions. (See fig.3). The change in direction and angle of plunge of the L_1 lineations about a uniformly plunging fold (L_2 or L_3 Lineations) would tend to indicate that the former are folded by the latter.

A curious feature of the lineation plot for this sub-area is the marked spread on a great circle. The significance of this great circle can be better understood from a plot of the foliation data (fig. 2a). The foliation data show a well defined double maximum lying on a great circle, the pole to which is the lineation L_1 which defines the plunge of the synclinal structure. These maxima indicate the presence of a relatively "tight" fold. (These poles to the foliation and axial plane surfaces tend to be concentrated in a relatively small area.) The two-point maximum is due to the fact that the southern limb of the fold is steeper than the northern limb (fig.2c).

If a point in the centre of these two maxima is taken to represent the pole of the axial plane, then it can be seen that the subsequently plotted trace of this plane forms a great circle which contains all the lineations (fig. 2b). In other words, the axial plane of the fold (and since the fold is approximately isoclinal the axial plane would apply to the average orientation of all foliations of the sub-area) very rigidly controls the positions of the lineations L_2 and L_3. The original attitude of the beds after L_1 folding gave rise to a series of parallel-orientated foliation surfaces in which the new superposed lineations lie. The control of superposed lineations by the previous geometrical attitude of the foliation is particularly clear in the case of L_2 lineations which form two distinct maxima, the northernmost one, L_2', controlled to a high degree by the shallower dip of the northern limb of the syncline (figs. 2b and 2c).

Lineations L_2, L_2' and L_3 are thus rigidly controlled by the original geometrical attitude of the syncline, and on this reasoning alone it can be concluded that the L_2 and L_3 lineations must have been superimposed on an older L_1 structure. Furthermore, the intensity of these later fold movements in this sub-area was not sufficiently strong to rotate (or fold) the original structure about new axes. To the south and the west of the simple synclinal structure the latter deformational phases have certainly been more intense than the earlier phase, resulting in marked changes in the outcrop pattern.

The concentration of L_2 lineations (fig. 2b) defines a pole to a second great circle of poles to foliation planes which is also present in fig. 2c.

In this sub-area then it can be established that a primary period of folding (L_1) was followed by two distinctly later sets which have not been dated with respect to one another.

Sub-Area II

This area also has a simpler structure than some of the other sub-areas, and for this reason was chosen to characterise a certain trend and orientation of folds, and thus possibly, a certain

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trend and orientation of folds, and thus possibly, a certain age of folds within the whole area.

The trend of the lineations and the trend of tightly folded synclinal structure are almost at right angles to those in Sub-Area I. (PLATES II and IV; compare fig. 2b and fig. 4b).

The foliation plot displays the isoclinal nature of the folds (fig. 4a). It can be established that all foliations have essentially the same orientation. A statistical plot of all the foliations defines a distinct maximum which is the pole to the axial plane of the isoclinal folds. The limbs of the folds are very long in relation to their hinges. This is also shown by the fact that essentially all the foliations have a similar orientation. Due to the isoclinal nature of the folds the orientation of the axial plane cleavages and the foliations are virtually the same (see fig. 5). For this reason, these two parameters have been plotted together in all the foliation diagrams of the Albrechtshöhe-Koliombo area.

The trace of the axial plane is again seen to be the great circle containing the spread on all the lineations of Sub-Area II (fig. 4b). The maximum is close to that of the original foliation trends established in Sub-Area I where all the foliations dipped steeply towards the south. With superimposed folding this is to be expected. The plunge of the L_2 folds is controlled by the attitude of the foliation surfaces prior to their formation. In this particular sub-area, however, the outcrop pattern reveals a fairly homogeneous structure plunging to the south. No vestige of the L1 structure is present except for the position of the L_2 fold axis which was certainly controlled by the earlier fold geometry. It follows, therefore, that in this region the second fold movements were much stronger than the earlier movements, in that the earlier structure has been completely obliterated.

A weak set of lineations lying at right angles to L_2 has been observed on a few occasions only. These are mainly boudin structures, but in other cases appear to be later folds. The boudins have been observed in the banded limestone-biotite schist sequence (fig. 6). The fact that these boudins are perpendicular to the statistical fold axis would tend to suggest that they are manifestations of one and the same period of folding. The tension required to develop the boudins was possibly a result of a regular s - c plane of weakness in the more competent biotite schist bands. Such joints, perpendicular to lineations, are also shown in Fig. 7. The cracks are filled with recrystallized carbonate material. Where the boudins are not developed, foliation bands may be exposed with small fingersized folds extending straight across the main lineation L_2.

In this sub-area it can, therefore, be established that there is tight isoclinal folding (S_2 maxima) in which the folds plunge at an angle of 40° to the south (L_2 maxima) (fig.4). Since all the foliation surfaces are virtually parallel with the plane defined by the S_2 maximum, the lineations are controlled by the attitude of this plane, which in comparison to Sub-Area I indicates superposition of folding. In some cases, however, the boudins which are formed at 90° from the fold axis, may be genetically related to the later act of folding.

There are not enough data to date with certainty other lineations that lie on the axial plane trace; they may be contemporaneous with L_2 (e.g. boudins) or possibly later. At one locality lineations of possibly later age than L_2 occur. These fold the L_2 lineations as can be seen in fig. 8. The orientation of these lineations are as follows:-

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	Bearing:	Plunge:
L_2'	186°	44°S
L_2	185°	34°S
L_3 (?)	202°	44°SW

Sub-Area III

The pattern of folding in this sub-area is essentially uniform. Fig. 9a shows that the folds are essentially isoclinal. Lineations show a weak spread which lie on the axial plane of the folds (fig. 9b).

It was observed at one locality that two distinctly different sets of lineations do in fact occur, e.g.

	Bearing:	Plunge:
L_2 folded (?)	161°	30° S.E.
do	94°	44° E.
L_3 (?)	24°	5° N.N.E.
do	20°	9° N.N.E.

Positive age relations between the two could not be determined.

Sub-Area IV

This area is similar to Sub-Area III. The lineations show a spread on the axial plane of the fold. The axial plane is defined by foliation data (fig.10). Trends of S_1 foliation also seem to be indicated in fig. 10a.

This fact is supported by the outcrop pattern (PLATE II). When the folds are strongly developed with the obliteration of the L_1 folds, the outcrop pattern has a strike which is north-northeast (Sub-Area II). In the area under discussion the southern portion reveals the L_2 trends while the northern part probably contains a modified L_1 trend.

The last two sub-areas (III and IV) show clearly that the foliation is essentially of the same orientation in each sub-area. In both areas lineations show a decisive spread on a great circle which is the axial plane of the folds.

Considering the axial plane control of lineations in Sub-Areas III and IV, this phenomenon could be explained on the grounds suggested on pages 8 to 9 , i.e. when lineations are superimposed the only constant parameter common to these lineations is the great circle in which they lie. (This great circle is the axial plane of the new superposed folds).

Sub-Area I

It has been established that two major fold trends are present in the sub-areas described so far. A weaker third trend is suggested by the superimposed L_3 maximum obtained in fig. 2c. Locally a later third trend has also been indicated by folds observed in Sub-Areas II and III. It remains to be seen if all these trends can account for the highly complex structure found in Sub-Area V.

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Fig. 11a and 11b show the inhomogeneous nature of the fold trends, a fact which is also clearly indicated by the complex outcrop pattern of PLATE II. Fig. 11a reveals two distinct maxima. These compare well with the simple maxima obtained in two type areas of fairly homogeneous folding, i.e. Sub-Areas I and II. The TT trace for the L_2 is shown in fig. 11b as well as a very weak TT trace which is related to the L_3 folds.

The spread of the lineations is controlled essentially by the axial planes of the two dominant fold directions (fig. 11b). Again the folds show isoclinal characteristics (fig.11a).

The L_3 lineations show a spread on a third great circle (fig. 11b). The maximum of this group of lineations corresponds closely with the maximum for the same lineations when it is superposed on a L_1 structure (fig. 2b). From the discussion on pages 8 and 9, this spread of L_3 on a great circle is due to its superposition on previously existing structures. The synthesis of fig. 11c reveals that the L_3 maxima is in fact the pole to the TT trace marked S_3 thus confirming the presence of these folds.

The phenomenon of the controlled spread of the lineations on the axial planes of the two major fold sets observed in this sub-area, can be explained partly in the light of the discussion on pages 8 to 9. In the approximate isoclinal fold where the original structure L_1 is not destroyed the axial plane of this fold rigidly controls the spread of later superposed lineations, - Sub-Area I. In other cases where the L_2 structure is dominant, the axial plane of these folds will contain the spread of contemporaneous lineations and will also contain the superposed lineations which are not sufficiently pronounced to destroy the overall L_2 structure.

Sub-Area VI

This area is also extremely complex and, although further, more detailed work is advisable, the observations made clearly demonstrate certain relationships.

The lineations themselves show a very marked spread (fig. 12a, 12b). In the field it was established that L_2 folded L_1 (fig. 13).

From the interpretation of Sub-Area I the trend of superposed L_2 lineations was established (fig. 2c). This trend represents the great circle formed by the axial plane trace of the L_2 folds. Falling on the same great circle are the maxima for L_2 lineations of Sub-Areas II, III and V (fig. 12b).

The spread on the lineations observed on the most northwesterly exposure of banded limestone-biotite schist in Sub-Area VI has been plotted seperately on fig. 12b. The great circle containing these lineations has a slightly different attitude than the ideal L_2 axial plane as determined in Sub-Area II, and the associated spread of L_2 on the first-formed structure as determined in Sub-Area I. This deviation is possibly due to the effect of L_3 folding which may have disturbed the ideal pattern. However, this does show that the lineations in fig. 12 can, in part be accounted for by the superposition of L_2 on L_1. The reason for the more complete spread of L_2 lineations in Sub-Area VI is that the areas of the L_1 folds have been exposed, while in Sub-Area I, for example, only the limbs of the fold were exposed.

L_3 is also present in this sub-area. The other great circle containing L_2 lineations has been interpreted as the folded equivalent of L_2 lineations by L_3 folds. That one is dealing with L_2 lineations in this case is verified by the fact that the great circle passes through the unfolded maximum position of L_2 on a pre-

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existing L_1 structure. In the case of similar folds, a folded lineation will fall on a great circle (Weiss 1959, Ramsay 1960).

Having obtained from Sub-Area V the spread of L_3 lineations superimposed on an L_1 and L_2 structure, and assuming this spread to coincide with the trace of the axial plane of the L_3 folds, the kinematic axes of this final phase of folding can be determined by using the method of Ramsay (1960) (see fig. 14a).

4. Structural Synthesis

By integrating the interpretations made of the lineation studies described above, it is now possible to attempt a kinematic, and possibly dynamic, analysis of the folding in the Albrechtsböhe-Kolombo area. The basic assumption has been made that the attitude of the beds was originally horizontal.

The first period of folding was about axes trending west-north-west, giving rise to the almost isoclinal fold found in Sub-Area I. Such folds possibly existed in the other sub-areas as well. Unfolding of the synclinal structure of Sub-Area I would bring the foliations down to a plane which is practically horizontal except for a slight tilt to the east-south-east, brought about by the regional fold axis plunging in this direction at an angle of 16°. This tilting of the fold axis might possibly be due to later movement.

In order to account for the nature of those folds in which the foliations dip fairly steeply towards the south-west (70° for the south limb and 45° for the north limb), a slight rotation of the directive forces is involved which probably resulted from the changes in the stress field due to the piling up of sediments (fig. 15).

The second phase of folding gave rise to northerly-trending structures which plunge to the south in Sub-Area II where the folds are best developed. The attitude of these folds was governed by the original attitude of the beds, i.e. eastwest foliations of Sub-Area I. This conclusion is supported by the fact that the fold axis for the L_2 folds in Sub-Area II corresponds well with the northernmost superposed L_2 maximum on an L_1 structure in Sub-Area I (fig. 2a, fig. 4c.).

Knowing the fabric which existed prior to L_2 folding, it can be established that the ideal directive force required to produce the L_2 folds would be represented by the pole to the L_2 lineation spread, e.g. fig. 12b. The spread on the lineations is therefore in the a - b plane, or, in other words the axial plane.

The interpretation of the final phase of folding L_3 is slightly more difficult. From previous evidence it has been suggested that there was a folding phase later than L_1 and L_2. The only phase of superposed folding in a complex area such as Sub-Area V, which shows a spread controlled by its uniform axial plane intersecting L_1 and L_2 folds and combinations of these, is L_3. The evidence would seem to suggest that L_3 is the latest phase of folding.

The interpretation of this last phase of folding is shown in fig. 14a. The orientation of the idealized compressive force required to produce the L_3 folds is represented by the pole to the L_3 lineation spread.

The interpretation of L_3 folds in time is based on rather weak evidence. The final synthesis in fig. 14a shows steeply dipping a - c joint planes with a strike of 304°. Drainage patterns have been analysed and one group has a direction of 299° (mean of

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20 values) which might be a manifestation of the L_3 folding.

The ideal directed forces required to produce L_2 and L_3 folds are essentially similar, e.g. L_2 folds require a force acting in a west-north-west direction, acting downwards at 38°, while the force required to produce the L_3 folds acts in an east-south-east direction downwards at 10°. The essential difference is, therefore, merely a rotation of the ideal directed force in a vertical plane.

Without more detailed knowledge of the regional geology, it is impossible to determine whether these three phases of folding were part of one act or whether they are relat i to definitely different ages of folding.

The structural synthesis has so far been confined to folding only. The wrench fault passing through the area also requires consideration.

The pegmatite emplacement is closely related in time to the wrench fault. Pegmatites are found in the fault zone itself. These are possibly the result of minor irregularities in the planar shear surface where crushing and tensional openings might have developed. Furthermore, in the bottom left hand section of PLATE II, several pegmatites occur which have a pronounced linear trend. The angle made between the strike of these pegmatites and the wrench fault is 26° (average). This angle approximates to the accepted 30° angle made between the surface of shearing and the maximum compressive force required to produce a wrench fault (Moody and Hill 1956, Badgley 1959). Tension cracks would have developed parallel to the main compressive force. The emplacement of these pegmatites occurring in the south-west corner of the map area, therefore, appears to be related to a period of compression resulting in the wrench fault.

Having seen that only some of the pegmatites within the area are related to wrench faulting and its associated stress field, there remains to be explained the mode of emplacement of other pegmatites in the area, e.g. those bodies occurring in Sub-Area V. Here the pegmatites show two distinct trends. One is the northerly trend which forms part of the large "S" - shaped pegmatite. This is the same direction that the pegmatites have in the south-western part of the map area. The second pegmatite trend is east-west.

The pegmatites occasionally appear to be conformable to the foliation in plan. In three dimensions, however, they cut across the foliation and generally have a steep dip, e.g. Brockmann's pegmatite dips at 70° to the north.

The pegmatites show, therefore, a characteristic orientation either north-south or east-west. This two-directional trend was also found to be present adjacent to the Karlsbrunn wrench. It can thus be seen that two directions virtually at right angles to each other have influenced the pegmatite emplacement over a large area. The north-south direction is that of tensional opening as explained above. The east-west trend is possibly explained by the existence of tension joints formed by the elastic release of the major compression (De Sitter, 1956).

There must have been a lapse of time between the north-south tension joints and the east-west tension joints. However, both produced zones of potential weakness with a certain amount of tensional opening which influenced pegmatite emplacement.

That tensional openings controlled the pegmatite emplacement is also suggested by the immediate wall-rocks of the pegmatites. Foliations and structures in the wall-rock show no signs of bending or deformation to indicate a forceful injection of a magma. It would

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seen that a quiet, permissive emplacement of pegmatite magma took place where tensional openings had produced a favourable environment (see fig. 16).

There still remains the question of the age relations of the wrench faulting and the three distinct phases of folding ascertained in the area. The pegmatites which are related to the period of wrench faulting give no evidence of having been folded, i.e. they show no signs of internal deformation or cataclasis. It would seem, therefore, that the folding took place prior to their emplacement.

The possibility that the wrench fault mechanics might have accounted for the third period of folding (L_3) also has to be considered. This period gives rise to so few lineations, that it is not nearly as intense as the two preceding periods (L_1 and L_2) and, therefore, it might not noticeably affect, or fold the pegmatites. L_3 folding may, therefore, also have been contemporaneous with pegmatite emplacement.

The basis for considering a relationship between L_3 folding and the wrench fault is that a re-orientation of the stress field takes place after the initial development of fractures. After the formation of the wrench fault, a secondary stress field would have been established in each block, which in turn would have given rise to second order shears and folds (Moody and Hill 1956, Badgley 1959). The L_3 period of folding could be fitted into such a pattern, but only if numerous assumptions are made.

The strongest objection to this interpretation would be the lack of folds perpendicular to the major compressive force producing the wrench fault. If such first order folds were not produced, then it is difficult to imagine how the second order folds could have formed.

The Albrechtshöhe-Kolombo Area demonstrates clearly the influence of structure on pegmatite emplacement. Here pegmatites occur in both dolomitic marbles and Khomas schists. A secretion-diffusion origin is unlikely for these pegmatites (see page 10). A pegmatite magma, possibly a mobilized product of palingenic origin, emplaced in tensional joints seems to suit the data most satisfactorily.

This interpretation of a very small area in the Damara-Otavi geosyncline has rather well documented phases of separate deformations. The critical questions are: how large is the time interval between each phase; are these separate phases part of a single or orogeny or do they represent different periods of deformation, and finally how does this pattern fit into the larger framework of the Damara-Otavi orogeny?

Martin has already commented on the feasibility of relating these separate phases to the Damara-Otavi orogenic belt (see Roering 1961). He concluded that all the directions found in the small area analysed in this paper occur as major elements in the orogenic belt as a whole. The time element established for the different phases are possibly related to the following modifications of a <u>single</u> regional stress:

- The first folds may have been controlled by the pre-Damara-Otavi basement which formed basins and ridges which initially guided sedimentation and formed a fairly rigid frame to which the original folds had to conform.

- The main regional stress seems to have had a dominant south-east- northwest direction. This could have produced the

L_2 folds whose axial planes have a northeast trend. It can be envisaged that with increasing metamorphism the basement became sufficiently "soft" to allow the regional stresses to overcome the resistance of the older basement structures. The steep dip of the L_2 folds is ascribed to steepening of the fold axes which become more pronounced with the increasing compression. The present author, however, believes that the steep axes are the result of superposed folds, the control being merely the attitude of the foliation prior to the L_2 deformation and the orientation of the axial plane of the second folds. Had there been no difference in local stress in L_1 and L_2 times, the folds should all have the same axial plane and within this plane the fold axes themselves should show a variation in dip (i.e. the L_1 folds should vary in plunge in the axial plane of the same folds.) However, two if not three axial planar trends can be established in this area; a fact which can only be reconciled with locally varying stresses. The symmetry of the superposed L_2 folds lying in the established axial plane of these folds where it intersects the L_1 foliations supports this assumption. It is not suggested that the overall regional stresses changed radically to produce the different fold phases in the investigated area. A single stress may become modified with time due to factors indicated by Martin, e.g. basement control. Furthermore, he suggests that under conditions of high grade metamorphism and granitization deformation may become so strong that certain larger anticlines become diapirs. Such a feature could very well set up local stresses that differ from the regional stress and thus add another component to it, resulting in local folds of differing trends. During the whole progression of an orogeny local modifying factors are to be expected with time and these will be reflected in the fold patterns of the rocks if mapped in sufficient detail.

- The last and minor deformation L_3 can probably be explained by a slight disharmonic movement of the incompetent marbles and schists over the plunging nose of the more competent Karlsbrunn quartz[illegible] anticline. That the latter was more competent was proved by its nearly circular outline and its nearly symmetrical dips.

- The wrench fault with its associated tension fissures seems to indicate a main compressive stress acting in a north-north-west instead of the assumed northwest direction. However, this fault may be a rejuvenated pre-Damara dislocation and may thus form an angle with the ideal direction required by the dominant regional stresses. This interpretation is suggested by the existence, to the southeast of Windhoek, of numerous north-south pre-Damara faults.

- Finally concerning the emplacement of pegmatites Martin suggested the following explanation:

The lack of deformation of the pegmatites indicates their post-kinematic intrusion. In the development of an orogenic belt the cessation of the folding stresses is, as a rule, followed by the beginning of isostatic uplift. This up-arching of the folded belt must produce a state approaching universal tension at a time when pegmatitic magma highly charged with volatiles is still present. Under such conditions this residual magma may become intrusive into all existing planes of

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weakness or inhomogeneity, regardless of what their origin may have been. This mode of emplacement would effectively explain the presence of undeformed pegmatites in bedding planes, cleavage planes, a - c and other joints, as well as wrench faults.

(iii) Brockmanns. Pegmatite on Tsaobismund 58: fig. 17

This pegmatite occurs in Damara quartzites. Although it is a considerable distance from the Karibib pegmatites, it is considered to be of the same age as the latter group. The pegmatite has an extremely rich beryl zone in which columbite is also present. Li is incorporated in phosphates lithiophilite which occur as huge rounded masses (up to 5 feet in diameter) on the margin of the quarts zone.

The structural investigations were restricted to a study of an anticline containing the pegmatite and plunging to the north-east. Lineations and foliations could not be measured at regular intervals in the generally featureless Damara quartzites forming the core of the anticline. Observations of these parameters were made in the Marble Series in which dolomitic marbles are intercalated with schist bands.

The beryl-bearing pegmatite lies almost at right angles to the anticlinal trend leading to a first assumption that it was emplaced in tension joints during normal folding.

In the other rock groups, viz. Marble and Khomas Schist Series, large white granite bodies, which are irregularly pegmatoid, are syntectonic or slightly pre-tectonic. Some dyke-like bodies, cross-cutting Khomas schists and up to several feet in thickness, are distinctly folded. Other sill-like bodies which sometimes transgress the foliation, but generally conform to the structure of the surrounding meta-sediments, appear to be syn-tectonic.

The beryl pegmatite is mineralogically very different from this earlier group of whitish granites and pegmatites. The occurrence of pinkish-brown microcline is particularly characteristic of the beryl pegmatite as is its complex mineralogy(lithiophilite, beryl, muscovite, columbite, uranium minerals). The pre- and syn-tectonic types are simple quartz-feldspar varieties with muscovite and biotite and relatively few accessories.

The Brockmann beryl pegmatite cross-cuts the structure, which fact supports its classification as late tectonic. Again there are no signs of internal deformation to indicate that the pegmatite has been deformed.

A plot of structural data reveals the northeast plunge of the anticline (fig. 14b).

A complete understanding of the sequence of structural events can be gained only from an investigation on a more regional scale.

However, the anticlinal structure does seem to have had an influence on pegmatite emplacement. Instead of massing themselves in a cluster to form a pole to the great circle containing the foliation poles, the lineations show a spread in a north easterly direction. This could be due to either folding of the lineations or superposition of the lineations on a previous structure.

In either case it seems reasonable to relate the pegmatite site to the north-easterly fold axis trend, i.e. to an a - c joint plane. Although the lineations do not lie exactly perpendicular

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to the plane of the pegmatite, one observation measured immediately adjacent to the pegmatite did show this relationship (see fig. 14b). The other lineations were all measured in the Marble Series and are thus undoubtedly affected by the factors indicated above to account for the north-easterly trend of the lineations.

This north-easterly trend of folding is regional, the fold axes plunging to the northeast or the south-west, which requires a north-west or south-east stress direction. These stresses could well give rise to a - c joints in brittle competent rocks such as the quartzites.

D. SUMMARY

Detailed structural analysis has been undertaken with the aim of solving the tectonic history of the Albrechtshöhe-Koliombo area. An analysis of this nature was considered an essential part of determining whether there was any relationship between structure and the mode of emplacement of certain complex pegmatites.

Although the emplacement of the pegmatites post-dates most of the tectonism, certain conclusions concerning folding and the mode of emplacement of the complex pegmatites from this area can be reported.

The structural studies outlined in this paper show that in the case of superposition of folding the axial plane of the superposed folds for the most part contains the spread of contemporaneously formed lineations when projected on to a stereographic net. The controlling condition is that folding is of similar type and takes place along slip surfaces essentially parallel to the axial planes of the folds and at right angles to the compressive stress.

The fairly uniform composition of the Li- and Be-bearing pegmatites, and their occurrence in rock types of varying composition (quartzite, dolomitic marbles, biotite schist) suggest a magmatic origin. This igneous activity is undoubtedly associated with the Damara period of metamorphism and granite formation. Strong evidence against possible formation by a local secretion-diffusion mechanism is the occurrence of numerous pegmatite bodies in dolomitic marble.

On a regional scale, the genesis of pegmatites must be viewed against the background of their geologic setting. They need not be of the same origin everywhere. The simple Greenlandic pegmatites described by Ramberg(1956) are clearly related to the metamorphic grade of their environment and have formed by metamorphic-metasomatic processes. The complex pegmatites of the Karibib District are associated with an orogenic cycle involving metamorphism and granitisation culminating in late, intrusive, magmatic granites. The pegmatite ore-bodies are intimately connected with the latter and are found both within such plutons as well as in the surrounding meta-sediments. Occasionally these plutons are "pegmatites" themselves being made up of very coarse grained granite.

Structure has played an important part in the emplacement of the pegmatites, tensional openings being favoured loci.

The distribution of mineralized pegmatites is not systematic in the Karibib District. The only generalisation that can be made is that they must be sought for in areas of late tectonic intrusive granites. Environs of this nature are common in tectonic belts throughout the world. The primary composition of the granitic magmas will determine the nature of the minerals finally crystallising in residual fractions. In the case of derived magmas, this will also

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depend on the initial composition of the rocks undergoing bestonian, metamorphism and mobilisation. It remains to be seen which rocks may possibly constitute the most likely source of Li and Be in the Damara and Abbabis Systems.

A possible source is suggested by Keith and Degens (1959), who state that B and Li are geochemical "indicators" of shales of a marine environment. The biotite schist horizons of the Damara System, within which large scale granitisation effects are frequently prominent, may thus have contributed to the final pegmatitic end product.

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DESCRIPTION OF THE VARIOUS PEGMATITES

A. GENERAL STATEMENT

This section is devoted to the recording of all field data obtained from the individual pegmatite bodies. A great deal of attention was given to the textural relationships of the various rock and mineral types. The reason for this is that the characteristic coarse and often "giant" structure of pegmatite minerals allows the accumulation of a wealth of diagnostic data from field observations alone, which would normally be impossible without a microscope in other rock types. Among many other important aspects they may serve to elucidate mineral relationships and crystallisation trends within these complex bodies.

In many cases it is difficult to establish a definite time sequence of all the units in a particular body. However, after detailed examination of many pegmatite bodies certain trends are repeated with such regularity that a high degree of confidence is justified in synthesising all the data into a single idealised model. This, therefore, is the approach that has been adopted for the Karibib pegmatites. The next step is to see how this idealised model compares with others from different parts of the world.

The lithium-bearing pegmatites of the Karibib District 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 graphic granite. The economically mineralised portions probably represent volatile-rich fractions from these masses enriched in silica, alumina, alkali metals, and other elements such as lithium, beryllium, columbium, tantalum, bismuth, boron and phosphorous.

In this section 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) 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 margin of a larger mass of late-tectonic coarse-grained pegmatitic granite. While along its footwall the basal pegmatite is intrusive into quartzdiorite, in the hangingwa the upper mineralized zones grade into pegmatitic granite of progressively diminishing coarseness, whose northern boundary is obscured by surface deposits. (Geologic Map, PLATE I).

(b) The Main Ore-Body

(i) Structure

The main ore bodies are contained within an interrupted

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sc[illegible] lithium and beryllium mineralization stretching for a total len[illegible] of approximately 3,200 feet in a N.W. - S.E. direction. The east[illegible]n section of this zone is the richest and has been quarried over a continuous strike length of 1100 feet. Here the average thi[illegible]ss of the economically important zone is 100 - 150 feet. (Map: PLATES V and VI).

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 PLATE V). The higher portion forms the main Rubicon ore body with a central quartz-rich core zone, while the northern "limb", wit[illegible] less thick quartz core, provides subsidiary ore (PLATE V). 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° S.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.

(ii) 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 foot wall-rock is along its southern margin within the adit driven across the entire ore-body (PLATE VI). Here a finer grained border zone, not more than six inches thick, is made up essentially of perthite, quartz, and garnet, probably spessartite. The perthites are mostly 1/4 - ½" in size; locally larger crystals (1½" - 2") are characteristically oriented with their longer axes perpendicular to the contact. This zone is fo[illegible]wed inwards by another, the wall zone, 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 eccentric 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 ground-mass of albite-quartz-muscovite of 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. 16). 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 an An-content of the groundmass albite to be low, viz. 3 - 9% (See page 97).

Black schorl tourmaline occurs as an accessory in this zone. Small branching veinlets of schorl cutting into microcline perthite, together with the corrosive habit of groundmass albite

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towards perthite, indicate that these two minerals largely crystallised after the perthite.

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 1/4 inch of quartz and muscovite, the latter sometimes replaced by biotite or blue tourmaline, are separted 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 crystallising zone responsible, e.g. sudden local release of pressure with consequent rapid crystallisation?

Certain variations in this zone are not recorded on the map (PLATE V). 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 hanging wall side of the economically mineralised 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 (PLATE V). 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, $(Mn,Fe)_4(OH)_5(PO_4)_3$ (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. 19). The perthite crystals appear to have acted as crystallisation nuclei for the albite, quartz and muscovite.

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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. 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 itself. Either the logs crystallized before the beryl and lepidolite zones were formed (highly improbable if one envisages the pegmatite as crystallising 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 crystallisation 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 hanging wall 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, PLATE V). Viewed as zones of lithium mineralization only, the latter is symmetrically disposed 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 exaggerated in PLATE V.

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 (PLATE VI). The adjacent lepidolite-albite phase shows very clear corrosive contacts with the petalite, a fact which makes it desirable to know quantatively how much lepidolite might have been derived from the 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 (PLATE V and VI) 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 1/4 - 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.

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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 concentration 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 slots of extremely fine-grained pure albite in which individual grains can be distinguished microscopically only. In size the slots vary from ¼ - 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 result of a sudden release of pressure? They could have been isolated spots in the crystallising 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 1½ 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.

(c) The Hangingwall Ore-Body

For the structural position of this subsidiary northern ore-body reference should be made to the initial account and to PLATE V. 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.

Lithium mineralisation 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

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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 (PLATE V). 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 (PLATE V). 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 (PLATE VI - extreme western beryl zone shown on map).

(d) Other Ore-Bodies

(i) Rubicon West Ores

1. General Statement

Immediately west of the main Rubicon ore-body there occurs a sporadic zone of Li and Be- mineralization which continues for a distance of 2,100 feet in a northwest direction. The 300 feet continuous zone of mineralization occurring immediately to the west of Rubicon is known as the B-ore while further to the northwest a quartz blow is developed which has been prospected sporadically on its margins for beryl and is called the C-ore.

2. The B-Ore

The pegmatite consists of three basic units:

(a) An outer zone of albite-perthite-quartz-muscovite.

(b) Beryl-bearing zone. 2 - 3 feet wide. Cleavelandite-muscovite-quartz-beryl-columbite (amblygonite?).

(c) A quartzose core zone rich in Li-bearing minerals 6 - 15 feet wide.

The outer zone is essentially similar to that found in the main Rubicon ore, consisting of a finer grained (1/4" - 1") matrix of albite, quartz and muscovite in which there occur larger crystals of flesh coloured perthite varying from fractions of an inch to several feet in size. Beryl crystals have been found, but these are rare. One particular individual occurred some 12 feet from the main beryl zone and weighed several hundred pounds.

Occurring as a shell enveloping the central core zone is

a distinct unit which contains scattered beryl crystals, or locally, a concentration of these. Cleavelandite is the major constituent while muscovite and quartz occur in lesser amounts. Accessories are beryl, columbite and lithiophilite. Figs. 20 and 21 show the typical beryl, columbite paragenesis. Large perthite crystals showing evidence of having been replaced by cleavelandite are found in subordinate amounts. These possibly represent components of the outer granitic zone which have survived replacement action to varying degrees.

The core zone is of variable thickness, averaging 6 - 15 feet and locally swelling out to 30 feet. Dips of 50°- 70°W. have been measured. but at some localities a distinct flattening in depth to the north seems indicated, (e.g. the easternmost workings show irrefutable evidence of a relatively shallow dip of the core zone to the north.)

Lithium minerals are characteristic of this unit but tend to have a rather random distribution. The major components are lithia -micas, albite, petalite, amblygonite and quartz.

The lithia -micas are represented by mauve lepidolite and a grey massive lithium-bearing mica. Relatively pure masses are mixed with varieties in which sugary albite and quartz are the major dilutents. This mixing may be essentially even, or else veins and bands enriched in albite are present.

Petalite, which is often pinkish in colour due to the presence of hectorite, generally has a random distribution. In some places, however, where the ore zone swells out to form a larger body, petalite has been observed to distribute itself along the outer margins of the core zone. The petalite crystals are generally a few feet in their maximum dimension.

Amblygonite is scattered throughout the economically important zone. It may either be found in association with petalite or else together with the lepidolite-albite rock.

Quartz is scattered throughout the zone, often forming scattered lenses which may reach several feet in size.

In general, therefore, this pegmatite zone shows a striking similarity to the main Rubicon ore-body. The obvious difference is the non-fractionated nature of the core-zone.

3. The C-Ore

Due to the limited amount of opening up on this ore-body only an idealized section of the zoning will be given below.

Outer zone:	0 - 10 ft.	Coarse grained pegmatitic granite consisting of perthite, albite, quartz, muscovite and garnet.
	10 - 18 ft.	Muscovite-quartz-albite rock with minor amounts of perthite. The muscovite occurs as largish crystals often forming booklets up to 18" in diameter. Albite may locally be so abundant that it dominates over the other minerals.

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18 - 40 ft. A zone of albite-perthite-quartz-muscovite. The perthite often displays a graphic granitic texture, and the individual crystals may be several feet in size. These larger crystals lie in a matrix of albite-quartz and muscovite essentially similar to the zone lying adjacent to the economically mineralised zones in the main Rubicon ore and the B-ore. A systematic intergrowth of quartz and muscovite is also present, where quartz occurs as narrow parallel oriented rods in the muscovite, simulating the graphic-granite texture.

40 - 55 ft. This is a zone made up of blocky perthite crystals lying in large masses of milky quartz. The feldspar crystals are up to 6 x 2 feet in size and are generally euhedral in shape. It is not possible to separate the zone into a blocky perthite zone and a quartz-core, as the perthite crystals are scattered throughout the quartz. Beryl is occasionally developed in this zone particularly close to the margins of purer, and larger quartz concentrations. Lithiophilite is found in a similar milieu. This mineral alters to a structureless Mn-Fe-rich wad which in turn alters to smaller masses of purpurite (fig. 22).

(ii) The D-Ore

Occurring approximately 700 feet to the south of the main Rubicon ore is a narrow zone of lithium-bearing mineralisation which extends for a distance of 800 feet in a northwest direction, and has an average thickness of 8 - 10 feet. The dip of 60 - 65° to the north.

The outer zone again is an albite-perthite-quartz-muscovite rock, in which larger perthite crystals lie in a base of albite-quartz-muscovite.

The core-zone is made up of quartz rich masses separated by lepidolite rich masses. At some localities quartz lenses overly the lepidolite rich bodies.

The lepidolite masses are mixed with quartz and feldspar in varying amounts. The felspar, either sugary-albite or cleavelandite, may be evenly mixed with the lepidolite or else occurs as distinct veinlets. Lepidolite often gives way to massive grey lithium-rich mica.

(e) Summary of Zonal Structure

The ore-bodies, described so far reveal a symmetrical pattern which can be divided into the following succession of zones:-

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(i) outer pegmatite zone: albite-perthite-quartz-muscovite. Essentially very coarse grained granite.

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

(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 to some extent replacing petalite. This residual system was probably trapped below the petalite zone (e.g. "hooded" zone of the North American investigators). Helicon II, described on page 39 , shows a similar feature. Here the core zone at one locality consists of massive petalite followed down dip by a lepidolite-rich zone.

8. THE HELICON AREA

(a) General Statement

Two large pegmatite dykes occur in this area which is located 13 miles east-south-east of Karibib on the northeastern corner of the farm Okangava Ost (Geological Map PLATE I). These two bodies, Helicon I and II, are described separately starting with the southern pegmatite Helicon I.

(b) Helicon I

(i) 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 schists, alternating with marble layers, make 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 southwestern 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.

(ii) Zoning of the Ore-body

Zoning is described from outer zones inwards towards the quartz core (see PLATE VII).

1. Albite-Quartz-Muscovite (Perthite) Zone

Data from this zone were not gathered from continuous

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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-quarts-muscovite. Albite is very commonly of cleavelanditic type which tends to occur independently, while quarts and muscovite are intimately associated. Locally quarts-muscovite intergrowths reveal a characteristic "conglomeratic" type of texture, with ¼ - 1½" rounded quarts nodules lying in a finer-grained matrix of muscovite and quarts. Such masses reach several feet in size, but are not common. Near the mineralised 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-quarts 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 quarts 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 (1/4 - 3/4 inch average grain size) matrix of albite-quarts-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 muscov[illegible] 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 quarts 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, 1/4 - 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.

2. Lepidolite Zone

At a 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 (PLATE VII). The zone virtually pinches out in this direction, only small lens-like bodies up to 100 feet in width of sugary albite rock with minor lepidolite occurring adjacent to the quarts core. The highgrade ore occurs in

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the east. 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 lithia-mica lying marginally in the quartz core as irregular blobs. The latter are invariably bordered by a 1 - 3 feet 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.23). 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 segregated 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 1/4 - ½ 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 mineralisation 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 1/8 inch or less in diameter. Larger aggregates also occur, such as the rounded inclusions 1/4 - 3 inches in diameter of micrographic albite found at Rubicon. Stellate forms of albite are also found not exceeding ½ inch in diameter. A curious feature is the occurrence of fine-grained albite pseudomorphic after larger grains 1½ 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

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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 or contorted 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.24 and 25). 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.24) may be later than the albite. Rounded involute and convolute structures (fig. 25) suggest some form of rotation and distortion of plastic material during the period preceding 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. 24, lepidolite may be later. But far more commonly, albite is later, as shown by the frequent exposures in which albite definitely crosscuts, 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.

3. Footwall Beryl Zone

Beryl is found on the footwall (south) side of the quartz core. It is generally of whitish colour and 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 and 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 characterized as cleavelandite-beryl-bearing, the cleavelandite certainly post-dating the massive lepidolite.

4. Hangingwall Mineralized Zones

Immediately overlying the quartz core there occurs an

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interrupted unit of mineralization which is differentiated down dip into three distinctive zones:

- amblygonite zone on the core margin
  followed downwards by:
- a "barren zone" passing in depth into:
- a beryl-columbite zone.

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

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 mineralisation 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 horisontal 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 fro 6 - 9 inches to 5 feet in diameter.

The main constituents of this zone are sugary alblte, 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 in the overlapping 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 quarts blobs (1/4 - 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.

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).

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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. 26). 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.

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.

Beryl-Columbite-Tantalite Zone

Down dip, below the barren zone, a spectacular enrichment of beryl and columbite 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.

(iii) Summary

The Helicon I 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- zone. Sugary albite, with minor lepidolite, is ubiquitous in the entire hangingwall zone adjacent to the quartz core, but may postdate 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 asymmetry of the zoning is the most prominent feature of the pegmatites described so far.

(c) Helicon II

(i) Structure

The pegmatite forms a long persistent eastwest striking

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dyke-like body which outcrops for a distance of 5,400 feet, the eastern 2,300 feet being economically important. The thickness of the body varies, but on an average is 30 - 50 feet. It has a distinctly cross-cutting relationship to the dolomitic marbles in which it occurs. The latter have an almost parallel strike to the pegmatite but dip at 20 - 45°S, while the dip of the dyke varies between 30° and vertical, but is generally 55 - 80°S.

The apparent apophysal portion of the pegmatite which is observed in its central part (PLATE VIII) is due to its flattish dip at this locality

Due to its great length and complex, variable nature, the pegmatite dyke has been subdivided into several sections described separately, over which exposures are fairly continuous and allow systematic mapping.

(ii) Description of the Pegmatite

1. Section I (East)

Two main zones can be distinguished in this area, i.e. an outer ore of plagioclase-quartz-muscovite and an inner central core zone of lithium minerals and quartz.

(a) Albite-Quartz-Muscovite Zone

The contact with the surrounding marble is generally highly weathered and reveals the presence of clay minerals. However, it would appear that the contact is rather sharp and the only visible effect of wall rock alteration is the development of skarn rock, rich in tremolite The zone of alteration is approximately 9 ins. to 1 ft. in width. This eastern terminal portion of the pegmatite is rather narrow with an average width, where exposed, of 2 - 5 ft.

The major constituents of this outer zone are albite, quartz and muscovite with greenish beryl and schorl tourmaline as accessories. A coarsening in the size of muscovite crystals towards the core zone is evident (3 - 4 ins. diameter in contrast to 1 - 1½ ins.). Immediately adjacent to this zone muscovite commonly forms larger reniform masses with narrow spines of lepidolite radiating out from the latter core-wards. Albite also shows a change with approach to the core-zone, developing a distinctly platy habit. Within this type of albite rare thin platelets (1/16 - 1/8 ins. in width) of columbite are often developed.

(b) Core Zone

This zone is exposed over a length of 150 feet, and is 10 - 12 feet wide, locally swelling to as much as 20 feet. The dip is essentially vertical.

Several minerals constitute this central core, viz. lepidolite, albite, petalite, quartz, amblygonite, topaz and beryl.

Petalite reveals a systematic distribution. It is generally confined to the outer margins, and is particularly concentrated on the north side of the core zone, where it forms an almost pure unit up to 6 feet in width. On the southern margin, petalite is only sporadically developed. This distribution can be

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interpreted either as being due to the presence of a complete petalite shell enveloping an inner core rich in lepidolite and albite, or else as representing the flanks of a petalite "hood" above the lepidolite-albite rich core.

The petalite crystals are generally large, up to 4 - 5 feet in length and 9 - 10 ins. wide. It is of a dull waxy opaque type. In between the individual crystals quartz is often developed, sometimes accompanied by a bluish-green topaz. Nearer towards the lepidolite-albite rich core the interstitial material is lepidolite, albite and quartz. Locally, veinlets of lepidolite-albite rock occur within the petalite, with parallel alignment and following the main cleavage direction.

Amblygonite crystals are scattered throughout the petalite rock. These are typically rounded and may be up to 1 ft. in diameter

As the centre of the core zone is approached, lepidolite and albite increase in importance until petalite is no longer present. When examined in detail, the lepidolite-albite zone varies considerably. Purer lepidolite masses lie in varieties mixed with varying amounts of sugary albite. Banded types are locally present; lepidolite-rich layers alternating with albite-rich layers. The banded type often displays folded and arcuate structures. Other varieties consist of purer lepidolite ores which are veined by albite, the individual veins having an irregular distribution. Mottling in lepidolite masses is caused by the presence of ½ - 1 in. concentrations of albite, which are often lens-shaped or stellate.

Quartz occurs in this zone either as evenly distributed grains in the lepidolite-albite rocks or else as larger segregated masses attaining sizes of several feet. Topaz, beryl and amblygonite have a tendency to occur at the margins of these quartz bodies, where they are associated with cleavelandite. The average grain size of these accessory constituents is 1/4 - 3 ins. in diameter.

2. Section II

In this area quartz is more abundant, occurring as two distinct blows within lepidolite-albite rock to form a central core zone surrounded by an outer aggregate of albite-quartz-muscovite which extends to the pegmatite-marble contact. The latter, however, is not well exposed in this section.

(a) Albite-Quartz-Muscovite

The average size of the individual minerals in the outer zone is ½ - 1 ins. in diameter. While quartz and muscovite are found in close association (greisen) albite is spread more independently throughout the rock, though on occasion it is linked with quartz. Albite and muscovite do not show a propensity to occur together. Cleavelandite is the prominent phase adjacent to the core-zone. Columbite, developed as plates 1/8 - 1/16 ins in width and 1½ ins. in length, may be found together with the cleavelandite. Massive muscovite nests with radiating spines of lepidolite are again characteristic textures adjacent to the core-zone.

(b) Core Zone

Two large milky quartz cores are prominent in this zone, being surrounded and separated by lepidolite-albite aggregates of highly variable character.

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On the margins of the eastern quartz blow the rock consists essentially of sugary albite with lepidolite. The latter may be evenly disseminated in subordinate amounts within the albite or concentrated into distinct bands, generally 1 - 3 ins. in width, which display folded shapes. Immediately adjacent to the quartz core cleavelandite occurs in a narrow band 4 - 6 ins. in width, in which stout 1 - 2 ins. wide euhedral columbite-tantalite crystals are found.

The main lepidolite-bearing mass shown in PLATE VIII exhibits diversity of rock types. This is mainly due to differences in the relative proportions of lepidolite to albite. The unit consists of purer masses of dense purple lepidolite, varying from a few inches to a few feet in overall dimension lying in a matrix made up of sugary-albite and varying amounts of lepidolite. Quartz occurs sporadically.

The quarries within this zone reveal textures useful in interpreting the crystallisation history. Close examination of the purer lepidolite masses (fig.27) reveals that they are often bordered by rims, of variable thickness, of less pure lepidolite impregnated by albite. These masses together with others showing varying degrees of albite admixture lie in a matrix rich in sugary albite. The latter often contains bands enriched in lepidolite which frequently exhibit contortions (fig. 27). These features suggest that in the final stages of crystallization larger masses of already partially consolidated lepidolite were surrounded by an albite-rich residual phase. The latter must have been able to permeate and break up larger lepidolite masses in part redistributing possibly even redissolving lepidolite within the residual albite phase, which on recrystallization then gave rise to a rock in which lepidolite was more evenly disseminated. Undigested fragments of lepidolite rock are still clearly discernable, while partial digestion or a high degree of permeation gave rise to the diffuse irregular masses and bands. The frequent contortion of the latter indicates that movement must have taken place in a semi-consolidated state. Locally within this variegated rock sequence are found rounded aggregates of microcrystalline albite 1/4 - 1/2 ins. in diameter. These are identical in character to those found at Rubicon within the lepidolite-albite rocks and whose possible mode of origin has already been referred to.

On the quartz-core margins, large bodies of massive purple or grey lithium-bearing mica occur. These are commonly associated with, and frequently veined by cleavelandite (fig. 28). Speckling by albite, often as stellate masses, is also found. These features again suggest that albite is later than the lepidolite. Beryl in crystals varying from 3 - 5 ins. in diameter have been found in association with this cleavelandite.

Apart from the two large blows, also smaller quartz lenses are locally developed in the lepidolite albite zone. Topaz, beryl and columbite are often associated with these, usually accompanied by cleavelandite.

A noteworthy feature is that also dark purple fluorite has been found in association with cleavelandite within this zone.

3. Section III

In this section the following zones can be distinguished from the pegmatite contacts inwards:

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(a) albite-quartz-muscovite

(b) lithium-bearing ore zone

(c) core margin mineralization

(d) quartz core.

(a) Albite-Quartz-Muscovite

This rock reveals similar features to those found elsewhere in the pegmatite. It consists of rather even grained rock, the individual minerals being 1/4 - 3/4 ins. in diameter. As usual, quartz and muscovite reveal a tendency to occur together (greisen) with minor amounts of albite, while albite itself is found independently or associated with quartz.

Adjacent to the lithium bearing zone, or when this is absent, the quartz core, rounded nests of muscovite with radiating masses of lepidolite are again found in a cleavelandite rich matrix. The width of this cleavelandite rich unit is 6 - 10 ins. at one locality.

(b) Lithium-bearing Ore Zone

Petalite once more makes its appearance in this section, occurring as a narrow 2 - 3 ft. wide and 10 ft. long lens lying adjacent to the quartz core (not shown on map). It is surrounded by lepidolite and albite.

Massive grey lithium-bearing mica occurs adjacent to the quartz core while purple lepidolite becomes more dominant away from the latter. As usual both types are associated with sugary albite, either in the form of an even textured mixture of the two minerals in varying proportions or differentiated into bands. In the vicinity of the quartz-core, veining and brecciation by cleavelandite becomes prominent.

Quartz is present in the form of evenly disseminated grains. Its distribution, however, is erratic. Locally developed quartz lenses are usually surrounded by cleavelandite which may contain beryl crystals 3/4 - 5 ins. in diameter.

(c) Core Margin Mineralization

Along the quartz core margin it is common to find an enrichment of cleavelandite in which crystals of beryl and columbite are developed.

(d) Quartz Core

This consists of massive milky white quartz.

4. Section IV

This section opened up by underground workings shows rather more diversified zonal differentiation of this pegmatite which as shown in PLATE VIII has assumed a more complex configuration. The following zones are distinguishable:

(a) albite-quartz-muscovite-perthite

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(b) beryl-bearing zone

(c) lepidolite-albite zone

(d) petalite zone

(e) quartz core.

(a) Albite-Quartz-Muscovite-Perthite

This makes up the outermost shell of the pegmatite and consists of an albite-quartz-muscovite rock in which are scattered rare crystals of flesh coloured perthite. The latter are up to 1 - 2 ft. in length. An interesting texture is developed by systematic feather-like intergrowths of muscovite and quartz. These have been described recently by Orville (1960).

A banded rock type is locally developed in which coarser ½ ins. bands of albite-quartz-muscovite are separated by a fine-grained (1/16 - 1/8 ins.) albite -quartz rock. Bluish green beryl crystals (1 - 2 ins. diameter) are scattered throughout the former phase. The relationship of this banded rock type to the overall pegmatite pattern could not be clearly established. It is suggestive, however, that it occurs fairly close to the quarts core (1 - 2 ft.) and may, therefore, have resulted from a metasomatism of the ordinary albite-quartz-muscovite rock by a later phase, rich in albite, to give rise to the bands of sugary albite.

(b) Beryl-bearing Zone

The beryl zone surrounds the inner lithium-bearing units and quartz core in a fairly uniform, 1 - 3 ft. wide, shell. It is essentially composed of cleavelandite, throughout which beryl, white and pinkish in colour is scattered as subhedral or euhedral crystals up to 1 ft. in length and 3 - 6 ins. in diameter. These crystals may project into adjacent zones.

A very striking feature already mentioned from previous sections is the abundant development of reniform nests, 6 - 9 inches in diameter of concentric flakes of muscovite attached to the inner margin of the outer albite-quartz-muscovite zone and projecting together with radial, narrow tapering spines of lepidolite up to 5 ins. in length into the surrounding cleavelandite (fig.29).

This zone marks the transition from the outer "granitic" shell to the inner lithium-rich units and quartz core. The transition is characterised by the cessation of disseminated quartz and muscovite. There is thus a marked reduction, finally even complete termination, of hydroxyl-bearing mineral formation, viz. the micas. Already within this zone lithia is introduced (spines of lepidolite) and when the crystallization of hydroxyl-bearing minerals is resumed in bulk, lepidolite is the characteristic phase formed. The renewed precipitation of quartz in bulk is withheld until the very last stage (quartz core).

The beryl-cleavelandite zone, therefore, marks an important stage in pegmatite crystallisation, progressive concentration of the minor components now being effective.

From now onwards only albite and, in the final stages, quartz are precipitated as diluents of economic minerals.

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(c) Lepidolite-albite Zone

Of genetic significance are the occurrence of finger-like protrusions of lepidolite-albite which project into the outer albite-quartz-muscovite rich pegmatite phase. These apophyses are up to 5 - 20 ft. in length, and 2 - 4 ft. in width, tapering outwards from the lepidolite-albite unit. Such macro-textures strongly support the conclusion that the outer pegmatite phase is earlier in the crystallization sequence.

As elsewhere the composition of this zone is extremely complex when examined in detail. Both grey and purple lithia-micas occur, mixed with albite in varying proportions. Banding due to alternating purple and grey types is developed in places. Banding may also be caused by albite-rich layers alternating with lepidolite-rich layers. Viewed as a whole the lepidolite-albite unit consists of massive purer lepidolite bodies lying in a sugary albite matrix containing varying amounts of lepidolite.

Locally quartz occurs evenly scattered in the varying rock types as smallish 1/16 - ¼ ins. grains.

As in section III there is a decided tendency for the massive grey lithia-mica, bordered and veined by cleavelandite, to occur adjacent to the quartz core, while the purple variety dominates further away from the latter.

(d) Petalite Zone

This zone shown in PLATE VIII is relatively narrow being some 175 ft. long and up to 8 ft. wide. The major constituents are petalite, quartz, amblygonite while fine grained lepidolite and albite are subordinate. Petalite occurs as logs of varying size up to 8 ft. in length and 18 ins. in width. Quartz occurs interstitially between the petalite and is locally accompanied by rounded amblygonite bodies. The latter vary in size, the largest mass being 15 ins. in diameter.

Lepidolite-albite, sometimes associated with quartz, also tends to occur interstitially between larger petalite crystals: sometimes this aggregate also veins the latter as already described from Rubicon.

(e) Quartz Core

This is made up of milky white quartz.

5. Section V

Outcrops and quarrying operations are so sparse in this section, within which the pegmatite body is comparitively narrow, that only certain generalization can be made.

The area is dominated by a prominent quartz blow 200 ft. in length and 12 - 15 ft. in width. Locally on the margins of the quartz irregular masses of dense (1/4 - 1/8 ins.) grey mica occur. In one locality pale blue tourmaline crystals are developed as radiating aggregates within the latter.

Grey mica masses give way on strike to bodies rich in sugary albite containing scattered amounts of the same grey lepidolite

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or the darker pink variety. Where these rock types are absent the quartz core is surrounded by a thin oleavelandite shell, about 9ins. in width, containing narrow muscovite spines similar to those already described from Section IV.

The outer pegmatite zone is not well enough exposed to permit systematic observation. It appears to consist of albite-quartz-muscovite rock.

6. Section VI (West)

As in the eastern termination of this long pegmatite so also in the western the nature of the zoning differs somewhat from the pattern found in the central section. The vertically dipping core of the pegmatite here consists essentially of petalite which forms a capping and is followed vertically downwards by a rock rich in lepidolite. Surrounding the petalite portion of the vertically fractionated core-zone is a narrow shell rich in quartz, but also containing petalite, amblygonite and albite. Forming the outermost shell of the pegmatite is the normal albite-perthite-quartz-muscovite rock.

The following zones, therefore, may be distinguished:-

(a) Albite-perthite-quartz-muscovite

(b) Narrow quartz rich transition zone

(c) Lithium-bearing core zones - (1) Petalite Unit
(2) Lepidolite Unit

(a) Albite-Perthite-Quartz-Muscovite

Two exposures in this section allowed study of the contact relationships. Some four feet from the contact the country rock is a greyish dolomite with flattish nests of tremolite, the latter lying in the main foliation plane. Adjacent to the pegmatite the dolomite assumes a banded character, white layers alternating with grey layers. There is no apparent change in the mineralogy of the rock, the bleaching of bands being the only visible change. The actual contact is mostly marked by a solution fissure 6 - 9 ins. in width, filled with rubble and sand. Where observable the contact rock consists of massive dull pale-green serpentinous material.

Along the contact the pegmatite itself consists of an albite-quartz-muscovite aggregate with scattered large crystals of pink perthite. The latter vary in size from less than an inch (near the marble contact) to as much as 2½ft x 10 ins. (close to the transition zone). As usual quartz and muscovite are commonly found in close association with each other (Greisen). Plumose intergrowths of these two minerals, forming nests several inches in diameter, are encountered sparingly throughout the zone.

Banding, almost at right angles to the pegmatite contact, is locally developed close to the transition zone. It is caused by:-

- Quarts and muscovite concentrating into distinct layers.

- Sugary-albite occurring as separate layers, often accompanied by a fine-grained pale blue tourmaline.

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- Poorly developed bands where quartz, in grains 1/16 - 1/8 ins. in diameter, tends to be enriched.

- Muscovite may also show a similar tendency of enrichment into fairly distinct layers.

While ordinary albite predominates in the eastern portion of this zone, at its inner margin cleavelandite is the predominant mineral. It either occurs alone or else together with quartz. Muscovite continues to be associated with the latter locally. Crystals of beryl up to 1 inch in length, have been found in the muscovite rock type; when occurring in cleavelandite the crystals are usually larger, up to 5 ins. in diameter. Columbite platelets, up to 1 ins. in largest dimension, also occur.

(b) Transition Zone

The mineral assemblage of this zone is rather variable due to the incorporation of minerals from adjacent zones.

The major constituent is quartz found either as large lenses several feet in diameter or as grains down to less than one inch in size. The larger quartz masses frequently contain beryl and amblygonite, the latter occurring as large masses up to 2 ft. in diameter or as concentrations of small irregular bodies 1/4 - ½ ins. in width.

This texture is remarkably similar to that described from the VANUTRÄSK pegmatite in Northern Sweden by Quensel (1956) who attributes it to the replacement of amblygonite by quartz. In the Helicon II pegmatite the finer grained amblygonite sometimes also occurs in a matrix of grey lithia-mica, albite and quartz. Significantly these mixed aggregates were always found within a zone of smoky quartz which further away grades into the normal milky quartz (fig. 30.).

Albite occurs throughout this zone. Although it may occur as independent masses of relatively fine-grained (1/4 - ½ ins.) cleavelandite, it is also mixed with the other minerals in varying proportions.

Darkish blue manganian apatite is a diagnostic mineral. Although only an accessory, its dark colour and rather large size (1½ - 2 ins. x 4 - 6 ins.) make it conspicuous among the other white and dull coloured minerals. Almost invariably narrow 1/16 - 1/8 ins. veinlets of albite traverse these crystals, indicating its later age. The apatite crystals also tend to have highly serrated boundaries with other constituents of the zone. These features suggest that apatite crystallized at a fairly early stage and then suffered a certain amount of corrosion when the other constituents crystallized.

Petalite is distributed throughout this zone becoming noticeably enriched towards the core, where it forms an independent unit. It is impossible to say whether the petalite started crystallising together with the other constituents of this zone or whether it formed by replacement of some previous phase(s). The point seems insignificant if viewed as a whole, for petalite progressively increases in amount until it must have been virtually the only stable phase to crystallize and form a separate unit in the core.

The petalite crystals vary in size, the average being

2 - 4 ft. x 9 - 12 ins.

Columbite has been found as concentrations of narrow pistolets in cleavelandite and quartz.

Uraninite has been observed as 1/4 - 1/8 in. rounded grains. These were particularly noticeable in the transition zone close to the contact of the petalite and lepidolite units.

(c) Lithium-bearing Core Zone

(1) Petalite Unit

This forms the upper part of the vertical core zone. With an average width of 17 feet mining operations have exposed it for a distance of at least 50 feet on strike, although it continues further. At a maximum depth of 50 feet it is followed downwards by a lepidolite rich unit.

The petalite occurs as large crystals up to 8 ft. by 3 ft. in dimensions. Locally a very subordinate matrix consisting mainly of quartz, but which may be accompanied by amblygonite and apatite is developed. A grey, rather coarse mica (1/4 inch grains) may also occur interstitially.

Close to the contact with the underlying lepidolite unit, veinlets of this mineral together with quartz can clearly be seen to transect and corrode petalite (fig.31). The petalite hood, of the zone, therefore, appears to have crystallized before the underlying lepidolite unit.

(2) Lepidolite Unit

Unfortunately only two exposures of this unit were available for examination. A vertical shaft, however, has proved its persistence in depth for at least 20 feet below the petalite hood. It is, however, not deep enough to ascertain whether the transition zone envelops this unit as it does the overlying petalite unit.

Where exposed, the lepidolite unit consists of massive grey and dark purple varieties intermixed in an irregular manner. Locally lenses of quartz, several feet in size and containing beryl crystals have been observed.

Fragments of brecciated amblygonite within the lepidolite suggest that the lepidolite unit may possibly have replaced portions of the transition zone enveloping the petalite unit.

(iii) Summary

The main feature of the Helio n II pegmatite is the manner in which the zonal units change along strike. There is no single pattern applicable to the entire dyke. In both terminations well differentiated cores are absent. In the same localities vertical crystallization is clearly indicated, the petalite zone capping the lepidolite -albite zone to form a "hood".

The zone immediately adjacent to and presumably preceding the lithium ore zones in crystallization, i.e. the zone marking the transition from essentially "granitic" components to lithium-bearing minerals, reveals particularly clearly the cessation of muscovite

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and quartz as stable phases during this period of crystallisation (cleavelandite and beryl) and the concentration of hydroxyl, silica, lithium and other components in the residual system. (This may be due to an effective increase in polymerization of the lithium mineral components and quartz in the residual system.)

Finally this pegmatite reveals excellent examples of the later age of magary albite with respect to lepidolite.

D. [illegible] PEGMATITE ON OTJUA

(a) Locality

This pegmatite occurs approximately 21 miles east-south-east of Karibib near the northern corner of the farm Otjua (Geological Map, PLATE I).

(b) Structure

An economically mineralized section of a larger pegmatite dyke constitutes the Tanker Ore-body. The pegmatite cross-cuts folded Damara dolomitic marbles, the important section striking west-north-west for approximately 700 feet and having an essentially vertical dip. Local narrow apophyses extending from the pegmatite clearly cross-cut the marbles (PLATE IX). The average width of the pegmatite is 80 - 100 feet.

(c) Description of Internal Structure

The pegmatite lens is characterized by the presence of tourmaline which is often of gem quality. In addition to the latter lepidolite, amblygonite and beryl have been quarried.

Zoning is excellently displayed, allowing the outer pegmatite zones to be mapped and separated into distinct units. The following zones have been identified:-

(i) Border zone of perthite-albite-quartz-schorl.

(ii) Graphic-granite zone.

(iii) Albite-quartz-muscovite-perthite- black schorl tourmaline.

(iva) Cleavelandite-quartz-muscovite-(perthite)-schorl-beryl.

(ivb) Albite-quartz-muscovite-perthite-dark green tourmaline.

(v) Blocky perthite-albite-quartz-muscovite-green tourmaline.

(vi) Lepidolite-bearing zone.

(vii) Core margin (a) Eastern Quarry
(b) Western Quarry

(viii) Quartz core.

(ix) Fracture fillings.

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(i) Border Zone

Unfortunately this zone is not well exposed and also often absent, the graphic-granite bearing zone then lying adjacent to the marbles. However, the narrow apophyses which project well into the wall rock of the pegmatite are representative of this zone. The major constituent is flesh coloured perthite developed as 1/4 - 1/2 ins. crystals lying in a matrix of albite quartz and schorl. The latter constituents are generally finer grained (e.g. 1/16 - 1/4 ins.) though albite individuals may be as large as the perthites.

(ii) Graphic Granite Zone

Feldspar crystals dominate in this zone. They vary in size from 2-3 ins. up to 1 ft. or more, the average size being 6-9 ins. There appears to be a decrease in grain size towards the east.

The feldspar has two distinct colours on surface, being either flesh coloured or white. The former is microcline perthite and the latter albite, identifiable by its well developed twin lamellae. This identification has also been confirmed microscopically.

Both feldspar varieties are almost invariably contaminated by systematic intergrowth with quartz. In the perthite the latter is coarser and typically graphic while in the albite quartz forms myrmekitic intergrowths. No textural relationships could be observed to suggest that the albite was derived from the replacement of perthite.

Another characteristic feature is the occurrence of nests, 2-3 ins. in diameter, in which quartz and muscovite are intergrown in plumose fashion.

Quartz also appears as local independent concentrations of variable size. Schorl is an accessary also of this zone.

On the map (PLATE IX) two local developments have been identified in this zone:

(a) The bulk of the rock consists of pink perthite, subordinate constituents being schorl, quartz, albite and biotite. The latter mineral gives the rock a diagnostic texture due to its development as narrow, randomly oriented platelets 2 - 3 ins. in length and

(b) [illegible] of perthite and albite. A banded texture due to changes in grain size is often developed. Clots, nests and streaks of quartz and schorl are scattered throughout the rock.

(iii) Albite-Quartz-Muscovite-Perthite-Schorl.

Albite, quartz and muscovite form the matrix and the [illegible] part of the zone. In this are scattered perthite crystals of [illegible] size, as well as schorl aggregates associated with quartz.

Quartz and albite frequently occur in close association with each other and locally display corrosive relationships with the perthite crystals. This feature is particularly marked where

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the perthite crystals are entirely surrounded by the matrix or veined by the latter. As a result of replacement the perthite is frequently reduced to disconnected patches of irregular shape.

Schorl is the characteristic mineral of this zone. It has a tendency to occur in rounded masses 2 - 4 ins. in diameter, in which quartz and the tourmaline are intergrown in a manner simulating the graphic granite texture. The size of individual components ranges from 1/16 - 1/4 ins. Larger euhedral schorl crystals, 1 - 1½ ins. in diameter, also occur in the matrix of this zone, generally lying in, or adjacent to, quartz enrichments.

Plumose quartz-muscovite nests are scattered about in subordinate amounts.

Local smallish quartz bodies (1-2 ft. in size) are found and these are frequently associated with a dark green tourmaline which is characteristic of the next zone following inwards.

(iva) Cleavelandite-Quartz-Muscovite-(perthite) Schorl-Beryl

This striking rock type has only been observed in and close to the western quarry where it forms an incomplete shell partially enveloping the central lepidolite zone on its western edge (PLATE IX).

The rock is spectacular in that it is shot full of black schorl and pale bluish-green beryl crystals. The schorl crystals are ½ - 2 ins. in diameter and up to 11 ins. in length. The beryl crystals are rather stumpy, being 1 - 3 ins. wide and not much longer in the direction of their c-axis.

The major constituent is cleavelandite which is often associated with quartz. Muscovite is scattered throughout the rock in subordinate amounts. The average grain size of these constituents is 1/4 - 1/4 ins.

Perthite crystals with highly irregular boundaries are present in only very subordinate amount. The highly corroded boundaries and occurrence of narrow penetrating albite veinlets confirm the replacement of perthite by albite. It is not certain, however, whether this perthite is a remnant of some pre-existing zone.

Locally clusters of dark green tourmaline are found.

(ivb) Albite-Quartz-Muscovite-Perthite-Dark Green Tourmaline

The only major significant difference between this and (iii) is the greenish colour of the accessary tourmaline. Its occurrence is confined to a centrally placed patch, 115 feet long and up to 80 feet wide, in the eastern portion of the mineralized pegmatite. Govers and Frommurse (1925) and more recently Staats et al. (1935) have already described systematic colour variations of tourmaline towards the core in pegmatites.

The characteristic rock type is made up of pinkish perthite crystals varying in size from a few inches to as much as 4 ft. x 1 ft., which lie in a matrix of albite, quartz and muscovite, the latter being 1/4 - 1 ins. in diameter. The perthites reveal rectilinear (intergraphic) as well as irregular corroded boundaries with the matrix.

Apart from the very rare isolated crystals of black schorl, the accessory tourmaline is of dark greenish or dark bluish-green colour. In general it shows a tendency to occur with quartz and muscovite. No systematic intergrowths of these green tourmalines with quartz, as described for schorl in (iii), have been noticed.

(v) Blocky Perthite-Quartz-Albite-Muscovite-Green Tourmaline

This zone is characterised by the presence of giant perthite crystals measuring up to 10 - 12 ft. by 4 - 5 ft. When the perthite is bordered by quartz, the crystals have euhedral outlines, but when they lie in contact with albite, corrosive boundaries are very marked. In the latter case also veinlets of albite are found to penetrate the perthite giants from the surrounding matrix.

Quartz also tends to appear as large lens-like bodies up to 6 ft. in length. The coarseness of the quartz and the microline perthite suggests that this unit is equivalent to Brotzens (1959) [illegible] zone, or may possibly represent a mixing of the quartz [illegible] the blocky perthite zone of the North American investigators. However, in the present instance it forms a uniform zone and is regarded as such. It is located in the central portion of the pegmatite (PLATE IX).

Apart from the large quartz bodies constituting the matrix of the giant perthite crystals, finer grained albite, quartz and muscovite behave in a similar manner. As so frequently in other pegmatites quartz and muscovite are fairly often found in association to form a "conglomeratic" texture, in which rounded 1 - 2 ins. diameter quartz bodies be in a finer-grained matrix of muscovite and quartz. Dark green or bluish green tourmaline, 1 inch in length and 1/4 inch in width accompanies these minerals. Locally nests of tourmaline are developed and the crystals are then of larger size up to ½ - ¾ ins. in width and 2 - 4 ins. long. There is a decided tendency for tourmaline to be associated with the muscovite of the matrix, while in some localities the matrix is almost exclusively composed of quartz and muscovite; at others albite is more abundant and may dominate. As stated, the enclosed giant crystals [illegible] Beryl is only a rare constituent [illegible] [illegible] quartz masses. Bismuth, an unusual accessory, was noted in [illegible] quartz-muscovite rock in a few instances.

[illegible] crystals of microline perthite are then usually [illegible] by albite.

Several exposures have revealed perthite crystals to be entirely surrounded by muscovite borders, up to 4 ins. in width. The muscovite flakes at first have their basal plane parallel to the perthite crystal faces, but then grow outwards concentrically to develop reniform surfaces. It would appear that perthite acted as crystallisation nuclei for the muscovite.

The earlier crystallisation of perthite is also confirmed by green tourmaline very clearly penetrating and veining it (fig.32). This feature was particularly apparent at the contact of a quartz lens and a perthite giant where tourmaline was enriched. Tourmaline and muscovite may also occur together under such conditions to form borders to perthite crystals (fig.32).

[illegible] quartz masses. Bismuth, an unusual accessory, [illegible] quartz-muscovite rock in a few instances.

(vi) Lepidolite-Bearing Zone

Lepidolite ore has been almost completely extracted. It occurred in large amounts in the westernmost quarry bordering on the quartz core. In the eastern quarry it was present in much smaller amounts adjacent to the quartz core. (The eastern occurrences were not mapped because of the small size of the lepidolite-bearing zones which are strictly an integral part of the core margin mineralisation).

The lepidolite ore consists essentially of both mauve and grey zinn mixed with varying amounts of quartz and albite. The grey mica is restricted to northern side of the quartz core, where large ore masses up to 10 ft. in diameter are found in its marginal portion, invariably containing evenly scattered rounded 1/4 - 1/2 ins. grains of quartz. Locally albite also dilutes this ore, its distribution being somewhat irregular in contrast to the quartz.

The mauve lepidolite ore is varied in character, this, as usual, being mainly due to the differing amounts and mode of occurrence of diluting albite. Remnant blocks of the zone occurring in situ show the lepidolite masses to be divided up into smaller bodies by albite. There is generally a gradation from the purer lepidolite to transitional types rich in albite.

In other cases the lepidolite is speckled by stellate aggregates of albite, 1/4 - ½ ins. in size. Quartz also occurs, either as rounded 1/4 - 2 ins. grains or as larger lenses reaching 1 - 2 ft. in length.

The lepidolite zone is generally separated from the adjacent pegmatite phases on both inner and outer margins, by a narrow border of cleavelandite which varies from a few inches in thickness up to several feet. These borders are characteristically crenulated or arcuate in shape and on the core margin are associated with accessorio minerals.

(vii) Core Margin

(a) Eastern Quarry

In the eastern quarry grey and pink lithia-mica occur as irregular masses in the quartz. These bodies may be up to several feet in size and are mixed with varying amounts of cleavelandite which commonly also borders them. Both are comparatively coarse grained for core-margin types (viz. 1/16 - 1/4 ins.) and often contain scattered rounded quartz grains 1/4 - 1/2 ins. in size.

Apart from the lithia-mica masses there are generally other core margin minerals associated with the cleavelandite ores, the most important of which is tourmaline. Nests, 9 - 10 ins. in diameter, of pink opaque tourmaline are found together with the cleavelandite aggregates just mentioned. The crystals are generally ¼ - 1/4 ins. in diameter. A bluish variety is also present, but this is rather uncommon. Generally, however, tourmaline occurs in the cleavelandite ores themselves, but locally individual crystals project into the quartz core from the latter. These crystals are very large, commonly several inches in length and 1/2 - 1 ins. in diameter. The cores of the tourmaline are reddish or pink while the rim is green. The colours are generally deep, though paler varieties of gem quality also occur. The colour zoning is not always symmetrical, some individuals possessing several alternating zones of

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...colour. In some instances the colour of individual tourmalines crystals is wholly reddish or pink within cleavelandite but changes to green in its outer portion where projecting into the quartz core.

Amblygonite also appears on the core margin lying partly in the cleavelandite and partly in the quartz. The crystals are generally euhedral, and not more than 5 - 6 ins. in their longest dimension. It is only rarely found with the lithiaeica-cleavelandite rock described above. Fig. 33 shows the typical amblygonite paragenesis.

Beryl is also characteristic of this unit, always appearing very close to the cleavelandite-quartz contact. Perfectly developed euhedral crystals 10 ins. in diameter and 12 ins. long have been observed.

The entire unit, therefore, reveals a complex assemblage of cleavelandite, lithia-micas, tourmalines, amblygonite and beryl. Opaque pink and bluish tourmalines are found in the lithia micas while deep red and green tourmalines (often of gem quality) are associated with the cleavelandite quartz contact. The thickness of the zone varies from 6 ins. to 4 ft.

(b) The Western Quarry

In this region similar core margin features are observed, the major difference being that the lepidolite zone is well enough developed to form a large independent unit.

Again cleavelandite is the characteristic mineral often developed as arcuate or completely spheroidal masses. The latter are particularly well developed on the southern side of the quarts (PLATE IX) and generally have a nucleus of the outer albite - quartz-muscovite-perthite-schorl zone (fig. 34). Particularly interesting features are revealed. The lower half of the core is a perthite crystal dissected by albite veinlets from the surrounding cleavelandite border. The other half of the nucleus consists of a quartz and muscovite aggregate with very subordinate associated albite, and is separated from the perthite crystal by a narrow quartz-albite band. The first concentric unit outwards from this core-nucleus is composed of two halves: the upper consists of quarts with scattered muscovite aggregates which develop poor reniform surfaces, while the lower is composed virtually entirely of cleavelandite with very subordinate scattered muscovite masses which also have a tendency to develop reniform masses particularly near to the outer adjacent lepidolite-rich unit. The quarts of the upper half of this first shell is clearly cut by numerous branching veinlets of cleavelandite. The next shell is characterized by lepidolite and cleavelandite and this in turn is surrounded by a shell of pure cleavelandite. A narrow 2 ins. quarts veinlet connects the enveloping quarts of the main core zone of the pegmatite with the interior quarts (with subordinate muscovite) of the spheroid, thus suggesting a late-stage origin for this latter quartz (fig. 34).

These spheroidal features are rather common. Another example shows a 9 ins. tabular perthite crystal, lying in a quarts-muscovite-albite matrix, surrounded by a 1 ft. zone of cleavelandite radiating outwards towards the main quarts core of the pegmatite. In the middle of this cleavelandite shell a narrow poorly developed lepidolite shell is indicated, the spines of the latter widening away from the spheroid nucleus in the direction of the enveloping main quarts core.

Similar zoned spheroidal bodies are found in lesser

abundance also along the northern margin of the main quartz core eg its contact either with the lepidolite zone or other units (PLATE II).

As in the eastern, so also in the western quarry abundant coloured tourmalines are found in the cleavelandite-rich core margin, which here has a variable thickness of a few inches up to 3 feet. Near the quartz core contact the most common type of tourmaline is a pinkish variety with a green shell. Again crystals wholly pink when surrounded by cleavelandite may develop an outer green shell, or become entirely green, when projecting into the main quartz core. In localized areas tourmaline is enriched within the cleavelandite to form radiating "suns". The central parts of these "suns" consist of pink and bluish types (latter are uncommon), which are followed outwards by pale greenish tourmalines, and these in turn are followed by a unit of pink tourmalines which give way to green varieties or are surrounded by a green shell when projecting into the quartz as already described. The mineral ankerite is occasionally found in the central parts of these multicoloured radiating tourmaline "suns".

Other minerals found in this paragenesis are wolframite and small 1/8 inch monazite crystals.

(viii) Quartz Core

Milky white quartz forms the bulk of the pegmatite core. A druse containing smoky quartz crystals several feet in length was exposed in the eastern quarry.

(ix) Fracture Fillings

This pegmatite reveals a spectacular development of large but narrow planar fractures which definitely cross cut the outermost pegmatite zones. These are particularly well developed in the eastern quarry and in section appear as narrow veins, but where they have been exposed along their two major dimensional axes, reveal a distinctly planar form.

The fractures project out from the quartz core (or close to it) into the surrounding albite-quartz-muscovite-perthite zones for distances of 3 - 8 ft. No exposures permitted observations showing the relationship of the fractures to core-margin and lepidolite units. The strike and dip of these fracture-fillings varies considerably.

The characteristic feature of these fracture fillings is the development of muscovite with its basal cleavage oriented parallel to the fracture planes. Tourmaline crystals, dark greenish in colour, lie with their c-axes in the fracture plane.

Muscovite also occurs together with quartz in pillars oriented perpendicular to the fracture planes, the muscovite still, however, having its basal cleavage aligned parallel to the fracture surfaces. Smaller amounts of albite may also appear in this association.

Concerning the age relationships of these fracture fillings the following suggestion is made. No fractures were ever found in the quartz core and thus they must be pre-quartz core in age. They also cross cut the outer albite-quartz-muscovite perthite-green tourmaline zone and thus clearly post date this unit. As mentioned above no clear age relationships could be established with respect to the core-margin mineralisation but it can be mentioned that the tourmalines of the core margin are bright coloured varieties while those in the fractures are dark green. Since the brighter coloured

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tourmaline varieties may form later in the pegmatite crystallisation sequence than the darker more Fe-rich members. (schorl, dark green tourmaline) it might be possible that the core margin mineralisation post-dates the formation of the fractures.

(d) Summary

This pegmatite reveals certain significant features. the most important of which is the zonation of tourmaline colouring in the body as a whole, viz:

	Colour of Tourmaline
Graphic Granite	Black
Albite-quarts-muscovite-perthite (a)	Black
Albite-quarts-muscovite-perthite (b)	Dark opaque Green
Cleavelandite-quarts-muscovite-beryl	Black
Core Margin	Pink, Red, Pale Green, Pale Blue.

Staatz et al (1955) have published data from the Brown Derby Nos. 1 and 2 pegmatites, Gunnison County, Colo., and found systematic colour changes in tourmalines from the outer wall to the core, viz. black, dark green, blue, light green, pink. This S.W. African example is remarkably similar except for the telescoping of several colour varieties on the core margin. Identical features have also been described by Gevers and Frommurze (1929). According to Staats et al (op cit) the significant changes in tourmaline towards the core are the increasing concentrations of K, Rb, Cs, F and Li, while Fe, Mg, Ti, Na, Co, Ni, Cr and V decrease in concentration towards the core. The main variation in composition is the substitution of lithium for iron.

Bradley and Bradley (1955) have suggested that valency and bonding of iron and manganese are possibly responsible for the pink and green colours in zoned tourmalines. Pink tourmalines should contain divalent manganese and green ones ferrous iron. However, pink tourmalines contain also ferrous iron and the green ones often contain a high content of manganese. It is suggested by these authors that stringent electronic conditions in the tourmalines have to be provided for Mn to produce a pink colour. In the green crystals the total iron content is always in excess of that found in pink varieties, and it seems that certain limiting values of iron content produce green colours even if manganese is present.

Another noteworthy feature of this pegmatite is the variation in zoning along strike, already commented on in the case of the very long Helicon II pegmatite. The central portion is similar in many respects to Brotzen's (1959) fundamental pegmatite type, in that it reveals a graphic-granite zone followed corewards by a pegmatitic zone of giant perthite mixed with quartz. However, where Li-bearing zones are developed there is the usual tendency for the pegmatite to fractionate in the manner common to the other pegmatites of this district, i.e. an essentially granitic zone followed inwards by a lithium-ore zone and the quartz core. Core margin mineralisation is common to most of the pegmatites of the Karibib district.

Certain observations from this pegmatite suggest that the quartz core consolidated after the lepidolite zone and core margin minerals.

This pegmatite also reveals the presence of fracture fillings which definitely post-date the outer granitic and pre-date the quartz core and possibly also the core margin mineralisation.

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E. THE KARLSBRUNN AREA

(a) Locality

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

(b) Structure

This pegmatite forms a highly irregular outcrop pattern (PLATE X). It is intrusive into dolomitic marble of the Marble Series, which contains 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 quarts core forms a prominent krants below which the ground slopes to the east.

The detailed structure of this pegmatite is extremely complex (PLATE X). 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 PLATE X) give a good idea of the attitude of the mineralization in this area. These exploit a beryl-rich zone which is 70 ft. long, 8 ft. wide, and dips vertically down to the maximum depth attained (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 ft. 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 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 N20°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, and albite.

(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 (20 x 4 ft. down to smaller individuals 1 ft. x 7 - 9 ins.) which lie in a matrix of albite-quartz-muscovite, the latter three minerals varying in relative proportions. As at Rubicon and elsewhere 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 crystallised 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. Quarts 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 quarts. Near to the lithium-bearing zones the albite is distinctly of cleavelandite type. It tends to occur on its own or together with quarts. Small beryl crystals (1 inch in diameter) and columbite are sometimes found with the cleavelandite of this zone.

As a generalisation, it can be said that the amount of perthite seems to increase towards the inner lithium-bearing zones where it may make up 30 - 40% of the rock. Further away from the lithium zones, muscovite and quarts increase while perthite decreases Here the quarts and muscovite are very often intergrown in a manner simulating graphic granite. The quarts "pencils" are mostly rather coarse, 1/8 - 1/2 ins. 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 crystallisation 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, 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 quarts core, which appears to peter out northwards causing the petalite to lie directly on the lepidolite zone. In the line of section (PLATE I) 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 ft. 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 crystallisation. Locally, quarts forms the matrix, sometimes

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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. 35).

Amblygonite is found fairly evenly spread throughout the whole zone. Individual masses have sizes 4 x 2 ft. and 3 x 1 ft. 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-quarts-albite-beryl.

(iii) Lepidolite Zone

High-grade lepidolite ore is only found below the quarts 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 cleavelandite 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 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. 36 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 quarts bodies of variable size which, without exception, show a marginal development of cleavelandite containing rubellite, topaz, and amblygonite.

(iv) Core Margin

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 ft. in diameter, of massive grey lepidolite occur immediately below the quartz. Their margins, usually containing albite, are locally enriched in columbite occurring as subedral crystals 1/32 - 1/4 inch in size. Blue apatite of the same size occurs together with columbite. Beryl, in small 1/2 - 3/4 inch crystals, is distributed in these albitic margins (fig.37). Fragments of 3 inch diameter, found on the mountain-side, indicate also larger crystals to be present.

This type of mineralisation along the lower quarts core margin is very local and was seen only in its southern reaches over

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a strike length of 40 - 50 feet.

(v) Core Zone

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

(d) Development of Albite Domes

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 domes also penetrate into the overlying petalite.

The salient features of the domes are:

(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, the horizontal attitude of the quartz core and the overall configuration of the pegmatite are, therefore, primary features. Eight major domical structures 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 associated subsidiary lenses. 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. Also fragments of quartz are found (fig.36). The domes are, therefore, late in the crystallization sequence, post-dating all other zones, inclusive of the quartz core.

(iii) The composition of the dome rock is fairly uniform and consists of fine-grained saccharoidal albite with small amounts of evenly disseminated lepidolite. Near the top of some domes the lepidolite may be concentrated into diffuse bands which are symmetrical with the dome contours (fig.38). The average thickness of these bands is 2 ins.

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 1/2 - 1/4 inch; but at lower levels larger fragments of lepidolite have been found. These foreign 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. 36 the process of brecciation and veining by albite is quite evident.

Rare clots of quartz up to several inches in diameter, also occur within the domes.

Fig. 38 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 massre 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.39, 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 1½ - 3 in. 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 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 crystallisation, 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 on their upper surfaces. The columbite grains are of the size order ¼ - ¢ 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 (H_2O etc) in such structures. The beryl described from unit 3 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. 40. Here a 2 ft. diameter mass 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

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may be completely cut off by an obliquely trending set. Furthermore, precipitation 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 lepidolite 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 during the final complete consolidation of the lepidolite-albite unit after the main quartz core was already precipitated and more or less solid. That the emplacement and crystallisation of sugary albite continued beyond that of much of the lepidolite has already been described in detail from other pegmatites in the district. It is also known from other pegmatite areas, e.g. North Mtoko, Southern Rhodesia, that late stage crystallization and mineralisation after 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.

(e) The North East Lens (See Page 57 and PLATE X)

(i) Outer Pegmatite Zone

Exposures are limited to a single quarry which exposes the entire pegmatite from its outer contact to the core zone. The remaining exposures are confined to the core zone and the immediately adjacent beryl-bearing zone.

The outer pegmatite zone is essentially similar to that over the main body of the pegmatite. Rather large pale pinkish-brown perthite crystals lie in a groundmass (¼ -1½ ins. grains) of white quartz and muscovite. Though rather more evenly distributed in rocks of this zone described on page 58, and having been observed very close to the outer pegmatite contact with the surrounding gneiss, there appears to be here an enrichment of the perthite crystals. Sizes vary rapidly and widely from small crystals being several inches, or even fractions of an inch in size to giants measuring 5 ft. by 3 ft.

The albite of the matrix is commonly cleavelandite, and this reveals a steady enrichment towards the core zone. Apart from this trend, albite is fairly evenly distributed throughout the rock. Muscovite, as usual, tends to occur with quartz. These minerals may sometimes be evenly mixed to form a quartz-muscovite rock, (greisen) or locally show plumose intergrowths 2 - 3 ins. in diameter. "Semi-pegmatite" nests, 2 - 5 ins. in size, consisting almost entirely of muscovite are found close to the beryl-bearing zone. They may be quite spherical in shape. Also another, pale brownish mica is developed, being conspicuous both by its colour and its habit of forming bladed crystals (e.g. 1/8 in. x 1 - 3 ins. x 12 ins.) The latter mica becomes noticeably less common towards the core zones.

(ii) The Beryl-bearing Zone

This zone which, of variable width (1 - 4 ft. average), is confined to the margin of the innermost core zone mineralisation. The major constituent is cleavelandite, though muscovite is also abundant. In places these two minerals, together with beryl, are mixed with the outermost zone (i.e. albite-quartz-muscovite with perthite) resulting in a highly complex rock.

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The beryl of this locality is different to all other types the author has seen in this district. It is characteristically developed as incomplete skeletal crystals showing both prism and pyramid faces, or as complete shells of beryl enclosing a core of cleavelandite quartz and muscovite (Fig. 41). In size these skeletal growths are generally 1/4 - 3/4 ins. thick and 1 - 3 ins. wide in areal diameter.

Similar incomplete growths of beryl have been described from different parts of the world. Fisher (1942) concluded that when such forms of beryl grew they engulfed any material in their way, this being attributed to the "great crystallising power" of beryl. On this basis, the beryl must either have displaced or pushed aside other constituents to a certain degree. Heinrich (1948), on the other hand, suggested that such textures were formed by "the replacement of selected zones within the beryl by albite and quartz". Schaub (1937), by contrast, interpreted similar textures as clearly indicating contemporaneous crystallization.

The interpretation of such textures is, therefore, highly subjective and is left open.

(iii) Core Zone

This unit is approximately 120 ft. in length and on average 10 ft. wide. It has been mined to vertical depths of 30 - 40 ft.

The mineral distribution is highly erratic. The major constituents are quartz and grey (or pink) lepidolite developed as irregular pods. Pink lepidolite is often mixed with evenly disseminated albite, and to a lesser degree with quartz. ½ - 2 feet wide quartz blebs occurring in this material are often bordered by, or contain, clusters of topaz and beryl. The latter are generally ¼ - 3/4 ins. in size. The grey lepidolite occurs as huge masses within massive quartz, which are either free of or mixed with albite. Banded lepidolite-albite rocks are also developed.

Also petalite, amblygonite and columbite have been extracted from this mixed zone. (Personal communication by mine personnel). Only petalite has been observed by the author in situ and this was in a highly weathered state.

On the margins of the core zone cleavelandite frequently develops externally splayed spheroids or arcuate bands 6 - 9 ins. in width. These are generally formed around cores of albite-quartz-muscovite rock.

(f) North Western Offshoot (PLATE X)

In this area a small extension is seen to project out from the main pegmatite body. An outer pegmatite unit of albite-quartz-muscovite with perthite crystals surround local small pods of pink or grey lepidolite. The latter are relatively free of fine-grained albite and contain quartz as the major dilutent.

(g) South Eastern Offshoot (PLATE X)

The outer phase of this offshoot is made up of albite, quartz and muscovite. Quartz and muscovite may locally dominate over albite. Exposures are not good enough to permit a systematic distinction of these two types. Locally nests of a dark blue green

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tourmaline are found in this outermost phase.

In the south-easternmost extremity a small 3 - 6 ft. wide quartz core is present which can be followed for a distance of about 100 ft. The strike is essentially north south and the dip vertical. Surrounding this quartz core is an evelope rich in lepidolite and albite which has a variable thickness not exceeding 5 - 6 ft. The relative proportions of lepidolite and albite vary rapidly over short distances.

Some 200 ft. to the north-northwest of this quartz lens another small body of economic mineralisation is found. The major minerals are quartz, lepidolite-albite petalite, and perthite. The lepidolite-albite is of the banded variety. In the weathered rubble of this lens numerous crystals of columbite are found, up to 2 ins. in diameter. This mineral is presumably associated with the lithium mineralisation. Beryl has been observed adjacent to a lithium rich lens.

(h) Concluding Remarks

At Karlsbrunn the final albite (+ minor lepidolite) stage is developed in a singularly unique form characterised by striking dome structures convex upwards. In part, their development is no doubt due to the flat-lying attitude 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 under-cooled fluid, or a fluid saturated or super saturated with albite, could take place. That "mineralisers" were still active is demonstrated by the symmetrical concentrically disposed quartz-rich cappings of some of the domes (3 in fig. 38), the occurrence of beryl and columbite-tantalite within the capping, and particularly by the widespread concentration of columbite-tantalite on dome crests.

The outer "granitic" zone of the main ore-body may be subdivided into two units; an outermost one of albite-quartz-muscovite, and an inner adjacent to the lithium ore zone, containing also perthite crystals in a matrix of the same minerals.

F. BROCKMANS PEGMATITE ON ALBRECHTSHÖHE

(a) General

This orebody occurs at the northeastern extremity of a large sigmoidal granitic pegmatite dyke in the Albrechtshöhe-Kolioabo area (PLATE XI). It is situated approximately 3 miles southeast of the nearest railhead, Abrechts, on the main Windhoek-Swakopmund line. The large dyke transects the Damara Marble Series and Khomas Schists, as well as a highly contorted rock composed of alternating bands of limestone and biotite schist, marking the transition between the stratigraphical units, already described on page 12.

The ore-body has been mined chiefly for lepidolite and amblygonite. In detail (PLATE XI) it is an irregular lensoid body

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striking approximately eastwest for a distance of 850 ft. The pegmatite dips steeply to the N. ($70^{o}\pm$). Economic minerals are confined to the northern half of the pegmatite where an irregular quartz blow is developed.

A broad zonal pattern can be established:

(i) Outer Pegmatite zone

(ii) The main economic zones:-

1. Lepidolite-albite zone
2. Lepidolite-albite-K-felspar zone
3. Amblygonite rich zone

(iii) Quartz core

(iv) The western unit of economic mineralisation

(b) Description of the Pegmatite

(i) The Outer Pegmatite Zone

The absence of good exposure does not permit a systematic mapping of the non-economic portion of the pegmatite and its subdivision into distinct units. A large gulley on the northern side of the pegmatite, extending from the economic zones to the limestone-pegmatite contact, reveals several zones which may be characteristic of the outer pegmatite. This, however, represents only one single cross-cutting section and it is not known whether these zones are developed everywhere within the outer portion of the pegmatite.

In the gulley a narrow border zone along the contact, some 3 ins. wide, has suffered severe weathering and is now represented by sandy debris. Immediately adjacent to this is a rock, 4 ft. wide, made up of albite-quartz-muscovite of 1 - 1½ ins. average grain size.

A narrow 1 - 2 ft. wide zone of quartz-muscovite-albite can be distinguished as the next zone. The grain size 2 - 3 ins. up to 5 ins. is distinctly coarser than in the previous zone. Dark blue tourmaline is developed as radiating nests. Beryl is also an accessory.

This rock type is followed inwards towards the core by a 5 ft. wide zone of albite-quartz-muscovite which extends as far as the lower zones. Altered spodumene is found as an accessory close to the contact of the latter and probably owes its presence to a slight mixing of the zones near the contact.

It is thus seen that a mineral assemblage consisting essentially of albite, quartz and muscovite with subordinate accessories characterises the outer pegmatite. Variations in grain size and relative proportions of the major components are noticable, but when viewed as a whole the albite-quartz-muscovite rock is similar to that found in the outer portions of other pegmatites in this region.

Scattered outcrops and trenches in the remainder of the outer pegmatite indicate a fundemental rock essentially similar to that exposed in the gulley, but also containing scattered crystals of microcline perthite. The latter occurs as widely dispersed crystal which vary in size from a few feet down to several inches in diameter. The albite content of the matrix (albite-quartz-muscovite) varies from

66/...

place to place. When present in abundance it tends to be associated with quartz. The average grain size of the albite is 1/4 to 1 ins. as commonly found elsewhere, quartz and muscovite are frequently associated and then relatively free from albite. A "conglomeratic" texture, consisting of larger rounded 1 - 3 ins. quartz grains lying in a matrix of muscovite, smaller quartz grains and subordinate albite is again frequently developed. Locally quartz and muscovite are intergrown in a systematic manner to produce plumose textures. The latter vary in size but are generally 2 - 4 inches in diameter. Muscovite may also occur as independent plates up to 5 ins.in diameter.

The most common accessories, as noted, are beryl and tourmaline. Beryl is found both close to the Li-ores contact and further away. Close to the Li-ores it is associated with cleavelandite, while elsewhere it is found in quartz-muscovite rock containing minor albite. The crystals are smallish, 3 - 5 ins. in length and 1 - 1½ ins. in width. Tourmaline, dark bluish green in colour, is commonly found in nests consisting almost exclusively of this mineral. These may approach 1 ft. in diameter, the individual tourmaline crystals being 1/8 - 1/16 ins. in diameter. Smaller tourmaline concentrations show a tendency to occur in the quartz-muscovite rock poor in albite.

At a few localities fine-grained sugary albite is present as lenticoid masses being as much as 20 ft. long and 2½ ft. wide. This rock is often banded due to parallel enrichments of blue tourmaline or reddish almandine garnet. This massive sugary albite is probably not directly related to a similar phase found in the lepidolite-rich zone because:

- it is free of lepidolite
- it contains tourmaline and garnet which are lacking in the sugary albite phase of the Li-ores.

These lenses are, therefore, related to the outer zone. Their origin may be similar to the sugary albite masses found in the outer "granitic" zone of the Rubicon pegmatite.

(ii) The Main Economic Zones

1. The Lepidolite-Albite Zone

Quantitatively albite is more abundant over the entire zone than lepidolite. Nevertheless a considerable number of bodies of high grade ore were found in the albite-rich rock. These were all mined out at the time of mapping and their representation on (PLATE XI) is, therefore, largely schematic. Mr. Brockman who worked this deposit has, however, helped the author in determining approximately the dimensions and distribution of major lepidolite-rich bodies now removed, so that the general configuration of the pegmatite as shown is correct.

Although two distinct rock types can be identified, they have been included under the same heading as they are always so intimately associated.

Here again it is quite clear that the albite-rich rock post-dates the lepidolite-rich masses. The latter are clearly veined, cross-cut, and brecciated by the fine grained sugary albite. The rock types are not always as sharply contrasted as in the Rubicon pegmatite. It is quite common to find a highly mixed assemblage with richer and poorer patches of lepidolite, grading into sugary albite rock.

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Two varieties of lithium mica are found, viz. bright [illegible] grey. At the eastern extremity of the ore zone both types [illegible] here the grey type quite clearly forms an envelope around [illegible] elsewhere, however, their association is not so [illegible]. Both types are mixed with varying amount of sugary [illegible]. Another rather common feature of the grey type is the [illegible] dissemination of small quartz grains.

Quartz has a rather sporadic distribution. It is [illegible] completely absent in places, particularly in the sugary albite-rich rocks, while elsewhere it occurs as evenly scattered grains, or irregular masses up to several feet in size, but mostly measuring 9 ins. - 1 ft. in diameter. With the appearance of these quartz bodies there is a decided tendency for columbite to occur, either as concentrations of small 1/4 - 1/16 ins. grains in the adjacent lepidolite-albite [illegible] or else within the quartz itself close to the margin.

In the neighbourhood of the quartz core and at other localities in this zone, banded rocks are present. This is generally due to the development of lepidolite in distinct layers. Also potash-felspar crystals (1 - 1½ ins. in diameter) are found in the form of distinct bands. This is the first instance of K-felspar to occur in lepidolite ore-zones.

5. Lepidolite-Albite-K-Felspar

The most significant outcrop of this rock occurs in the [illegible] of the pegmatite, on the footwall side of the quartz core and [illegible] the amblygonite rich zone. A similar rock type occurs in a small pear-shaped trench in the southwestern portion of the [illegible].

The characteristic feature of this unusual rock type is the [illegible] of a highly weathered pink to reddish k-felspar mixed [illegible] with both grey and deep purple lithium micas and [illegible]. Under the microscope the k-felspar is clouded by brown iron oxide (?) stains which do not permit a positive identification. It contrasts sharply with the albite grains which are relatively fresh in [illegible] condition. The crystals are generally ½ - 2 ins. in length and 1/8 - 1/4 ins. in width.

These major constituents change in relative proportions [illegible] rapidly. Albite shows a tendency to occur near to the core [illegible]. It, too, is rather unusual in that it is not the [illegible] white type but occurs in grains 1/4 - 3/4 ins. in size. Quartz [illegible] in lesser amounts as irregular lumps, generally a few inches [illegible], scattered throughout the rock. Smaller grains, ½ ins. in [illegible] diameter, are frequently found dispersed in the lithium [illegible].

Columbite, an accessory mineral, is distributed in uneven [illegible] grains, generally in association with the grey and purple [illegible] micas. It has also been observed together with the k-felspar. The [illegible] are generally small, 1/16 - 1/4 ins., although locally [illegible] up to ½ ins. have been found. Monazite occurs subordinately under very similar conditions.

Other accessories are beryl, topaz, and amblygonite.

Of significance is the occurrence of a 2 ins. quartz [illegible] which cross cuts this zone and emanates from the quartz core. [illegible] thin fracture fillings generally lined with a film of grey [illegible] and sometimes containing columbite, have also been [illegible] in this zone but are generally rare and in no way comparable

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as their spectacular development in Beckers pegmatite on Otjua (page 35).

3. Amblygonite-rich Zone

The major constituents of this zone are albite-quartz-amblygonite. Albite and quartz are generally of smaller grain size than amblygonite having average diameters of 1/4 - 1 ins. These two components usually form a relatively even grained rock with a homogeneous mixing of the two phases, though locally quartz is entirely lacking. Amblygonite varies greatly in dimensions from several inches to as much as 5 ft. in diameter. Its characteristic shape is as rounded boulders scattered throughout the albite-quartz rock. There is a decided propensity for amblygonite to be enriched on the quartz core margin.

Quartz often reveals unusual textural relationships. It frequently occurs as veinlets or irregular blobs which quite clearly cross-cut the albite-quartz matrix. These veinlets have never been observed to transect the amblygonite boulders and in some instances can be traced back to the quartz core.

Beryl and spodumene appear sporadically as accessories. Beryl has been observed as rare crystals directly on the quartz core. Spodumene, an uncommon constituent, is developed as always highly altered crystals up to 1 ft. in length.

A peculiar feature observed is the development of conical surfaces in the albite-rich phases of this zone. Individual cones are up to 2 ft. in length and 10 ins. in diameter across the base. The cones are defined by distinct surfaces lined with a thin film of grey mica. They must represent fracture fillings of a peculiar form.

4. Quartz Core

This consists of milky white quartz. Cleavelandite is sometimes developed on the core margin and may be associated with topaz and microcline perthite.

It is possible that an original pegmatoid zone of blocky perthite was subsequently replaced by the lepidolite-albite units. This perthite may also have been incorporated into the albite-lepidolite-k-felspar zone described above.

(iii) Western Economically Mineralized Lens

Two types of lithium-bearing mica, similar to those in the main area of economic mineralization, are developed in this lens. There is a tendency for fractionation so that the mauve and grey types occur in separate areas. The grey variety is mixed with albite and minor amounts of mauve lepidolite, the grey mica tending to occur as scattered irregular masses, with varying amounts of albite, lying in a dominantly albite-rich rock. The mauve lepidolite masses by contrast contain only minor amounts of albite. Small amounts of k-felspar may accompany both types.

The lithium-bearing mica zones give way on the west to a quartz vein approximately 60 ft. in length which in turn is surrounded by a narrow zone rich in amblygonite. The amblygonite-bearing assemblage is composed of albite-quartz-amblygonite-muscovite. Spodumene is a rare accessory. Within this unit there is again good

evidence of veinlets and more irregular masses of quartz distinctly cross-cutting the albite-quartz phase of the rock.

(e) Summary

Although the outer pegmatite zone reveals a certain degree of differentiation the main constituents are albite, quartz and muscovite. Locally perthite crystals are present and then the outer zone becomes identical with the so-called outer "granitic" zone of the other pegmatites.

The lithium ore zones in this particular body again display good evidence of the late nature of albite in relationship to lepidolite. An unusual feature of the lithium-bearing ores is the appearance of a k-felspar phase. The very late nature of quartz which cuts across the amblygonite-bearing zone as well as the lepidolite-albite-k-felspar zone is also demonstrated by this pegmatite.

G. [illegible] CLAIMS ON ALBRECHTSHÖHE AND KOLIOMBO

(a) General Statement

On PLATE II a large pegmatitic granite dyke of sigmoidal shape is shown intruding the meta-sediments of the Damara System. At the north-eastern extremity of this body is the large accumulation of lithium minerals described above under Brockmann's pegmatite. The remaining portion of the pegmatite, and in particular the north-south-striking section, exhibits only sporadic lithium and beryllium mineralization. To date no large ore-bodies have been discovered. Only small sporadic lenses have been worked from time to time, mainly for lepidolite, amblygonite, beryl and columbite-tantalite. Since they are of no great economic importance, they are not described in detail.

(b) Description of the Pegmatite

(1) Pegmatitic Granite Zone

The rock is characteristic of the numerous late tectonic pegmatitic intrusions of the Damara orogeny. It consists of a matrix of albite, quartz and muscovite in which be scattered larger perthite crystals. At some localities the perthite has a graphic granite texture. The felspars generally predominate over the other components. In detail variants in rock type may be distinguished, but without sufficient outcrops and trenches, only the general overall nature can be determined. The limits of the pegmatite can readily be noticed by soil changes.

One such locally developed variant is the common quartz-muscovite rock, occurring as lenses several feet in dimension characterised by larger rounded 1 - 3 ins. quartz lying in a matrix of finer grained muscovite and subordinate quartz. In such a rock type larger perthite crystals up to 3 feet in maximum dimensions are found, with euhedral or subhedral, but sometimes also highly corroded outlines. In this case the perthite often also contains inclusions of quartz-muscovite. Such textures may be interpreted in the following ways:-

- simultaneous crystallisation

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- replacement of perthite by quartz-muscovite
- later replacement of quartz-muscovite by perthite (e.g. Quensel 1955).

The question of albite distribution may also be problematical [illegible] smaller lenses of quartz-muscovite greisen occur in albite-quartz-muscovite rock with scattered perthite. It may thus be argued that the quartz-muscovite rock with perthite is the primary rock type which has subsequently been replaced by albite. This viewpoint is not favoured by the author because:-

- the rather even distribution of albite suggests that it is a primary phase
- the albite invariably associated with the later phases of the pegmatite crystallisation sequence and usually highly corrosive, is either cleavelandite or sugary albite.

It is, therefore, considered that albite, perthite, quartz and muscovite are all primary constituents of this zone although certain minerals may have crystallized earlier than others, viz. perthite is often corroded by the other components.

Accessories of the general rock type are beryl (associated with the quartz-muscovite rock) and a dark bluish tourmaline.

(ii) Lithium-and Beryllium-bearing Fractionates

Occurring in the above major rock type there occur irregular patches enriched in other minerals, e.g. quartz blows, massive mica rocks, lepidolite-albite rocks, etc. These bodies are often lens-shaped and may have the same strike of the major pegmatite or be oriented at right angles to the latter. They are also highly variable in mineral constituents and the nature of their zoning. The following types of fractionates are developed:

1. Albite rocks.
2. Lepidolite-rich rocks.
3. Quartz blows with associated mineralisation.
4. Small well zoned mineralised bodies.

1. Albite Rocks

Scattered small lenses consisting almost entirely of sugary albite and small amounts of cleavelandite occur in the pegmatitic zonite. Quartz and lepidolite are the most common accessory minerals generally tending to occur as smaller isolated masses in a sugary-albite matrix, the lepidolite frequently revealing varying degrees of mixing with albite.

The exposed overall size of these albite-rich lenses is generally 10 - 20 ft. in length and several feet in width.

2. Lepidolite-rich Rocks

Lepidolite-rich rocks occur in a variety of ways. Both pink and grey lithium-bearing micas are enriched in lenses of varying dimensions but generally small, up to 2 - 3 ft. wide and 20 ft. long.

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Quartz and albite may be intermixed with these massive fine-grained zones in varying proportions. A cleavelandite-rich border sometimes envelopes these masses.

3. Quartz Blows with Associated Mineralization

Two such bodies are exposed.

The northernmost lens is 140 ft. in length and attains a maximum exposed thickness of 8 - 10 ft. The adjacent rock type is the normal albite-quartz-muscovite phase with scattered pink perthite crystals, the latter revealing highly irregular outlines. A few large (1 - 2 ft. in the maximum dimension) euhedral perthite crystals are developed also within the quartz, particularly along its margin. Irregularly scattered on the quartz core margin occur even grained masses of grey lithium-bearing mica with subordinate quartz and rare albite.

The other quartz blow is essentially similar (40 ft. long; 10 - 12 ft. maximum width). The lithium-bearing minerals here form an irregular zone on the core margin, and are represented by pink and grey lithium-bearing micas and amblygonite. Casts of the latter on the core-margin reveal that individual crystals attained large sizes, sometimes measuring 5 ft. x 2 ft. Smaller crystals have been observed in situ. The lithium-micas are relatively free of albite, the main dilutent being quartz. Perthite crystals are scattered through the assemblage on the core-margin. A dark blue manganian apatite is a characteristic accessory.

4. Small Well Zoned Mineralized Bodies

Two small well zoned bodies are present in this pegmatite. The northern, dipping steeply to the west, occurs close to the northernmost bend of the pegmatite where it swings to the east. (The pod is exposed in a small pit only so that its overall dimensions are not known). The uppermost contact with the outer coarse pegmatitic granite zone is sharp and defined by narrow pinching and swelling zone, with a maximum width of 1 ft, made up entirely of quartz and muscovite. The latter has a tendency to develop aggregates which are elongated perpendicularly or subperpendicularly to the contact, the basal cleavage of the muscovite, however, being parallel to the contact. These muscovite bodies alternate with quartz.

The next zone, in towards the core, is 2 - 3 ft. in width, and made up of perthite, quartz and muscovite. The pink perthite is by far the most dominant mineral phase, occurring in crystals which vary in size from 2 ins. to giants 2 ft. in diameter. (Average size 6 - 9 ins.). They lie in a matrix of finer-grained (½ - 2 ins.) quartz and muscovite.

With respect to these zones two observations are pertinent. Firstly, an inclusion of sugary albite in the perthite-quartz-muscovite zone is surrounded by a radial growth of quartz and muscovite. The sugary albite body would appear to have acted as a crystallization surface from which the quartz and muscovite have grown outwards. Secondly, small stringers made up of these two zones extend into the surrounding coarse pegmatitic granite. These veinlets owe their origin either to replacement or fracture filling. In either case a pre-existing fracture is probably necessitated.

The next zone, forming the central core of the body, is approximately 2 ft. in width and consists of a mixed mineral assemblage. Both pink and grey lepidolite occur as scattered lusps up to

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2 ft. in diameter. Both types are intergrown with varying amounts of albite. Quartz is developed either as large lumps or evenly disseminated grains in the lithia-bearing mica aggregates. Amblygonite is present in the form of elongate lens-like bodies of variable size from 2 ft. x 5 ins. down to 6 ins. x 2 ins. The albite is a platy cleavelandite which is evenly dispersed throughout the unit and also projects into the adjacent perthite rich zone. Accessories are white beryl developed as small 1 - 2 ins. diameter crystals lying in or adjacent to quartz lenses, and columbite-tantalite which behaves in a similar manner.

Below this core-zone the underlying unit consists of perthite-quartz-muscovite. This rock type merely grades into the coarse pegmatitic granite.

The other zoned body occurs almost in the middle of the pegmatite dyke. It is 30 ft. in length, 2 - 6 ft. in width, vertically dipping, and has been mined to a depth of 6 - 10 ft. The exposures are good and allow accurate delineation of the various zones.

The outermost unit of the exposed zone of the pegmatite is comprised of albite-quartz-muscovite in which are scattered crystals of perthite, i.e. it is basically comparable with the coarse pegmatitic granite zone. The perthite crystals are generally less than 6 ins. in their largest dimension. Fine-grained nests of radiating muscovite are also present.

The above rock is followed symmetrically core-wards by a narrow 0 - 2 ft. wide zone consisting essentially of perthite. Quartz and muscovite fill the interstices between the perthite crystals. This perthite unit, when fully developed, can be sub-divided into two sub-units:-

(a) In the 9 - 10 ins. thick outer part (with respect to the core) the perthite is developed entirely as graphic granite. The quartz consists of the latter and abruptly along a boundary within individual perthite crystals. Here they are somewhat broader, viz. 1/3 - 1/4 ins. while further away they are normally 1/8 - 1/16 ins. in width.

(b) The inner portion which consists of the same perthite crystals being entirely free from graphic granite quartz intergrowths. These quartz free portions of large perthite crystals often project into the quartz core.

Beryl and columbite are found at the quartz core margin.

This general zonal pattern is made complex by:-

- various portions of zones may be lacking entirely
- slight mixing or telescoping of zones.

Followed along strike the quartz core gives way to masses of lithia-mica.

The pegmatite pattern described above parallels that of Trueman (1939) which he considers fundamental for pegmatites on to which complex mineral assemblages may be superposed.

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(e) [illegible]

From the brief description of this particular pegmatite it is evident that within a coarse grained granitic pegmatite various types of residual fractionates may develop which are within themselves of ordinary pegmatite composition in which nevertheless either in part rarer elements are concentrated. (e.g. Rb in albite; Li in mica and/or amblygonite; Be in beryl; Cb and Ta in columbite-tantelite). Varying trends in fractionation are present from Breisaga (1959) simple "first type" pegmatites to his more complex "third" or "fourth type" pegmatites. See page 111 where Breisaga pegmatite types are briefly described.

H. NORTHERN PEGMATITE ON KOLIOMBO

(a) Locality

This pegmatite is situated on the farm Koliombo approximately 4 miles south-southeast of the railway siding Albrechts on the Windhoek - Walvis Bay line, PLATE I.

(b) Structure

This pegmatite is a narrow, eastwest striking, steeply dipping dyke in dolomitic marble of the Damara System which frequently contains bands rich in tremolite. Outcrops and quarry exposures allow more or less continuous mapping of the pegmatite for 950 ft. along strike. Unfortunately, only the northern side of the quartz core has been opened up by quarrying operations, and thus the zonal pattern can be determined for this portion only. Exposures on the southern side of the core are too intermittent to permit systematic mapping and thus to ascertain whether or not a symmetrical arrangement of mineral zones about the quartz core is present.

(c) General Description

Detailed mapping on a scale of 1:250 has made it possible to subdivide the pegmatite into the following units:- (See PLATE XII)

(i) Border zone of albite-quartz-tourmaline.

(ii) Albite-quartz-muscovite.

(iii) Complex albite-quartz-muscovite zone.

(iv) Beryl-rich zone.

(v) Lepidolite-albite zone.

(vi) Highly complex and weathered clay mineral units.

(vii) Quartz core and associated core margin mineralisation.

(i) Border Zone

This is visible only on the northern contact of the peg-

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with the marble in the central portion of the body (PLATE XII). It may be defined as an albite-quartz-tourmaline zone. Tourmaline however, is subordinate. A variation in thickness from a few inches to a maximum of 1 ft. is discernable. The contact itself is generally highly weathered, so that no detailed information is available about it. Tremolite is abundant in the adjacent marbles and may in part at least be due to contact metamorphism by the pegmatite. It must be remembered, however, that the marbles in the area generally contain numerous tremolite-rich horizons on a regional scale.

(ii) Albite-Quartz-Muscovite

The major minerals of this zone are albite, quartz and muscovite, while tourmaline and beryl are common accessories. The composition remains remarkably consistent over the whole zone.

Three forms of albite have been observed, viz. cleavelandite, sugary albite and "normal" albite crystals. The distribution of cleavelandite is somewhat erratic but would appear to be more prominent towards the Li-bearing ore units which in themselves are associated with cleavelandite. Sugary albite occurs as lumps which vary in size and shape and have an irregular distribution. This type is commonly speckled with quartz and muscovite. "Normal" albite applies to crystals which attain a maximum size of 1/4 to 1/2 ins., and are evenly distributed through the rock, revealing no splaying, bending or radial textures which characterise the cleavelandite.

The quartz grains are 1/4 - 3/4 ins. in size and mostly evenly spread throughout the zone, though often showing a preference to be associated with muscovite in which case very little albite is present.

Muscovite varies considerably in size, generally being 1/4 - 1/2 ins. in diameter, though larger 2 ins. diameter plates may also be found. The accessories are tourmaline, beryl and more rarely columbite. The tourmaline is generally dark bluish in colour, developed most commonly as fine-grained nests or radiating aggregates 1 - 2 ins. in diameter. The beryl, a very pale aquamarine variety, is normally anhedral in shape, its crystals being 1 - 2 ins. in length and generally never more than 1 inch in diameter. It has a tendency to be concentrated near the albite-quartz-tourmaline rock of the border zone. Locally radiating blades of columbite, 1/8 ins. in width and up to 1½ ins. in length, have been found in quartz-muscovite concentrations.

Nests of brown limonitic material are scattered throughout the zone in very small amounts. These represent alteration products of some pre-existing iron-bearing mineral which has not been found in the fresh unmodified state.

(iii) Complex Albite-Quartz-Muscovite Zone

This zone occurs immediately adjacent to the lithium-mineralisation and quartz-core. It is completely dominated by albite. Quartz and muscovite follow in order of importance, while tourmaline is absent. The grain size is similar to that of the previous zone except for quartz which locally develops larger anhedral crystals 9 ins. in diameter.

This simple assemblage is complicated by the appearance of additional mineral phases. Lepidolite is present in massive lumps

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zation with the marble in the central portion of the body (PLATE XII). It can be defined as an albite-quartz-tourmaline zone. Tourmaline however, is subordinate. A variation in thickness from a few inches to a maximum of 1 ft. is discernable. The contact itself is generally highly weathered, so that no detailed information is available about it. Tremolite is abundant in the adjacent marbles and may in part at least be due to contact metamorphism by the pegmatite. It must be remembered, however, that the marbles in the area generally contain numerous tremolite-rich horizons on a regional scale.

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The quartz grains are 1/4 - 3/4 ins. in size and mostly evenly spread throughout the zone, though often showing a preference to be associated with muscovite in which case very little albite is present.

Muscovite varies considerably in size, generally being 1/4 - 1½ ins. in diameter, though larger 2 ins. diameter plates may also be found. The accessories are tourmaline, beryl and more rarely columbite. The tourmaline is generally dark bluish in colour, developed most commonly as fine-grained nests or radiating aggregates 1 - 2 ins. in diameter. The beryl, a very pale aquamarine variety, is normally subedral in shape, its crystals being 1 - 2 ins. in length and generally never more than 1 inch in diameter. It has a tendency to be concentrated near the albite-quartz-tourmaline rock of the border zone. Locally radiating blades of columbite, 1/8 ins. in width and up to 1½ ins. in length, have been found in quartz-muscovite concentrations.

Nests of brown limonitic material are scattered throughout the zone in very small amounts. These represent alteration products of some pre-existing iron-bearing mineral which has not been found in the fresh unmodified state.

(iii) Complex Albite-Quartz-Muscovite Zone

This zone occurs immediately adjacent to the lithium-mineralisation and quartz-core. It is completely dominated by albite, quartz and muscovite follow in order of importance, while tourmaline is absent. The grain size is similar to that of the previous zone except the quartz which locally develops larger anhedral crystals 3 ins. in diameter.

This simple assemblage is complicated by the appearance of additional mineral phases. Lepidolite is present in massive lumps

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of varying size. It is generally speckled with albite and has a [illegible] to become abundant close to the quartz core. The lepidolite may either be of replacement origin, or it may have begun to separate [illegible] before the close of this albite-quartz-muscovite unit to [illegible] its crystallization ultimately to form an independent [illegible], i.e. overlapping crystallization at the transition period of [illegible] to the next may have occurred. In the latter case replacement of constituents of earlier zones may have accompanied the formation of the lepidolite-albite unit, the bulk of which was formed by direct crystallization.

Fine-grained lumps (1/8 - 1/16 ins. grains) composed essentially of albite but containing also minor quartz and muscovite further add to the complexity.

Pink beryl has been found and possibly occurred in economic amounts. Its crystals not only differ in colour from those of the previously described zone (pale aquamarine) but are also noticeably larger up to 4 ins. long and 2½ ins. in diameter. Locally also smaller (1/4 - 1/2 ins. diameter) crystals of greenish beryl are present. The larger beryl crystals occur in the zone itself as well as within the quartz core margin when this zone abuts against the latter.

Other accessories are bluish apatite, greenish and reddish alteration products of spodumene and amblygonite. All these minerals are generally small in size (1/4 - 1/2 ins. in maximum dimension) though the spodumene is found in somewhat larger bodies.

(iv) Beryl-Rich Zone

The main concentration of beryl is either close to the contact of one of the outer zones with the lepidolite-albite unit or, when the latter is absent, the quartz core. The maximum width of the zone is 2 - 3 ft. To the east and west of the main quarry area it is apparently absent. There is generally a certain amount of incorporation of minerals from adjacent zones into this unit.

The characteristic associated mineral is cleavelandite, generally occurring as coarse radiating masses. Beryl is found as rather large euhedral to subhedral crystals up to 1 ft. diameter. The beryl is mostly pink; some crystals, however, display a distinct [illegible] with a pale pinkish core being surrounded by a pale green shell (fig.42).

Other minerals appearing frequently in this zone are [illegible], [illegible]ite and columbite. It cannot be said how much of the [illegible] and muscovite crystallised together with the cleavelandite and beryl, and how much may represent incorporated material from [illegible] zones.

(v) Lepidolite-Albite Zone

As so frequently elsewhere, both pink and greenish-grey lepidolite are present in massive form. Each type tends to occur as more or less independent units; even in larger masses of lithia-[illegible] the two types are usually segregated. Thus banded ore types [illegible] separate bands of green-grey and pink lepidolite usually [illegible] by a more albite rich layer though this is not always the [illegible]. On available exposures the pink type is far more abundant than the greenish-grey.

Both types are subject to varying degrees of fine grained albite alteration. The most common manner in which this takes place is by more sparkling; the albite tending to occur as evenly scattered aggregates of small grains. Less frequently, albite is developed along definite bands, as just described. Locally, instead of parallelogram bands, small schlieren or lenses of albite are present in which the albite is relatively coarse (1/4 - 1/2 ins) and associated with quartz. These lenses are generally of the same order of thickness as in the normal banded rock types, viz. less than 2m. The albite-quartz-schlieren are sometimes accompanied by lithia-tourmaline (pinkish rubellite and zoned blue and pink types) and topaz.

Quartz is also admixed with the massive lithia-mica rocks, as dispersed small grains (1/4 inch) which reveal local [illegible].

(vi) Complex Clay Mineral Units

At several localities close to the core margin there occur small patches of clay-like aggregates (PLATE XII). It was found impossible to determine their original nature. Sometimes certain crystal outlines suggest petalite. The frequent pink colouration is reminiscent of the hectorite so common at Rubicon which is certain to be derived from petalite, (page 28). Relatively fresh cleavelandite is scattered throughout the clayey material. The surrounding clayey zone is largely phyllosillicates. Other pink and green alteration products appear to have been derived from spodumene crystals. Fresh spodumene grains, of 1/4 - 1/2 ins. average diameter, are an accessory constituent.

(vii) Quartz Core

This consists of massive milky quartz free from other minerals. However, rock debris found near the eastern large quartz [illegible] to be a core margin phase. In the extreme eastern portion of the map (PLATE XII) lumps of triplite-lithiophilite are embedded on the core margin.

(b) [illegible]

Apart from the differentiation of the outer pegmatite zone, this pegmatite shows a pattern similar to that found in other pegmatites of this district. The outer zones are followed inwards by a cleavelandite-beryl zone, a lepidolite-albite zone and finally the quartz core.

2. [illegible] PEGMATITE ON DERNBURG

(a) Locality

This pegmatite cuts across Chuos quartzites, forms a low ridge, and is situated 4 miles west-southwest of Karibib (PLATE I).

(b) Structure

The body is essentially a narrow west-northwest striking

discontinuously quarried over a distance of 500 ft. (PLATE XIII). The contacts against the quartzites are in places clearly exposed. The latter are flat dipping (10 - 20° NE) while the pegmatite dips steeply to the southwest. Locally the pegmatite sends offshoots into the quartzite country-rock (PLATE XIII). It has an average width of 15 - 25 ft.

The most striking feature of the pegmatite is its tremendous variation in mineral development along strike. For the purpose of description it has, therefore, been subdivided from east to west into five distinct subareas dealt with separately (PLATE XIII).

(a) Description of Pegmatite

(i) Subarea I

In this section a very distinct zonal pattern and paragenetic sequence can be established.

In contact with the quartzites the pegmatite has developed a very uniformly grained rock (1/4 - 1/2 ins. average grain size) composed of quartz, muscovite and very small amounts of sugary albite. The average width of the zone is 4 - 9 ins.

Inwards this is followed by a narrow zone, 2 - 6 ft. in width, made up mainly fine grained sugary albite (1/8 - 1/16 ins.) with only minor amounts of quartz and muscovite.

Occupying the central portion of the dyke is a unit made up largely of flesh-coloured microcline perthite crystals generally several feet in size. Large euhedral to subhedral beryl crystals are found in this blocky perthite rock. One measuring 6 x 2 feet was observed in situ.

Irregular quartz masses, on average 1 - 2 ft. in maximum dimension are developed within the coarse perthite aggregates. They reveal a decided tendency to occur close to the outer margins of the latter. Considerable quantities of amblygonite are associated with these quartz bodies, generally as round lumps, 3 - 5 ins. in diameter found close to the edge of the quartz lenses. Sometimes the latter are also bordered by small topas crystals.

Within the central perthite (PLATE XIII) there lie two main bodies of massive greyish-green lithia-mica in which quartz occurs as small evenly spread grains or as scattered grains and blebs reaching up to 2 ins. in diameter. In general this rock shows very little mixing with albite. Tantalite-columbite is widely disseminated throughout this rock as small 1/8 - 1/4 ins. dark grains.

A peculiar feature of these mica-rich masses is the development of a border, 1 - 2 ft. in width, and apparently completely enclosing them composed of cleavelandite and spodumene. Reddish amblygonite occurs in close association with the cleavelandite. Some extremely rich pockets with crystals up to two inches in size have been found. Where the beryl of the latter zone comes into contact with this border phase it is completely altered to a white cryptocrystalline aggregate made up of bertrandite and an aluminous regular mixed layer chlorite-swelling chlorite. (Roering and Rozenzweig in preparation).

The cross-cutting nature of these lithia-mica masses, together with the highly reactive nature of the cleavelandite-rich

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[illegible] reveals their later age of formation. They probably represent the final phases of crystallization in this subarea.

(ii) Subarea II

The zoning starts off in a similar manner to the adjacent [illegible] area. The outermost border zone, composed mainly of quartz, [illegible] and minor albite is still developed. But the major central portion of the pegmatite now consists of much smaller crystals of perthite, generally only several inches in size, mixed with angular quartz masses and a greater proportion of albite, and instead of lepidolite, the mica is now mainly muscovite occurring in plates 1/4 - 1/2 ins. in diameter. Locally crystals of highly altered [illegible] (?) occur. These again reveal corrosive relationships with perthite.

(iii) Subarea III

In this section the individual pegmatite units show a high degree of asymmetry. The perthite-quartz-muscovite-albite zone, forming the major part of the pegmatite in subarea II is split by a narrow quartz core and continues some distance westwards only to the north of the latter. Along the southern margin a rapidly swelling zone of albite-quartz-muscovite, devoid of perthite, is developed. The latter rock consists of fine grained sugary albite (1/8 - 1/4 ins in which grains of quartz and muscovite (or aggregates of the two minerals) are scattered.

In the westernmost section a zone composed of quartz and blocky perthite is developed in the northern portion of the pegmatite

Forming an envelope about the western part of the quartz [illegible] is a complex unit consisting of numerous phases, the most important of which is cleavelandite. Scattered in the cleavelandite are blebs of greyish-green lithia-mica, altered spodumene crystals (2 - 4 ins. diameter) amblygonite, topaz and beryl. The amblygonite ranges in size from 1/2 x 1½ ins. to 4 x 5 ins. Topaz and beryl are generally euhedral to subhedral in shape and range between 1 and 5 ins. in diameter. Other minerals observed are: quartz which is irregularly scattered through the unit; perthite which may represent residuals from a pre-existing mineral assemblage; and columbite which is a rare constituent.

This highly variable mineral assemblage possibly owes its origin to the telescoping of various zones. This is a common feature of larger pegmatite dykes. Large ellipsoidal bodies (e.g. Rubicon, Bikita) show a very much higher degree of fractionation.

(iv) Subarea IV

The border zone still persists in this area although it is not depicted on the map. It continues to be narrow, e.g. 4 - 6 ins. [illegible] on either side is followed by the previously mentioned albite-quartz-muscovite rock. In this area, however, the latter rock type is distinctly coarser than farther to the southeast (e.g. ½ inch [illegible] in size.)

The central core-region is once more characterised by a [illegible] of perthite. Unfortunately the exposures in this [illegible] area are highly weathered and the detailed nature and [illegible] of the various rock types is somewhat conjectural.

Cleavelandite is quite common in the core zone, revealing ...ular boundaries with the perthite suggesting a corrosive ... Towards the margins of the perthite unit, massive ... and pink lithia-micas, both separate and mixed, occur ...dite which is often enriched about their margins. The ...te found in the perthite zone may thus also be related to ...-rich concentrations. Spodumene is associated with this ...eralization so that the overall pattern does not differ ... that found in subarea I.

...nother assemblage found in association with this perthite ... a cleavelandite-muscovite rock in which the muscovite ... subedral plates 2ins. in diameter.

Amblygonite is often abundant close to the margin of the ...-rich zone, and is generally associated with quarts.

Considerable quantities of columbite-tantalite occur in ... sometimes in crystals over 1 in. in size. Both black ...-tantalite and reddish tantalite have been found in this ... Smaller grains of the black mineral are widely distributed ...-mica rich areas.

Also small yellowish-brown specks of partially decomposed ... are often abundant in very fine grained mica-albite rich ... This particular pegmatite has the most abundant distribution ... tantalum-bearing minerals in all the pegmatites studied from this ...

(v) Subarea V

The pegmatite in this section exhibits a number of zones ... arranged from the quartzite contact inwards in the ... following manner:-

1. Narrow border zone of quartz-muscovite-albite.

2. 1 - 2 ft. wide albite-quartz-muscovite zone relatively fine-grained, 1/4 - 1/8 ins. grain size.

3. Albite-quartz-muscovite-beryl-amblygonite (?) zone with an average width of 2 ft. The 1½ ins. wide muscovite plates render the rock very much coarser than the previous zone.

4. The core, which is made up of quartz and perthite. Cleavelandite is often found on the core margin and again reveals corrosive relationships to the perthite. Amblygonite is formed on the core margin.

(i) ...

The pegmatite reveals marked and rather rapid changes on ... (PLATE XIII). Of all the pegmatites mapped by the author in ... district this is the only one which reveals any significant ... of spodumene.

The zonal patterns developed in this pegmatite are rather

[illegible], particularly in the central core region, e.g. perthite-beryl unit with quartz-amblygonite lenses; massive lithia-mica unit surrounded by cleavelandite-spodumene border. There is good evidence to suggest that the massive lithia-mica units crystallized after the perthite-rich zone.

Another noteworthy feature of the pegmatite is the relatively abrupt change in zonal pattern from one subarea to the next.

This may in part be due to vertical zoning cut obliquely by the present surface. There is also a possibility that the various zones plunge at a certain angle and again the present surface exposes different oblique sections. Deeper mining will give the ultimate answer to these problems.

J. VAN DER MADES PEGMATITE IN THE ERONGO SCHLUCHT

(a) Locality

This pegmatite occurs within the main gorge deeply incised into the late Karroo Erongo igneous massif. It is situated 19 miles northeast of Usakos which itself is approximately 20 miles west of Karibib on the Windhoek-Walvis Bay railway line.

(b) Structure

PLATE XIV reveals the regular dyke-like nature of this pegmatite body. Quarrying operations have exposed the various zones over a distance of 1,700 feet. The body varies in width from 20 - 50 ft. and is essentially vertical, occasionally revealing dips of 70° and more towards the north. It lies in Salem granite and clearly cross-cuts earlier more simple quartz, felspar, mica, schorl pegmatites.

In the eastern section a fault cuts across the dyke displacing it by some 20 ft. in plan.

(c) Description of the Pegmatite

(i) General

Since the pegmatite shows rather marked lateral variations on strike its eastern and western sections are described separately; the dividing line being placed at the point at which numerous extra zones begin to be added to those found in the east when the pegmatite is followed in a westerly direction.

(ii) The Eastern Section

The less complex eastern section exhibits the following zones:-

1. Outer zone of albite-quartz-muscovite rock.
2. Cleavelandite-quartz-beryl-zone.
3. Lithia-mica unit.
4. Albite rock.
5. Quartz core.

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1. Outer Pegmatite Zone

This is made up of an albite-quartz-muscovite rock of 1½ - 2 ins. average grain size. The quartz grains in particular show large variations in grain size and it appears as though the size is dependent on the amount of albite present. When albite predominates over the other minerals the quartz grains are only 1/4 - 1/2 ins. in diameter, but increase to 6 ins. where albite is locally subordinate.

As with so many of the other pegmatites described from this District quartz and muscovite often show a decided tendency to occur together with no, or very little, associated albite. Quartz and muscovite also reveal plumose textures. On other occasions muscovite occurs as individual books ½ - 1½ ins. in width and 4 - 5 ins. in diameter.

Quartz and albite in places also show a tendency to be closely associated and in such cases muscovite is entirely absent or present in very small amounts only. Albite-muscovite associations in these rocks are, therefore, an exception. The reason for these relationships is rather difficult to assess. To many pegmatite investigators quartz-muscovite zones are characteristic, and it could be argued that albite is later in age and of replacement origin. However, when the zone is considered as a whole, albite shows no particular variation from the core outwards. On this evidence the albite could be a paragenetic component of this zone.

Isolated giant perthite crystals are found in this zone. They also occur in the next inward-lying zone and thus show a rather random distribution in this eastern section. It would seem that these large perthite crystals were rather early products of crystallisation which did not segregate preferentially into any particular zone. In the western section, however, perthite occurs adjacent to the quartz core and builds up an independent zone thus indicating lateral variations in physico-chemical conditions in the same pegmatite body.

Black schorl tourmaline is scattered throughout the rock as an accessory. As far as can be determined, this outer pegmatite zone extends right up to the granite contact without any intervening zones.

2. Cleavelandite-quartz-beryl Zone

The average width of this zone is 8 - 10 ft., but locally it swells out to 20 ft. and more. The same rock type persists well into the western section of the pegmatite body.

The characteristic feature of this zone is the obvious lack of mica and the preponderance of cleavelandite and quartz. Quartz increases in amount towards the core, (PLATE XIV), and reveals wide variation in grain size, viz. ½ to 6 ins. in diameter. A "conglomeratic" texture is rather common, in which rounded quartz grains lie in a matrix of albite. Locally isolated giant crystals of perthite are found in this zone. (PLATE XIV).

Very few beryl crystals have been observed in situ, but the existence of beautiful casts within the quartz core give a good indication of the beryl mineralization. The distribution of beryl is confined more or less to the core margin. Individual crystals show considerable size variation, ranging between 2 - 5 ins. and 1 ft. in diameter perpendicular to the c axis. The beryl is a milky

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variety. Locally it is altered to clay minerals similar in appearance to the beryl alteration products already described from Greenbush pegmatite.

Locally beryl crystals must have been tremendously enriched, their casts making up 40 - 60% of the outcrop. Under these conditions the crystals are up to 2 - 3 ft. in length and 1 ft. in diameter.

3. Lithia-mica Unit

This is a complex unit of highly variable nature. Its distribution is rather irregular tending to occur as smaller masses when situated between the beryl-bearing zone and the quartz-core, and as larger bodies when it occupies the central core position of the pegmatite, massive quartz then being absent.

The unit itself is made up of varying rock types. Dense massive pure greenish-grey lithia-mica with minor albite grade into varieties in which both minerals occur in almost equal proportions. An analysis of this mica is given in Table 2. In the varieties composed almost of pure mica, albite speckles the latter in the form of small 1/4 inch scattered nests. Locally thin pencil-line veinlets of albite cut the massive mica rock indicating a later age for albite.

Fine grains of columbite-tantalite also locally speckle the rock, other portions being quite free of this mineral.

4. Albite Rock

Essentially underlying the lithia-mica rich unit is a [illegible] of virtually pure fine-grained albite rock. The contact between the two may be either sharp or transitional.

The rock frequently contains small cavities lined with quartz crystals, iron-oxides (hydroxides) and clay minerals. Lumps and lenses of quartz are developed here and there but are quite subordinate.

Locally the albite rock contains minor amounts of rather evenly spread lithia-mica.

Several interesting features have been observed close to the contact of the lithia-mica rich unit and the albite rock. As already mentioned, the former is locally traversed by mostly narrow veinlets. One such vein 1½ - 2 ins. in width is zoned with a border of feldspar which in turn is followed inwards by quartz which occasionally contains drusy cavities in its central portion. This zonation becomes rather diffuse and indefinite in the albite rock and shows no obser able continuation through the latter into the quartz core.

From a genetical point of view this is significant. The lithia-mica rock must have been well consolidated to have given rise to straight fracture planes. The albite on the other hand, must have been sufficiently plastic to be injected in vein form. Apart from the zoned common quartz druses and subordinate lenses of quartz, the albite rock is also cut by quartz veins extending from the quartz core the latter, therefore, can only have crystallised after the albite had.

The order of crystallisation was, therefore, lithia mica - albite - quartz. The late nature of albite is in keeping with

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distinct features already described from the other pegmatites of this district.

In the central portion of this unit a single perthite crystal was noted, strongly corroded by albite.

4. Quartz Core

This consists of a homogeneous zone of massive milky white quartz.

(iii) The Western Section

This section is much more varied than the eastern. In the extreme west all zones are symmetrical about the quartz core, but elsewhere the zoning is asymmetrical. It is further complicated by the development of an apophysis (PLATE XIV) extending into the surrounding Salem granite. The various zones are shown on PLATE XIV. To indicate more clearly the very considerable variations in the zonal arrangement and its asymmetry, a number of cross-sections, indicated on the map are described in detail.

1. Profile A-B.

North side of quartz core.	South side of quartz core.
Quartz core	Quartz core
Cleavelandite-quartz-beryl	Cleavelandite-quartz-beryl
Muscovite-albite-quartz	Muscovite-albite-quartz
Albite-schorl-muscovite-quartz-hematite	Albite-quartz-muscovite
Fine-grained albite rock	
Muscovite-albite-quartz	Muscovite-albite-quartz
Fine-grained albite	Schorl-albite-quartz-muscovite
Salem granite	Salem granite

Quartz Core

At numerous localities in the western section portions of the quartz core are cut by a multitude of irregular veinlets composed of greenish lithia-mica imparting a brecciated appearance to the rock (Fig.4).

Cleavelandite-quartz-beryl

The ratio of quartz to cleavelandite varies, so either may locally dominate over the other. The quartz is, however, generally veined by cleavelandite or rounded grains are surrounded by cleavelandite giving a "conglomeratic" texture. The quartz grain size varies considerably, viz. 0 - 8 ins. Beryl does not appear to have been very common in the N side of the quartz core. On the south side of the latter, however, very large beryl crystals up to 4 ft. in diameter have been found lying partly within the quartz core and partly in the adjacent cleavelandite-quartz rock.

Locally rectangular crystals of perthite are observed both in the quartz core, while in other cases the perthite is completely absent. Amblygonite has also been found locally in this zone. Lithia-micas may also add further to the complexity of the zone. Lithia-micas are only local, the main constituents of the zone being as defined above.

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[illegible]-albite-quartz

These are generally rather narrow zones 6 ins. - 1 ft. in width. They are characterised by the abundance of muscovite occurring as plates, 1/2 - 3 ins. in width and 3 - 12 ins. in diameter. Often a pinkish colour can be discerned. The individual mica crystals also contain portions which are extremely brittle and have a dull lustre. (See page 9)).

Albite varies in quantity; sometimes present in significant amounts generally it only makes up a minor proportion of the rock. The type of albite is also variable, both sugary albite and cleavelandite being present.

Quartz is also a subordinate mineral occurring in grains and masses of variable size, the average grain size being 1/2 - 3/4 ins. Apatite crystals, 2 ins. in diameter are an important accessory of the rock.

[illegible]-albite-muscovite-quartz-apatite

The albite occurs as an even textured mosaic of cleavelandite with scattered quartz grains up to 1 ft. in diameter. Schorl is relatively abundant, occurring in large crystals up to 6 - 7 ins. in width and up to 18 ins. in length. There is a slight tendency for the schorl grains to orientate themselves perpendicular to the dip of the pegmatite. The boundaries of prismatic crystals are irregular, particularly against albite. Small fractures are healed with albite, indicating that they had crystallized out before all of the albite. Muscovite occurs as scattered plates of irregular outline and is also veined by albite and quartz. Individuals are up to 1 - 2 ins. thick and 7 ins. in diameter and reveal marginal alteration to brittle mica. Patchy aggregates of veined and corroded greenish-blue apatite are also found in the albite.

albite-quartz-muscovite

Albite and quartz are the major constituents of this zone. Muscovite is quite subordinate. Apart from scattered plates up to 1 - 2 ins. thick and 3 ins. in diameter, it also occurs intergrown with quartz to give the familiar "conglomeratic" texture.

Albitite rock

This rock consists of very fine sugary albite. Under the microscope it is seen to consist of small (0.57 mm x 0.24 mm) tabular albite grains of random orientation. Scattered throughout the albite are occasional stumpy bluish-green tourmaline crystals of similar grain size. Topaz grains are a rare constituent.

Schorl-albite-quartz-muscovite

This zone is rather characteristic of the southern border zone of the pegmatite in its western section. It is characterised by abundant schorl crystals on average 4 ins. in diameter and 10 ins. - 1 ft. in length. There is a decided tendency for the schorl crystals to be aligned perpendicularly to the contact of the pegmatite. On the whole the crystals exhibit fairly good subedral outlines. However, corroded jagged boundaries are developed, particularly when in contact with albite.

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Quartz and albite form the bulk of the matrix interstitial to the schorl crystals. Muscovite is subordinate and occurs as scattered 1 - 2 [illegible] diameter plates.

2. Profile C - D

N. side of Quartz Core	S. side of Quartz Core
Quartz core	Quartz core
Perthite-quartz	Perthite-quartz
Cleavelandite-topaz	Cleavelandite-topaz
Brownish [illegible]-rich zone	Brownish mica-rich zone
Muscovite-[illegible]ite-quartz	Muscovite-albite-quartz
	Albite-quartz-muscovite

Perthite-quartz

This zone consists essentially of euhedral perthite crystal embedded in quartz. The perthites are generally a few feet in size and locally tend to aggregate into pure perthite masses. Occasional small masses of greenish lithia-mica invariably show clear corrosive relationships with the perthite. Large apatite crystals, up to 6 ins. in diameter and 18 ins. in length are associated with the quartz of this zone. Also lensoid lumps of amblygonite are sometimes found in this zone. Their size is variable; one individual measured 15 x 6 ins.

Cleavelandite-topaz unit

Cleavelandite is the dominant mineral and has a tendency to occur as arcuate or radiating aggregates. Euhedral crystals of topaz, of variable size, up to 10 x 6 ins. are scattered through this rock in varying proportions. Two varieties are found: opaque greyish white and turquoise-blue. They lie in cleavelandite close to quartz cores. Dark green apatite also occurs in the same position. Only one beryl crystal has been observed in this paragenesis.

Brownish Mica-rich zone

The mica is a darkish variety with a brownish colouration. (See page 94 for mineralogy). It occurs as purer aggregates or mixed in varying proportions with albite. On the N. side of the quartz core it can be established that this unit is in fact a replacement zone. It clearly cuts across other zones. Thus inclusions of topaz are found where the cleavelandite-topaz zone has been [illegible]. But instead of the normal euhedral crystals the topaz now occurs in the shape of highly resorbed irregular remnants in the mica-rich rock.

A characteristic feature of this zone is the scattered occurrence of uraninite. The latter tends to occur as rounded grains, generally less than ½ inch in diameter, which are concentrated in a limited area. They are usually highly altered, oxidation minerals of uranium surrounding cores of uraninite.

The other zones occurring in this profile are similar to those described from profile A - B.

3. Profile E - F

In the western section of the pegmatite the zoning is again

ones symmetrical.

Quartz core

Cleavelandite-topaz-muscovite-apatite-uraninite

Schorl-albite-quartz-muscovite.

Schorl-albite-quartz-muscovite

Here again a schorl rich border zone lies adjacent to the granite contact. Locally the quarry walls are almost entirely black due to enrichment with schorl tourmaline. The crystals of the latter are smaller at the margins of the pegmatite, mostly being 2 - 3 ins. in width, but increase in size with distance from the pegmatite contact, eventually reaching 5 - 6 ins. in diameter. The prismatic crystals are oriented perpendicular to the outer pegmatite contact.

These black tourmaline crystals lie in a matrix of albite and quartz with scattered plates of muscovite. The latter show a marked enrichment adjacent to the next cleavelandite-rich zone following inwards. They reach 4 - 5 ins. in diameter, but in general are only 1½ - 2 ins. in width and ½ - 1 ins. in thickness.

Albite dominates over quartz, the latter having a tendency to occur as larger aggregates veined by albite or as semi-rounded grains ½ - 1 ins. in size. Also the schorl crystals exhibit corrosion and veining by albite (fig.44).

An added feature in the western part is the occurrence of reddish aggregates lying in the albite, which locally assumes a reddish colour.

Cleavelandite-topaz-muscovite-apatite-uraninite

This unit differs from the cleavelandite-topaz zone occurring to the east, in the appearance of additional minerals.

The cleavelandite again tends to occur as a massive rock in which are embedded euhedral topaz crystals 1½ x 1½ ins. to 8 x 8 ins. in size.

Within the cleavelandite in this section there occur muscovite bands which tend to have an arcuate or circular habit. The bands are generally rather narrow having a width of only ½ to 1½ ins. Uranium minerals (uraninite and alteration products) are confined to these muscovite bands. They again have the form of rounded grains, less than ½ inch in diameter (average 1/4 inch) and apatite clusters are found in reddish-stained cleavelandite in a manner similar to that of the previous zone.

(d) Summary

The striking feature of this pegmatite is the marked zonal development along strike. The western section in particular shows rapid changes. The distribution of perthite demonstrates this variation particularly well. (PLATE XIV). In the east it occurs as scattered crystals both in the outer and inner zones. This random distribution regardless of mineral zoning would suggest these crystals to have been among the earliest to have formed in the pegmatite. The fact that they are most abundantly developed

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present to the quartz core may suggest a later age of perthite formation with the implication that there are two generations of perthite crystallisation.

In the innermost zones the normal order of crystallisation for lithia-mica, fine grained albite, quartz core. This sequence is therefore similar to that observed in other pegmatites. However, the "brecciated" nature of portions of the quartz core, veined by greenish lithia-mica as described on page 83 (fig.43), indicates small amounts of lithia-mica to post-date the main crystallisation of the quartz core.

Of special interest is the replacement behaviour of the brown mica-uraninite zone, which, though its bulk position would appear to belong to the outer assemblages crystallising generally before the inner blocky perthite-quartz and cleavelandite-topaz zones, nevertheless on a significant scale cuts across the latter two units, replacing a large portion of their essential constituents. Its late age is thus quite clearly demonstrated.

A most noteworthy feature is that the uraninite, with its alteration products, invariably occurs in the form of smallish rounded grains. This fact, is of great importance with reference to the origin of the small rounded grains of uraninite in the uranium bearing bankets of the Witwatersrand and associated systems. Particularly the round cores of fresh uraninite surrounded by alteration products are significant. On erosion only very small round grains of detrital uraninite would possibly result.

E. GENERAL SUMMARY OF FIELD OBSERVATIONS ON PEGMATITES OF THE [redacted] DISTRICT

In order to present a synopsis, and attempt a synthesis, of all the information gathered in the field Table 1 has been constructed. All the zonal units have been assembled in a rather subjective sequence of oldest to youngest in order to establish whether any generalised sequence is applicable to the pegmatites of the whole area. The fact that certain units tend to recur in an orderly sequence from pegmatite to pegmatite provides a reasonable basis on which a generalized pattern can be built up.

Certain shortcomings in the construction of the table should be mentioned. For instance, owing to the frequently rapid variation it is often difficult to establish the overall relative proportions of the major mineral constituents in a particular zone. The albite-perthite-quartz-muscovite zone is particularly illustrative of this point. The Karlsbrunn pegmatite, for instance, shows a continuous lateral variation from an albite-quartz-muscovite zone to a perthite-albite-quartz-muscovite rock. When several large perthite crystals are fairly closely aggregated, perthite quantitatively dominates over the other constituents while immediately adjacent exposures may only reveal a single perthite crystal in a mass of albite-quartz-muscovite. In fact, when considering this zone, the tables and descriptions should merely be considered as indicating the most important minerals and not necessarily that the sequence of listed minerals accurately portrays the trend from the most dominant to the least important mineral (excluding accessory minerals).

Concerning the zone distribution in Table 1 there is also a certain amount of doubt as to the true position of the cleavelandite-topaz zone of the van der Kaap pegmatite. This is probably a replacement unit and its more common position would, therefore, be

down to the core margin.

The point to be considered next is whether the general zonal pattern summarised in Table 1 is in any way comparable with the zonal sequence described by Cameron et al (1949) for North American pegmatites. The latter, from the margins inwards towards the core is as follows:-

1. Plagioclase-quartz-muscovite
2. Plagioclase-quartz
3. Quartz-perthite-plagioclase, with or without muscovite, with or without biotite
4. Perthite-quartz
5. Perthite-quartz-plagioclase-amblygonite-spodumene
6. Plagioclase-quartz-spodumene
7. Quartz-spodumene
8. Lepidolite-plagioclase-quartz
9. Quartz-microcline
10. Microcline-plagioclase-lithia micas-quartz
11. Quartz

Those zones corresponding best with those developed in the Karibib pegmatites, have been listed in Table 1. Study of the latter immediately reveals many discrepancies and lack of complete correlation. In this connection the following points are relevant.

- A petalite-rich unit. The American classification does not list such a unit. North American lithium-pegmatites appear to be mainly spodumene-amblygonite-lepidolite-bearing types, in contrast with the Karibib pegmatites which often contain abundant petalite and are notably deficient in spodumene.

- A late-stage quartz albite unit, which is well developed as independent masses in several of the South West African pegmatites, (e.g. Karlsbrunn; the van der Made pegmatite) has been included.

- A core margin zone is introduced for the Karibib pegmatites. This is considered to be justified since many economic minerals are found in this position. The same group has been used by Heinrich (1948) as a particular variety of the intermediate zone. Brotzen (1959) also considers such a zone as a diagnostic group in his pegmatite classification.

- In the Karibib pegmatites a clevelandite-rich unit is very often developed immediately prior to the Li-bearing ore zones.

- The mixed core zone group is another zonal type introduced by the author for those narrow pegmatite dykes in which the lithium ore zone, the quartz core and the core margin mineralisation are telescoped into a single unit.

Other reasons for lack of perfect correspondence between zonal patterns have been suggested by Cameron et al (1949) who

present few divergences from their eleven dominant mineral assemblages as being caused by the following factors:-

- a given lithologic unit occurs at two places in the sequence
- two or more zones may be telescoped. See also Hanley, Heinrich and Page (1950)
- The mineral assemblage is slightly different from the norm.

Considering all the above points the correspondence between the two pegmatite sequences is exceptionally good - a fact which was first pointed out by Cameron (1955).

The greatest difficulty in a precise correlation of the two sequences is provided by the author's albite-perthite-quartz-muscovite group and the American group 3, consisting of quartz-perthite-plagioclase with or without muscovite, with or without biotite. This zonal rock type in pegmatites of the Karibib district is of common occurrence in many of the late-tectonic intrusive massifs of pegmatitic granite. The rock, as described, is essentially a very coarse pegmatitic granite with phenocrysts of microcline perthite embedded in a matrix of albite-quartz-muscovite that often shows corrosive relationships with the perthites. This rock type resembles very closely one described by Page (1953) from the Ulu Hills area. In his zone 3 (perthite, quartz, muscovite and plagioclase being the major constituents) he finds that concentrations of perthite are characteristically confined to the upper part of the pegmatite body and that the perthite content "decreases from the outer to the inner contact and also down dip". Furthermore "textures indicate that the uniform intergrowth of albite, quartz and muscovite which forms the groundmass throughout the zone formed later than the perthite". The rock type is apparently identical to the South West African type as described by the author. It would appear that the Karibib albite-perthite-quartz-muscovite rock type is merely a variety of the American zone type 3.

From the detailed descriptions of each individual pegmatite and the summarised tabulation of the data, it is necessary to select a generalised pegmatite pattern which is chosen for its simplicity in the hope that it may serve as a useful basis in attempting to establish a crystallisation sequence of these bodies. The following idealised zonal arrangement and sequence of mineralisation is taken to be the most typical of the types of pegmatite deposit found in the Karibib district.

(a) The outer pegmatite zone of variable thickness which is essentially a very coarse-grained granite consisting of larger perthite phenocrysts lying in a matrix of albite, quartz and muscovite. The inner portions of this zone may reveal a great enrichment of perthite, so much so, that it may grade into a giant perthite zone e.g. Rubicon main ore-body; Karlsbrunn close to the Li-bearing ore bodies. This outer portion of the pegmatite may also reveal a sub-division into two distinct units: an outermost zone of albite-quartz-muscovite and an inner zone of albite-perthite-quartz-muscovite.

(b) This sequence of essentially granitic crystallisation is often abruptly broken by the appearance of a zone consisting essentially of almandite with minor quartz and muscovite. This zone

is characterised by the appearance of numerous accessory minerals often in economic quantities, e.g. beryl, columbite-tantalite, pseudolite, topaz and apatite. The zone is generally of the order 1 - 5 feet depending on the original size of the pegmatite and the degree of fractionation. That it is not a late replacement unit is confirmed by observations at Rubicon where corroded crystals of beryl belonging to this zone are found lying in a matrix of lepidolite and albite which is the next unit to form. The lepidolite-albite zone in fact replaces the beryl-bearing zone. The striking symmetry alone of the Rubicon body testifies to this zone preceding in crystallisation sequence the Li-ore zones.

The significant fact about this zone is that it marks a distinct break in the crystallisation history of the pegmatite, i.e. it marks the change from crystallisation of essentially granitic components to the formation of late phase constituents, viz. Li-bearing and associated minerals. It possibly marks the break from magmatic crystallization to late-magmatic conditions when pneumatogenic and even hydrothermal processes begin to operate.

(c) The next group of minerals to form are noticeably rich in Li and are frequently associated with sugary albite. The major minerals are petalite, lepidolite and albite, while minor amounts of amblygonite also occur. There is a definite spacial relationship and time sequence in the formation of these minerals. Petalite crystallises first and collects in the upper part of this unit generally forming a hood. Amblygonite, albite, quartz, may occur at the same time. Immediately below this petalite hood, and at a somewhat later stage, fine-grained lepidolite crystallises together with albite and minor quartz. The final phase to form at this general stage is sugary albite which collects at the bottom of the still non-crystalline portion of the magma chamber. The sugary albite phase is able to behave diapirically and can intrude, brecciate and replace any of the previously crystallised zonal constituents. Each successive stage here can assume corrosive relationships to previously consolidated units. No assessment is made as to the amount of replacement that may take place as the criterion commonly used for such diagnosis are somewhat subjective. The question of replacement is brought up again on page124 .

During this entire process of complex diffusions and crystallisation, silica is apparently being concentrated in the residual fractions of the pegmatite magma.

(d) The next zone to form is a cleavelandite-rich rock confined to the quartz core margin. This cleavelandite is able to vein and brecciate and corrode the immediate adjacent lying lepidolite and is often associated with minerals such as beryl, columbite, tantalite, tourmaline, topaz and apatite. Amblygonite may also belong to this stage of mineralisation though in general it tends to be associated close in time with the petalite stage of mineralisation.

(e) The final stage of the crystallisation sequence is the quartz core. Quartz veinlets emanating from the core have been observed to cut across adjacent lepidolite-rich and amblygonite-albite zones. Euhedral crystals of columbite and beryl at the core margin are completely surrounded by quartz. These observations may suggest that quartz, although concentrated in the centre of the dyke, probably existed in some unconsolidated state (e.g. a gel as Brotzen (1959) has suggested). The narrow veinlets of lithia-mica transecting the quartz core in the van der Made pegmatite (fig.43) indicate

and the silt may post-date the final consolidation of the quartz core. In general, however, quartz is the last zone to form, though on all occasions accumulated sufficient residual silica to produce a well differentiated core of massive quartz. This point is discussed further on page 125.

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MINERALOGY OF THE KARIBIB PEGMATITES

A. GENERAL STATEMENT

Throughout the author had difficulty in procuring a sufficient number of chemical analyses for adequately detailed mineralogical and petro-chemical studies. Not only were the necessary facilities for reliable analyses not readily available on a sufficient scale, but the funds kindly made available by the South West African Administration allowed only 29 chemical analyses in all.

Money kindly made available by the South West African administration enabled the Research Unit to have 29 silicate analyses undertaken. The problem then was how to allocate these limited facilities to the different pegmatite bodies described. Ideally a particular pegmatite should be examined in sufficient detail to discover what variations may exist in any one particular mineral from the borders to the core. In this way details of mineralogy could be integrated with field observations and serve as a scientific basis for petrologic interpretations. However, the approach adopted in this investigation was to establish the characteristics of the major minerals on a regional scale. The minerals examined in a particular group are, therefore, representative of the area rather than of a particular pegmatite. An attempt was, however, made to discover what variations may exist for a particular mineral group in a single ore-body, viz: the micas and plagioclases. The micas were selected because they can show a wide range of element substitution. Furthermore, the micas and felspars with quartz are the major constituents of pegmatites.

Another factor which imposed a certain bias in the selection of minerals for chemical analysis was the fact that this area is characterised by Li and Be-mineralisation. The micas and beryl, therefore, account for 19 of the 29 analyses, Li-micas and beryl representing the most common economic minerals.

Only the major minerals are described in this paper. There exists a wide range of alteration products of pegmatic minerals which could yield some very interesting data e.g. the alteration products of bismuth from Rubicon and Helikon I; of amblygonite from the Erongo Schlucht; of petalite, lepidolite and amblygonite from Rubicon B; beryl from Dernburg (Roering and Hechroodt, in preparation).

X-ray determinations were all done on a Phillips X-ray diffractometer. CuK_{α}, FeK_{α} or CoK_{α} radiation were employed. Lake Lozaway quartz was used as an external standard between runs requiring more accurate d-value determinations.

Refractive index determinations were carried out with sodium light, the accuracy obtained being ± 0.003. A pycnometer was used for S.G. determinations. It was often found that the specific gravities ascertained were unusually low in comparison to values shown in the literature. These values are, therefore, not cited; it is assumed that many of the minerals probably contain minute fluid inclusions.

B. MICA GROUP

(a) Occurrence

The micas are widely distributed in all the pegmatites.

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In general silvery grey muscovite appears as coarser plates in the outer albite-perthite-quartz-muscovite zones with a general size of the order 1/4 - 3/4 ins. in diameter. The muscovite is most commonly intimately associated with quarts. In a widespread type of association the latter occurs as rather large rounded bodies 1 - 3 ins. in diameter in a matrix of muscovite flakes to give the "conglomeratic" texture so frequently referred to in the previous text. In another type of intergrowth quartz is developed as small red like splaying inclusions within the mica in a manner somewhat similar to quartz-feldspar intergrowths in graphic granite or myrmekite. These plumose intergrowths have been recently described by Orville (1960). In some pegmatites larger muscovite crystals may be found as booklets up to 18" in diameter usually associated with lesser amounts of albite and quarts. In the van der Made pegmatite muscovite plates are often altered along their margins to a very hard and brittle variety.

Finer grained micas (1/16 - 1/4 ins.) are mostly developed in massive often almost pure micaceous bodies. Albite and quarts are the common dilutents, other rarer associated minerals being topas, tourmaline, apatite, columbite. These fine grained micas are normally found in the more interior zones, often adjacent to the quarts core. They are almost invariably lithium bearing, and exhibit a variety of colours e.g. pink, purple, mauve, grey, greyish-green and silvery-white. For the sake of simplicity the pink, mauve and purple varieties have been referred to as lepidolite in field descriptions. Structural and chemical data are, however, required to classify the Li-micas more rigorously. This restricts definite identification of these minerals in hand specimens.

(b) X-Ray Data

Eighteen selected micas were subjected to X-ray analysis in order to establish which particular polymorph(s) were present. See Table 1 (Yoder and Eugster 1955, Smith and Yoder, 1956). Levinson (1953) has shown that normal muscovites can have as much as 1.3% Li_2O in its lattice and crystallizes as a $2M_1$ polymorph. Micas with 3.4% to 4% Li_2O are usually fine grained, have anomalous optics, and generally consist of more than one polymorph, often including $2M_1$. With 4 - 5% Li_2O the micas generally have a $2M_2$ structure while those with more than 5% are usually 1M or 3T. It is possible, therefore, to establish very broadly the composition of the micas in the lithium-bearing pegmatites, particularly those in the lower Li_2O ranges. However, according to Forster (1962) the lepidolites (ranging from 4% LiO and upwards) do not show any apparent correlation between Li_2O content and the different polymorph

The results of the X-ray investigation show that the majority of polymorphs are $2M_1$ or $2M_2$ (Table 2). A high proportion of fine grained micas reveal two polymorphs, $2M_1$ and $2M_2$, indicating an Li_2O content of 3.4 - 4%. Some fine grained varieties, however, consist of one polymorph only. Colour, therefore, is no useful criterion in establishing the polymorphic variations. A brown platy lepidolite from Otjua (K330) reveals a 3T or 1M form. The coarser platy grey micas reveal the $2M_1$ structure.

The above data reveal that in most cases the coarser mica associated with the outer pegmatite zones is a $2M_1$ polymorph (lithian muscovite) which may contain up to 3.3% Li_2O, while many of the finer grained types consist of mixed forms belonging to a group of micas transitional between lithian muscovites and the lepidolites. The latter contain 3.4 - 4% Li_2O. With fractionation of the pegmatite bodies Li_2O becomes enriched in the later micas. Exceptions, however, occur, as illustrated by K98 which is a fine grained massive whitish-grey core zone mica. In this only a $2M_1$ structure is

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indicated which suggests a lithium muscovite. The core zone mica from the Erongo Schlucht (E5), although one of the last minerals to form in the pegmatite, also falls in the $2M_1$ polymorphic type. The same features are illustrated by K52 (Rubicon) and K99 (Helicon I). However, the overall trend is for the Li content to increase in the massive core-mica bodies. In general the highly coloured (pink, mauve, purple) micas consist of mixed forms although this is no rule. Massive fine grained greyish micas from the core margin region may either consist of mixed forms or only the $2M_1$ polymorph.

(c) Chemistry

Twelve different mica ores have been chemically analysed (Tables 3 and 3a). Ten of these analyses represent pure micas while two (K51 and K87) contain impurities (albite) and are representative of the typical ore rather than of a particular mica. Certain of the specimens analysed have been subjected to x-ray investigation as described above and it is, therefore, possible to check the relationship between the chemical composition and structure, using the diagram of octahedral occupancy prepared by Forster (1962) (fig. 45). A good correlation is obtained for all the analyses except K226 (Helicon II) which was found to contain two polymorphs ($2M_1$ and $2M_2$). The indefinite boundary of the mixed forms proposed by Forster (1962) may, therefore, extend slightly lower than shown in fig. 45.

K98, a massive fine grained mica from the ore zone of Helicon I is found to be the type most difficient in Li in all analyses. However, K99 is massive ore type taken further along strike in the same main ore zone and reveals a considerably higher lithia and fluorine content. Thus in the same massive fine grained core-mica zone lithian-muscovites showing considerable variation in Li-content are present - one being grey and the other mauve.

Fig.45 also shows how the micas from van der Maden pegmatite differ from other micas of the district. The main difference lies in the iron content which is noticeably higher. (See also Tables 3 and 4). The Erongo specimens taken from a single body also illustrate certain important petrological points. The first is the obvious fact that with progressive fractionation Li tends to become enriched. Specimens E19 and E25 are taken from the outer muscovite-quartz-albite zone, while E6 is the green massive core margin mica found in the eastern part of the pegmatite, and E32 is the brownish mica replacement unit found in the Western section of the body. Both the micas show a very similar composition with regard to their octahedral sites and are enriched in Li_2O. The later micas also show that with increasing Li_2O content the F/H$_2$O ratio increases. Fluorine must, therefore, play an important role in the late Li and Na mineralization aiding considerably in depolymerizing the silica networks and lowering the melting temperature of the various silicate phases.

The chemical analyses again confirm the point that no true lepidolites are present in the common micas of the Karibib District. The fine grained coloured ores generally belong to the transitional mixed form group between lithian muscovite and lepidolite. The name lepidolite has been used freely in the descriptive text; the author feels that for coloured micas (pink, mauve, mauve) the name should be retained as it is useful in the field for a very broad classification of the Li-micas and because such coloured types, when not too heavily diluted with other minerals are invariably of economic grade.

In the majority of analyses listed the Mn/Fe++ ratio seems

to have a considerable influence on the colour of the pertinent mica. When Mn is in excess of Fe++ they are usually pink, mauve or purple, while where Fe++ is in excess of Mn they are usually grey, greyish-green etc. The exception to this is specimen K226 which is a purple mica from Helicon II having a Mn/Fe++ ratio of [illegible]:1.15.

Some of the micas from the high grade ores reveal that the more unusual alkali metals also tend to become enriched together with lithium in the later pegmatitic fractions. This is particularly the same with rubidium in samples K51 and K142.

Qualitative spectrographic analyses of selected micas show again that the Erongo types differ from the others (Table 5) Co, Cu, Sc and V are noticeably absent. Those elements which are present in all the samples investigated are Be, B, Pb, and Sn. V and Sc are common to all the micas except those from the Erongo schlucht. Ni is also fairly common to all micas.

(d) Conclusions

Lithian muscovites ($2M_1$ polymorphs) characterise the outer granitic phases. The fine grained massive core zone micas of pink, mauve, grey, greenish-grey and silvery-white colour, generally consist of the $2M_1$ and $2M_2$ polymorphs. Locally, however, they may also comprise lithian-muscovites akin to those of the border zones. No true lepidolites have been identified among the common mica types occurring in the Karibib district.

With progressive fractionation of the pegmatite system Li is generally enriched in the later core mica types. Parallel with this enrichment is an increase in the amount of rubidium and fluorine Basic characteristic differences in the chemistry of major and minor elements of the micas distinguish the Erongo schlucht pegmatites from the others of the district which belong very close to the lithian-muscovite lepidolite "series".

The van der Made pegmatite is the only ore occurring in biotite-rich Salem granite, though the massive Rubicon body is also in contact iron-rich diorite along the footwall. All other pegmatite described are injected into sediments of the Damara System, mostly dolomitic marbles.

6. FELSPAR

(a) General

The felspars can serve as a useful basis for determining the crystallisation sequence of rock units in pegmatites. The An content of plagioclase is particularly useful in this regard, as demonstrated by Cameron et al (1949). It is shown below that the plagioclases of most of the pegmatites of the Karibib district, possess a remarkably high and consistent Ab content justifying the general term 'albite' used in the descriptive section.

(b) Microcline perthite

This mineral is present in varying proportion in all the pegmatite bodies. It is commonly developed as flesh coloured crystal

particularly in the outer pegmatite zones, which vary from fractions of an inch to several feet in size. This perthite generally occurs as phenocrysts, often corroded, in a matrix of albite, quartz and muscovite. In certain pegmatites pure blocky perthite zones are found in which individual crystals reach giant dimensions, up to 10ft. x 3ft. Such zones are present at Rubicon, Henckerts pegmatite on Dernburg and in van der Mades pegmatite in the Erongo Schlucht. Locally the perthite crystals reveal a graphic granite texture; in two pegmatites zones enriched in graphic granite were found, viz: Bowers pegmatite and Dr. Bergers claims. These well developed rock units give way corewards to a purer blocky perthite unit. The quartz pencils of the graphic granite vary in thickness from 1/16 - 1/4 ins. Recent work by Simpson (1962) on graphic granite from pegmatites of the Romana District, California, has shown that although the quartz may have a single crystallographic orientation in a particular specimen, this is different for different specimens," and is not consonant with any crystallographic law". Furthermore, the long axis of the quartz rods is not the c-axis, nor does the latter have a systematic orientation relationship to the walls of a pegmatite.

The author has examined numerous perthites microscopically. He has found plagioclase to have three differing modes of occurrence within the microclines, viz:-

- Rectangular single albite twins displaying subhedral outline scattered sparingly with fairly random orientation in the larger microcline crystal. Probably they were formed together with, or slightly earlier than the enclosing microcline perthite. Where secondary replacement albite veinlets contact such twinned crystals the edges of the latter tend to be more irregular than the normal rectilinear contacts revealed against microcline.

- Coarse albite veinlets of the size order 10 - 400 μ. These vary often reveal a systematic orientation frequently along (001). When examined in detail these veinlets have irregular edges; they branch, swell and pinch out unsystematically; contain scattered inclusions of microcline and are connected with cross cutting veinlets (fig.46). These irregular veinlets are locally associated with small amounts of muscovite. This latter fact suggests that the plagioclase to be of replacement origin, an interpretation reinforced by the field observation that perthite crystals lying in an albite matrix frequently display highly serrated and corroded margins. Where the plagioclase stringers have been coarse enough to permit universal stage investigations, it was found that the composition is $Ab_{95}An_5$.

- Another variety of plagioclase occurring in the microcline is an extremely fine acicular film perthite (see fig.47). This contrasts with the coarse replacement perthite and possibly represents true exsolution of albite.

Appreciating the difficulties in quantitatively separating the various types of albite from the microcline, it is clear that to use this mineral for any form of interpretation based on chemistry is fraught with difficulties. Since the mirocline perthites appear to have crystallized rather early in the sequence it was initially thought that trace element investigation might give an indication of

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in variation in chemistry of the source of the pegmatites. Later phases may reflect variations in the pegmatite system rather than in the bulk chemistry. However, taking into consideration replacement features of the microcline, plus the existence of other varieties of plagioclase, deductions based on such geochemical analyses would probably be inconclusive, even suspect.

A chemical analysis of microcline perthite from the petalite quarry of Helicon II is listed in Table 6. The weight proportions of this mineral are $Or_{82.7}Ab_{17.3}$.

The optics were found to be as follows:-

γ = 1.521 ± 0.003

β = 1.519 ± 0.003 2V (calc) = 72.7°

α = 1.514 ± 0.003

(c) Plagioclase

Plagioclase is developed in various types which occupy definite positions in the pegmatite bodies. In the outer "granitic" zones plagioclase is developed as 1/4 - 3/4 ins. grains together with quartz and muscovite. This albite invariably reveals very fine polysynthetic twinning. The beryl-bearing zone preceding the Li- and Na-mineralisation, and again the core margin mineralisation, commonly contain splaying cleavelandite masses. Closely associated with the lepidolite stage and extending in range beyond it, is a fine grained sugary-albite. Also within the lepidolite masses are rounded masses 1 - 4 ins. in diameter comprised of extremely fine micro-crystalline albite (0.1 mm. in size).

It was decided to obtain information as to the variation of the An content of plagioclases with distance from the contact of the pegmatite contacts. J. McIver of the Geology Department of the University of the Witwatersrand had already carried out a universal stage investigation on a large number plagioclases from different rock types in the Rubicon, Helicon I and II, and Karlsbrunn pegmatite deposits. McIver found that irrespective of position within the pegmatite body the composition of the plagioclases was $Ab_{90}An_{10}$. Only in two specimens, out of a total of 60 did he record values of $Ab_{80}An_{20}$. These higher values were found in the outer "granitic" phase below the footwall beryl zone at Rubicon and in the footwall of the lepidolite zone at Helicon I.

The author continued these investigations using x-ray techniques (Smith 1956). For the application of this method a low temperature state of the plagioclase is necessitated. Pegmatitic plagioclases are probably all of low temperature type. However, a control could be carried out on a plagioclase from the core margin of the Becker pegmatite on Otjua (K258 See Table 6). The chemical analysis shows $\frac{Al}{Al+Si}$ % ratio of the mineral is 1.2% while the X-ray 2θ(131) - 2θ(131) spacing gives a value of 1.8% indicating the validity of assuming a low temperature state. In most cases it was found that (132) reflection was weak and thus not suitable for using the pair (131) and (132). Hence the pair (111) and ($1\bar{1}1$) were made use of. Three to five runs were done on each mineral and the error in An was within 0.005. The values listed are thus accurate to within 1% An.

Table 7 shows the results of these X-ray determinations. All specimens examined are seen to be pure albites, though some may enter in the peristerite range (An_5-An_{17}). Smith (1956), however,

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suggests that the (112) and (111) peaks are reliable even in this lower composition range.

From the data presented there does not appear to be any marked variation in the An content of the plagioclases. The footwall portion of Rubicon pegmatite seems to be the only exception; here somewhat higher values (9 and 7% An) were obtained. In this case a certain amount of Ca may have been derived from the quartz diorite footwall while in the hanging wall where the An content is normal and the pegmatite merely grades into a vast mass of pegmatitic granite. Helicon II provides an interesting example of there being no influence of the Damara marbles on the plagioclase compositions. The plagioclases were all selected from the lower part of the pegmatite from one side to the other. In this region the pegmatite consists of an albite-quartz-muscovite rock with perthite. There is no suggestion whatever of a higher An content close to the marble contact even when the error of determination of 2% An is taken into account.

The use of the term albite in defining the various rock types in the descriptive section thus appears to be entirely justified.

Also the chemical analysis (Table 5) justifies to the relative purity of the albite. Apart from the very small percentage of Ca (0.31) also the other alkali and alkali-earth metals make up only a very insignificant proportion of this plagioclase.

D. PETALITE

Petalite is generally found as large crystals of the order of several feet in size. It commonly has a milky-white colour though locally may be almost colourless or else slightly pinkish. The mineral is characterised by a perfect 001 cleavage.

This mineral is found in the lithium ore zones which generally surrounds the quartz core. It has a tendency to accumulate in the upper portions of this zone, referred to in the previous text as "petalite hood". Cleavage controlled replacement by fine-grained lepidolite-albite is common. These veinlets are mostly fractions of an inch in width; they pinch and swell and locally cross-cut the main cleavage direction and join up with other veinlets. They can often be traced back to greater concentrations of lepidolite-albite.

Petalite frequently shows signs of alteration. Underground in the Rubicon mine a vug, several feet in dimension, within solid petalite was filled up with pale-pink clay minerals which are pseudomorphic after petalite. This material has been found to be montmorillonite by the Ceramics Unit of the Council for Scientific and Industrial Research, Pretoria (verbal communication - O.R. Backstrand). The mode of its occurrence suggests this alteration to be due to late or post-pegmatitic pegmatite solutions and not to surface weathering. In other cases similar clayey material was found only a few feet from surface so that the alteration could well be the result of weathering. A dull waxy petalite is found in large quantities in the Helicon II western petalite quarry. TABLE 8 shows an analysis of this mineral (K230). The considerably higher water content, when compared with other non-waxy types suggests partial alteration.

Three analyses of petalite from different pegmatites are presented in Table 8. Number K230 shows that with alteration the

significant changes are an increase in MgO coupled with a decrease in alkalis. The lower alkali content is particularly evident from the calculation of the cations.

The unaltered petalites reveal a very similar chemistry although coming from widely separated deposits.

5. TOURMALINE

Tourmaline is a consistent accessory mineral in all the pegmatites. In the outer "granitic" zones it is usually a black schorl. In the van der Made pegmatite this mineral is greatly enriched in the outermost zone, where it is associated with albite-quartz and muscovite. Individual crystals may be up to 1 ft. in length and 2 - 3 ins. diameter near the contact increasing in size towards the core. Locally the schorl may make up 50 - 60 per cent of the outcrop. The normally euhedral to subhedral prisms may locally be corroded by albite; they may even be fractured, the cracks then being "healed" by albite. At Beckers pegmatite on Otjua there occur knots 1 - 3 ins. in size, composed of a graphic intergrowth of schorl with quartz.

In the interior zones, viz. Li and Na mineralization or core margin, brightly coloured lithia-tourmalines are found, often of gem quality. In the Li- and Na-mineralized units the tourmaline is commonly associated with quartz enrichments, the most usual types being pink or blue in colour. (Radiating suns of opaque pink tourmaline have been observed in lepidolite ore from the Otjua pegmatite. Microscopically these latter crystals have a high proportion of included phyllosilicate-possibly cookeite.) The colours of the core-margin tourmaline are light-pink, pale red, light green, greenish blue and light blue. The crystals may be of one colour only or zoned, sometimes alternating in colour as already described from Beckers pegmatite on Otjua. In the dually zoned tourmalines the colour distribution is generally as follows:-

core	border
bluish green	green
pale red	green
pale whitish blue	pale red

The sequence of types from oldest to youngest, i.e. from border to core, is black, dark opaque green and then occurring together pink, red, pale green, pale bluish green and pale blue. Variations of tourmaline types in pegmatites have been investigated thoroughly by Staats et al (1955) who demonstrated that the significant changes towards the core are an increase in the concentrations of Li, Rb, Cs, Pb, Sn, and Li while Fe, Ti, Mg, Na, Ca, Mi, Cr and F decrease.

The refractive indices of several different tourmaline types are shown in Table 9. Deer, Howie and Zussman (1962) have prepared a graph relating refractive indices to the number of (Fe^{2+}+Fe^{3+}+Mn) ions associated with Y1(OH,F). Although this does not reveal the detailed chemical variation in tourmaline types it can be shown that the later lighter coloured tourmalines of the interior zones of the Otjua pegmatite have a lower number of (Fe^{2+}+Fe^{3+}+Mn) ions than the former schorl of the outer zone. (0.6 - 1.0 as compared with 1.25 - Table 9.) These ions are probably replaced by Li and Al. The above graph by Howie, Deer and Zussman was not used since it contains

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[illegible] control points and could possibly be displaced slightly [illegible] higher ($Fe^{2}+Fe^{3}+Mn$) values.

However, the main trend of pegmatitic fractionation as [illegible] by the tourmalines is one showing a transition from [illegible] to elbaite. The essential chemical change is the substitution of Li for Fe.

F. QUARTZ

Quarts is virtually present in all the various rock types of the pegmatites. The exceptions are massive monomineralic units, (e.g. perthite) or the cleavelandite core margin mineralisation.

The quarts core is made up of large milky-white masses. Locally vugs are found in which the quarts assumes a euhedral character and then is either colourless or smoky to dark brown.

The inversion of quarts from high to low quarts is one of the earliest geothermometers used in pegmatite investigations. The inversion temperature is 573° at atmospheric pressure and is raised approximately 1°c by each 40 bars of pressure (Deer, Howie, Zussman 1963). It appears that most graphic granite crystallized well above this inversion temperature. (Brotzen 1959). Using these criteria many investigators have broken up pegmatite genesis into a "orgmatic", "epi magmatic" or "pegmatitic" stage which crystallizes above 570°c. (See page122).

Brotzen 1959 has painted out some of the limitations of this method, viz. observational difficulties; development of secondary Dauphine twinning also in low quarts on quenching; development of highly regular twins by localized pressure.

G. SPODUMENE

This mineral occurs in several pegmatites but as an accessory rather than a major constituent. It is found in the outer pegmatite zone adjacent to the Li-ores of the Brockmann pegmatite in association with albite, quartz and muscovite, as well as in the [illegible] zone where crystals up to 1 foot in length are developed. In all cases the spodumene is highly altered to phyllosilicates. Another occurrence is in Bergers pegmatite on Koliombo where again greenish and reddish micaceous alteration products of this mineral are found in a complex albite-quartz-muscovite zone lying adjacent to the quarts core.

The best development of altered spodumene is in Hanskerts pegmatite on Dernburg where it is found with cleavelandite surrounding Li-mica replacement units. The altered products were examined using X-ray techniques and found to consist of quarts and a phyllosilicate whose X-ray pattern corresponds with cookeite.

Similar alteration products occur in the perthite-quartz-albite-muscovite zone which occupies a central position in this pegmatite.

The presence of this mineral is, therefore, postulated from the existence of alteration products made up essentially of phyllosilicates (possibly cookeite) and quartz. These products are invariably found in close proximity to the Li-ore zones or core margin suggesting that spodumene forms late in the crystallization history.

K. POLLUCITE

Pollucite has been found only in one pegmatite and that is at the core margin of the Helicon I ore-body. Most of the mineral was mined out at the time of the present investigation so that little is known about the details of its occurrence. Very fortunately data on this mineral are available due to a thorough investigation of specimens from the mine by H. Mel (1944).

The pollucite is characteristically traversed by numerous veinlets of lepidolite. Mel also records the occurrence of narrow clay mineral veinlets.

Mel has found that the unit cell formula calculated on the basis of 96 oxygens is

$$Cs_{10}Na_4Al_{14}Si_{34}O_{96}.6H_2O$$

L. BERYL

(a) Occurrence

Together with the Li-micas, petalite, amblygonite and columbite-tantalite, this mineral is one of the major economic minerals of the district. It is invariably present in all the complex pegmatites generally tending to be concentrated in certain specific zones in the pegmatite body thus allowing selective mining. The most important beryl-bearing zones are:

- the cleavelandite-rich unit immediately preceding the Li- and Na-mineralisation, e.g. at Rubicon ores.
- the cleavelandite-rich core margin, e.g. at Helicon I, Erongo Schlucht.

In these zones the beryl is generally of rather large size, some crystals measuring up to 15 ins. in diameter and several feet in length. A common size is 5 - 8 ins. in diameter. The colours are variable, viz. pink, orange, green, white. Multicoloured types have been observed in Bergers pegmatite on Koliombo. See fig. A2. The beryl often reveals a type of basal fracturing in which the fractures are filled with albite. Under such conditions the crystals may be intricately mixed with albite and also possess highly irregular corroded outlines suggesting that replacement by albite may have taken place.

In the E.E. lens of Karlsbrunn there occur shell-like forms of beryl which have a core of albite, quartz and muscovite (Fig.A1). The interpretation of these forms has already been discussed on page 63 .

In smaller amounts beryl is also found in other zones, e.g. albite-quartz-muscovite- zones at Dernburg and Bergers pegmatite on Koliombo. Here the crystals are generally smaller in size e.g. 1/2 - 1 ins. in diameter, the associated rock type having a similar grain size. The perthite core zone of the Dernburg pegmatite, on the other hand, contained enormous crystals up to 6 ft. in length.

(b) Alteration

Beryl pseudomorphs found in the perthite core zone of the

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...pegmatite on examination were found to consist of cryptocrystalline bertrandite and an aluminous regular mixed layer ...-swelling chlorite. (Roering and Heckroodt, in preparation). ...alteration of beryl is particularly noticeable adjacent to ... of Li-micas which are bordered by a narrow zone ... and spodumene. The alteration is characterized ... increase of BeO, and the addition of K_2O and MgO at the ... of SiO_2.

(c) Chemistry

The results of six chemical analyses of various beryls ... shown in Table 10. The BeO content is amazingly consistent, only varying between 11.85 - 12.80%. The theoretical maximum is 13.96 wt % BeO the difference being made up by the presence of alkali metals. Of the latter the most important are Li, Na and Cs. According to Hayton (1947) the pink colour of beryl is due to the presence of alkalis and attributable in particular to Li. This relationship, however, is by no means clear in the present analyses.

The number of cations related to 36 oxygens are shown in Table 11. Here certain relationships found in previous investigations by other workers can be confirmed, viz. both the refractive index and specific gravity increase with the increase in the tenor of alkalis. (Winchell 1951, Deer, Howie and Zussman 1962).

At the bottom of Table 11 the cation proportions have been arranged in decreasing Si content. There appears to be a very good relationship between a decrease in silicon and an increase in R^{+} and R^{+2} ions.

Although the beryls analysed are from different zones within widely separated pegmatites, i.e. the cleavelandite zone preceding the Li- and Na-mineralisation, and the core margin, there is no significant difference in the alkali or beryllium content between these two zones. The fractionation taking place in these pegmatite systems is thus not obviously portrayed by beryl composition as far as major and minor constituents are concerned. No investigation of trace element distribution was carried out.

4. LITHIOPHILITE AND ALTERATION PRODUCTS

Members of the extremely complex and wide range of minerals that forms from the combination of Fe, Mn, and P are represented in the Karibib district pegmatites. Most commonly they are found as soft, black, charcoal-like substances. Very seldomly are the original unaltered phosphates preserved.

The Rubicon ore-body is the best example of Mn and Fe phosphate mineralization. The beryl zone of the main ore-body is studded with black nests, 1/2 - 2 ins. in size, of a manganese-bearing mineral. The surrounding minerals, particularly the muscovite, are usually stained black by manganese oxides. The blackish mineral has been identified as frondelite $(Mn^{+2}, Fe^{+2})Fe_4^{+3}(PO_4)_3OH_5$. The d-values obtained from x-rays compare very well with the A.S.T.M. values for frondelite. X-ray fluorescence revealed the presence of Mn, Fe. Phosphorous was determined by conventional wet chemical methods.

A similar black mineral is found in the albite-quartz-muscovite zone immediately adjacent to the Li-ore zone of the Helicon pegmatite.

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On the core margin of the Rubicon C ore-body rounded masses, up to 18 ins. in diameter, of a yellowish brown mineral [illegible] which are veined and bordered by a soft black substance which in turn often gives way to a brilliant purple mineral. Fig.22 shows the mode of alteration of yellowish brown mineral to the soft black substance. Each of the various mineral types have been investigated. Table 12 lists the x-ray data of the yellowish brown phase and for comparison d-values of triphyllite are included. Quensel (1955) states the x-ray powder photographs of triphyllite and lithiophilite to be identical. A chemical analysis of the same material shows that Mn_2Fe. It thus belongs to the lithiophilite $Li(Mn^{"}, Fe^{"})(PO_4)$ end member of the series. The material shows a slight degree of alteration as portrayed by the Fe^{3+} and water contents.

Lithiophilite alters to a hydrated amorphous black manganese iron wad. The chemical composition of this material is given in Table 13. The main effects of the alteration are the removal of Li and phosphorous, the addition of water and the oxidation of Fe and Mn. K shows appreciable enrichment. Under the microscope, this material reveals no structure. But its distinctly purple alteration products, lining small cavities, is crystalline and has been identified as purpurite $(Mn^{3+}Fe^{3+})PO_4$.

This alteration sequence at Rubicon:

lithiophilite - hydrated amorphous Mn-Fe wad - purpurite, differs somewhat from that described by Quensel (1955) in the Varutrask pegmatite in Northern Sweden. There lithiophilite alters systematically according to the scheme: varulite - manganese alluaudite - purpurite or manganese sicklerite - purpurite.

I. APATITE

Apatite occurs in appreciable quantity, in the form of rather large crystals, in two of the pegmatites described. In the Rubicon petalite quarry of Helicon II, it is found rather abundantly as dark blue crystals 1½ - 2 ins. x 4 - 6 ins. in size, and is commonly traversed by narrow 1/16 - 1/8 ins. veinlets of white. The other minerals found in this unit are quartz, amblygonite, albite and petalite. Apatite commonly exhibits highly irregular crystal edges indicating a certain amount of marginal corrosion. The other notable occurrence is an albite-schorl-muscovite-quartz zone in the western section of the van der Made pegmatite. The individuals may be up to 6 ins. in size and are highly corroded and veined by albite.

In both cases the apatite is an accessory mineral but imparts a diagnostic character to the rock because of its dark blue colour. The latter is characteristic of the manganian varieties. Refractive indices of a dark blue apatite from the Helicon II pegmatite are:

ε	ω
1.643	1.647

L. AMBLYGONITE

Amblygonite is common in most pegmatites of the district.

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It is developed in greatest abundance close to the quartz core, frequently in association with petalite on the hangingwall side of a dipping quartzose core zone (e.g. Rubicon, Karlsbrunn). It is also found without petalite on the core margin and is then associated with albite and quartz and mica. This is the case at Helicon I and Brockmanns pegmatite. Another similar occurrence is the Dernburg pegmatite where amblygonite and beryl are associated with albite, quartz, and muscovite, forming a zone which surrounds a blocky perthite-quartz core.

Throughout, amblygonite has a tendency to form rounded lumps of varying size, sometimes reaching 3 - 4 feet in diameter.

Three chemical analyses of selected samples are listed in Table 14. The analyses have been recalculated in a manner similar to that used by Forster (1960) for the micas. The cationic elements are reduced to proportions of cationic valencies. The total number of cationic valencies are then made equal to 9 since the amblygonite formula is $(Li,Na)AlPO_4(OH,F)$. Each proportional cationic valency is divided by the valency of the particular element to give the cation proportions in a unit cell. OH and F are treated separately; but the anionic proportions (obtained by dividing the wt % by the molecular weight and multiplying by the valency of the anion in the molecule) are multiplied by the same factor used to bring the total cationic charge to 9. Thus a basis of comparison between the anions and cations can be obtained.

From these calculations it can be seen that the minerals approach a 1:1:1:1 ratio for P: (Al+Fe^{3+}+Si+Al):(Li+Na+K+Rb+Cs etc): (OH,F). However the low alkali content of K64 and the high water and fluorine content of K154 are divergent from the ideal, as a result of partial alteration. According to Dana (1951) with F > OH and Li > Na these analysed samples all fall within the range of true amblygonite.

8. TOPAZ

This mineral does not occur in significant amounts in all pegmatites. Where this is the case it is moreover, found in different environments. Generally, however, it is associated with core margin mineralization. Within several of the lepidolite ore zones, e.g. Helicon II and Karlsbrunn, it often occurs as 1/4 - 3/4 ins. opaque bluish green crystals associated with albite on the margins of enclosed quartz pods which attain a size varying from a few inches to several feet. Microscopically topaz grains may also be identified in many of the fine grained lepidolite-albite ores. On other occasions it is found in crystals up to 6 ins. in size on the quartz core margin and is then associated cleavelandite, lithia-mica, amblygonite and beryl, e.g. at Dernburg. The most spectacular development of the mineral is in the van der Made pegmatite where it is found in a distinct zone of cleavelandite and topaz.

The topaz is generally subhedral to euhedral in outline its colour varying from opaque greyish white to opaque turquoise blue.

The refractive indices determined in ordinary light of the van der Made topaz are as follows:-

α = 1.607 ± 0.004

β = 1.613 ± 0.004

γ = 1.620 ± 0.004

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According to a graph given by Deer, Howie and Zussman (1962) the refractive indices would indicate a molecular percentage of $Mn(OH)_2$ equal to 55. This topaz is, therefore a variety rich in F relative to water. Since this mineral forms fairly late in the sequence of pegmatite crystallisation of the pegmatite it also emphasizes the fact that the activity of F increases with progressive crystallisation.

5. NATIVE BISMUTH AND ALTERATION PRODUCTS

Native bismuth is a notable constituent only in two of the pegmatites described. In the main Rubicon ore-body it occurs in generally small residual amounts within yellowish and greenish bismuth ochre on the upper hanging wall quartz core margin. Yellow-ish bismuth ochre is also found in quartz-muscovite rock in the blocky-perthite-quartz-albite-muscovite zone of the Otjua pegmatite.

The best occurrence is that at Rubicon where straight edged veinlets of bismuth ochre distinctly vein and cross-cut the white quartz (fig. 48). The veins, are sometimes present in sufficient abundance to give the appearance of a breccia containing fragments of quartz. Since these veins fill a complex pattern of fractures in the quartz, bismuth mineralisation must postdate the consolidation of the quartz core.

Within the ochre are found masses of pinkish white grey native bismuth. Individual crystals are as much as 1 inch in size, and are often tarnished. Under the reflection microscope rather rare extremely small, needle-like inclusions of bismuthinite were identified. These are noticeably harder than the native bismuth, and of bluish grey colour. Another slightly yellowish white mineral occurring as minute rounded inclusions is probably eulytine-bismithite.

The native bismuth and included sulphides are generally highly altered to mostly a yellowish or greenish ochre. Pale olive rounded patches, approximately 1/4 inch or less in size, are also contained in the ochre. In places very dark greyish brown material is found in the same. All of these various coloured phases yielded identical x-ray patterns which correspond with d-values determined by Frondel (1943) for the mineral bismutite ($Bi_2O_2CO_3$).

From among these alteration products from Rubicon, Von Knorring (1962) has identified a new mineral belonging to the bismutite group.

Since the alteration is found so close to the surface it is supposed to be due to weathering, as is the case in many other bismuth occurrences.

The crystallisation temperature of native bismuth is usually given as 275°C. This is well within the hydrothermal range. For the quartz core to be fractured and veined by bismuth, it must have been already well consolidated and brittle above this temperature.

6. COLUMBITE-TANTALITE

This mineral group is present in most of the pegmatites in various specific positions in the generalised zonal pattern. The

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sites of development, however, are the cleavelandite-rich zone preceding the Li- and Na-mineralisation when this is developed, or otherwise, again, associated with cleavelandite, directly on the pegs core margin. The size and shape in these two zonal positions differ somewhat, being most commonly in the form of narrow platelets 1/16 - 1/4 inch wide in the outer first-named unit, while squat crystals up to 9 ins. in size are often found on the core margin.

Fine grained massive Li-micas sometimes contain small scattered 1/4 inch grains. When carefully examined the latter are frequently situated near quartz concentrations (e.g. Brocksgruva pegmatite and core-margin at Karlsbrunn). At Dernburg, however, columbite-tantalite is dispersed throughout the dense lithia-mica unit without any marked association with quartz. In the same ore-body rich pockets of ruby tantalite with crystals up to 2 ins in size occurs in coarse (1/4 - 3/4 inch) Li-micas and albite rocks. A rather unusual mode of occurrence is the concentration of columbite-tantalite on the upper surfaces of the albite domes at Karlsbrunn.

Chemical analyses of three different occurrences of columbite are listed in Table 15. Although coming from widely separated pegmatites there is a remarkable uniformity in the major constituents (Nb and Ta). According to Dana (1944) with Ob>Fe these minerals are all columbite. The Mn:Fe ratios are as follows:

K128	95:1
K135	36:1
K346	177:1

The analysed minerals are hence members of the manganocolumbite group. Partial analyses made available to the author of a ruby tantalite and a black irridescent member of this mineral group from the Dernburg pegmatite gave the following weight percentages:

	Ta_2O_5	Nb_2O_5
Ruby Tantalite	65.60	17.85
Black irridescent	55.20	26.75

These Dernburg minerals contain a markedly higher proportion of Ta, which greatly exceeds Nb. They thus belong to the tantalite group of the isomorphous series. The narrow Dernburg pegmatite itself shows considerable divergence in mineral zoning from the much larger pegmatites from which the analysed columbite specimens were derived. It is the only one of the pegmatites described in which the minerals of this group are characterised by a high Ta content.

7. URANIUM MINERALS

The most important occurrence of these minerals is in the van der Made pegmatite where rounded 1/4 - 1/2 ins. grains, consisting of an orange and bright yellow margin and small dark brownish cores occur scattered through a dense greenish mica-rich zone of replacement origin. Similar grains are found together with large muscovite and apatite in a cleavelandite-rich zone lying adjacent to the quartz core. Here the uranium minerals are associated with granite and crescentic bands of muscovite 1/2 - 1½ ins. in

[illegible].

Yellow uranium-bearing minerals have also been found in the complex transition zone of the Bailton II pegmatite, immediately adjacent to the Li-rich core found in the Western petalite quarry.

The material from the van der Kade pegmatite was examined by means of X-rays. The outer yellowish ochre is uranophane while the dark cores of the grains after heat treatment were found to be uraninite. Qualitative spectro-graphic analysis confirmed the identification of uraninite.

5. DISCUSSION

(a) General

Certain facts pertaining to progressive changes in the chemistry of the pegmatite system are discussed below in the light of chemical data. By necessity this discussion is concerned with qualitative changes.

(b) Fractional trends determined by the mineralogy

The mica group possibly reveals the greatest range of chemical changes in the pegmatite system with cooling. This group is generally represented in most zonal rock types. The most significant changes are an enrichment of Li in the octahedral sites of micas as one approaches the quartz core. The outer micas are generally lithian muscovites while the massive micas adjacent to the quartz core are generally mixed types (transitional between lithian muscovites and lepidolites) or at least lithian muscovites with a higher Li_2O tenor. Parallel with this Li enrichment is an increase in rubidium and fluorine content.

Also the compositional features of tourmalines indicate enrichment of Li in the residual fractions.

This progressive enrichment of Li is strikingly demonstrated in the field by the localisation of Li-minerals, lepidolite, petalite and amblygonite adjacent to the quartz core.

The appearance of topaz in concentrations on the margins of quartzose bodies lying in the lepidolite zones would also tend to suggest that the activity of fluorine increases in these final stages. Therefore, as Ginsbourg (1959) has suggested the OH/F ratio is extremely useful in determining crystallization trends in the pegmatite system, as this decreases with continued fractionation.

Thus prior to the formation of the dense economic lithia-micas, Li and fluorine are enriched in the residual fraction. Both these elements are highly efficient fluxes in silicate systems in that they tend to depolymerise the silica-alumina networks and thus lower the melting temperatures. Wyllie and Tuttle (19[illegible]) have shown the effect of HF on reducing the melting temperature of granite; they state that a solution containing only 1 wt. per cent Li_2O produces a slightly greater depression of the beginning of melting of granite than a 5 wt. per cent HF solution.

Phosphorous likewise must be enriched in the developing residual pegmatite fractions to form amblygonite and, locally, apatite and lithiophilite.

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Silicic has a peculiar behaviour in that it is constantly [illegible] throughout the process without any noticeable change in chemistry (i.e. as regards Ca content).

Thus from these data it appears that the most important factors controlling the behaviour of pegmatite crystallization as revealed by the chemistry of the minerals are water,(the massive Na zones close to the core), fluorine and lithium.

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CONCLUSIONS

A. INTRODUCTION

In this section the conclusions are treated separately in the following groups : firstly the regional aspects of pegmatite genesis are considered, followed by an interpretation of the cooling history and environment of the complex pegmatites. This subdivision follows the overall pattern of this thesis.

B. REGIONAL ASPECTS OF PEGMATITE GENESIS

(a) General Statement

The following discussion is confined to granitic pegmatites only. In descriptions of pegmatite areas the close relationship between particular types of pegmatites and their parent granites has often been neglected. Read (1957) has, through the years, synthesized various granite types into a genetic sequence the "granite series" which is intimately associated with events in an orogenic cycle. This granite series attempts to relate both time and place in the genesis of the plutonic rocks. From a relatively deep seated early ancestor are derived the later high-level members of the series. The original earliest and deepest term of the series is provided by autochthonous granites and granitisation granites surrounded by great sureoles of migmatites and metamorphic rocks. Paraautochthonous granites are higher and later in the series. By mobilisation, certain of the autochtonous granites begin to part company with their genetic setting and move higher in the crust, or more usually, into tectonic domains of lower pressure". With continued movement the "genetic ties are completely severed and true intrusive granites emplace themselves into higher levels of the crust either as magma but more likely as migma". The final member of the series are high level plutons "intrusive into non-plutonic regions late in the history of the orogen concerned".

It is surprising therefore, that pegmatites are hardly ever considered in this light. So much energy has been devoted to mineralogical and internal zonal aspects of pegmatites that the regional environment has often been overlooked. Notable exceptions, however, have been Fersman (1931), Govers (1936, 1937), Schurich (1948, 1953) and Ginsbourg (1960).

Possibly the most serious stumbling block in the way of establishing a "pegmatite series" is the fact that most granites at different crustal levels may have assorted pegmatitic types of their own and that these may migrate into different environments. Pegmatitic "disperse phases" ("disperse phase" - used to indicate a pegmatite system irrespective of its state i.e. gaseous, magmatic, diffusive flow of ions) are generally the most mobile in any metamorphic-metasomatic terrain. It could thus be envisaged that complex additions and mixings of these pegmatitic "phases" either in a horizontal or vertical direction may take place in a particular orogen. Another complicating factor is that granitic formation and injection under syntectonic conditions possibly results in the most mobile fraction being squeezed out of the area of granite generation while post-tectonic magmatic granites may not be subjected to such suitable conditions for the removal of pegmatitic fractions. In spite of these difficulties it will be pointed out below that attempts of synthesis have been effectively carried out in certain areas.

The following section is devoted to reviewing these aspects of pegmatite generation and to ascertaining whether any

systematic pattern can be applied to pegmatites which is in harmony with the cycle of metamorphism-metasomatism, granitisation and mobilization found in orogenic belts.

(b) Brief Survey of Current Ideas on the Regional Classification of Pegmatites.

Gevers and Frommuse (1929) noted certain specific variations in the size, shape and abundance of pegmatites, as well as the nature of their mineral content with distance from the parent body in the Erongo tin fields of South West Africa. But the first really systematic classification of pegmatite distribution and mineralization with reference to a parent granite body was presented by Gevers (1936, 1937) in his description of Namaqualand pegmatites. Here he recognised interior pegmatites of simple undifferentiated composition situated well within the parent body, and marginal pegmatites injected right outside the parent body into surrounding country rock. The interior pegmatites are characterised by a quartz-felspar "base" and are generally devoid of late concentrations of economic minerals. There is little evidence of "pneumatolytic" (post-magmatic) action. Accessory minerals are schorl, garnet and muscovite. Marginal pegmatites, when large enough in size, are often highly mineralised, exhibiting a high degree of post-magmatic processes. Minerals formed by the latter are albite, muscovite, beryl, tourmaline, lithium-bearing minerals, columbite-tantalite, monasite and other rare earth minerals, native bismuth, sulphides etc.

Heinrich (1948) has also found that a classification of pegmatites into interior, marginal, and exterior was valid for the Right Mile Park area, Colorado. The interior types are well zoned, consisting of microcline, quartz, oligoclase, muscovite, biotite and schorl, but showing no evidence of hydrothermal alteration. The marginal pegmatites reveal a rude zonal structure, are made up chiefly of microcline, quartz, muscovite, biotite and granulo-granite. Post magmatic mineralisation is revealed by replacement action which results in the production of albite, muscovite, beryl, tourmaline and triplite. Finally exterior pegmatites occurring in schist are well zoned, often showing evidence of extensive post magmatic replacement phenomena with the formation of albite, muscovite, schorl, apatite, beryl, triplite, columbite, lepidolite, alkali-tourmaline and natrozontebrasite.

A more hesitant position was adopted by Cameron et. al. (1949), who suggests that further data on the regional zoning of pegmatites should be accumulated.

Heinrich (1953), after accumulating and assessing such data from his own work and the literature, concludes that "in numerous pegmatite districts the size, shape, external and internal structure, texture and mineral content of an individual pegmatite can be shown to be functions of the distance of the body from its batholith source". As an explanation of these phenomena he suggests that the location and the composition of a pegmatite depend upon:

(a) "The chemical character of the source 'batholith'".

(b) "The stage of crystallization of the 'batholith' at the time of withdrawal of the pegmatite material".

(c) "The penetrability of the rock around the pegmatite hearth".

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Jahns (1955) states that "this well documented (regional) zoning constitutes one of the strongest arguments for a genetic relationship between intrusive masses and associated belts of pegmatite".

At this stage of the present review it is apparent that regional zoning of pegmatites with respect to "batholithic" and/or intrusive masses of granitic rocks can be considered a well established fact.

A basic pattern of pegmatites from the simple to the complex types has been proposed by Brotzen (1959a). This pattern portrays the variations in the mineralogical composition between the individual pegmatite types which can be correlated with the order of crystallisation of the pegmatite minerals, with the position of the pegmatites in zoned pegmatite districts, and with the complexity of the deposits" Brotzen (1959b).

Brotzen's four main types of pegmatite are the following:-

Granite Type Pegmatites

These are essentially granitic in composition and contain biotite as the dominant mica. They generally reveal the "normal" zonal pattern, i.e. an outer granitoid zone followed inwards by a zone of graphic granite, a pegmatoid zone and the quartz core.

Mineral Type Pegmatites

Almost of granitic composition but containing muscovite as the dominant mica. As a rule they reveal the "normal" zonal pattern although the granitoid zone may be lacking and "reversed" zoning may occur. The "reversed" or "American" zonal pattern refers to the standard zonal arrangement set out by Cameron et. al. (1949). It is called "reversed" because the outer zones of such pegmatites are represented by mineral assemblages generally found near the core in Brotzen's more simple pegmatite types.

Albite Type Pegmatites

Characterised by late plagioclase, mainly "albite". The dominant mica is muscovite, and the composition of the pegmatite may deviate from that of granite by having a higher silica content and a higher proportion of Na to K. "Reversed zoning" is frequent.

Lepidolite Type Pegmatites

These are characterised by the appearance of lithium minerals. Muscovite and lepidolite are the dominant micas. The composition may be far from granitic and reversed zoning is the rule.

Brotzen suggests that a filter press action may have been an important mechanism to produce these pegmatite types in zoned pegmatite districts. Furthermore his choice of the basic zonal pattern is based on the fact that this type is probably the most primitive pegmatite stage in the above sequence. Significantly albite type is localised in the central portions of pegmatite districts. There is thus again the suggestion of a systematic "pegmatite series" which increases in complexity with distance from a central region of simpler types.

In Russia the early classic work of Fersman has been modified by more recent investigations in Russia. Ginsbourg in 1960 has recently published current views on the genesis of pegmatites and has suggested the existence of a "depth facies of granitic pegmatites". Deep-seated pegmatites have an approximate depth of formation which is greater than 6 - 7 Km. The associated granitic rocks are "large intrusions", commonly made up of biotite as biotite-hornblende granite-gneiss. Migmatitic pegmatites are the usual type though occasionally well zoned bodies occur. Albitization processes are absent while quartz and quartz muscovite replacement action is common. This group of pegmatites is generally rich in Ca, Mg, Ti, Fe which may have been derived from assimilation processes. Sometimes U, Th and Nb occur as trace elements while Be is much more rare. Potential economic minerals are felspar, muscovite and rare-earth minerals.

Pegmatites of average depth are found 3.5 - 4 Km to 6 - 7 Km below the surface, and are usually associated with biotite and biotite-hornblende granites or banatite or granodiorite. This group is generally well zoned internally. Miarolitic cavities may be developed in the central portion of the pegmatite. Replacement processes are locally intense. Microcline is a major constituent and typical elements are B, Be, Nb, Ta, Sn, Li, Rb, Cs. Economic minerals are those of Li, Be, Nb, Ta and Sn.

Shallow seated pegmatites are formed at depths of 2 - 4 Km, being commonly associated with small domes of fine-grained alaskite granite. Pegmatites are developed as schlieren bodies with numerous miarolitic cavities. This group is rich in the volatiles B and particularly F. Be and Li are characteristic. It is this type which is responsible for gemstone deposits.

The "depth facies" concept is an important contribution to the understanding of pegmatite genesis on a regional scale. It is interesting to reflect that the most complex types of pegmatites according to Ginsbourg occur in the intermediate depth zones and are not associated with high level granites. In zoned pegmatite districts the exterior pegmatites (the most mobile type) are the most complex. In the case of high level magmatic granites it would be expected that, since such bodies on the basis of Read's "granite series" represents the accumulation of the most mobile constituents of metamorphic and ultrametamorphic processes, they would be able to give rise to fractionates rich in the uncommon suite of elements so characteristic of complex pegmatites. This point will be discussed later.

A recent contribution by Wiles (1962) on the Miami Mica Field, Southern Rhodesia, reveals certain features identical with those found in the Karibib District. Wiles considers two origins for pegmatites in his area, one magmatic, one metamorphic or metasomatic. The distribution of the economic mica-bearing pegmatites shows a definite metamorphic control "whereas the beryl bearing zones are clearly of igneous origin and related to intrusive plugs of late kinematic biotite-granite".

Hugo (verbal communication) has found features similar to those described by Gevers (1936, 1937) in an area lying to the east. In the Daberas area, Kenhardt District, Hugo has found that a large lense-like, non-foliated biotite granodiorite, has numerous pegmatites containing gadolinite, monazite, allanite and fergusonite, more or less symmetrically arranged around the margins of the massif. (The pegmatites are generally zoned as follows : granodiorite, graphic granite, perthite, quartz core). There thus appears to be a definite genetical relationship between the

pegmatites and the granodiorite. The same relationship, though not as clearly illustrated, was also found by Hugo on the farm Styrkraal in the Kenhardt district.

In the Kakamas area Hugo has established that the pegmatites swarms in the "grey Gneisses" consist essentially of a simple type and may cross-cut the foliation, while in the adjacent metamorphic rocks (often referred to as pink gneisses), more complex pegmatites occur in noticably smaller amounts. Further away, in the schistose metamorphic rocks, hardly any pegmatites are developed. These more complex pegmatites cross-cut the foliation more frequently than the simple types. From his field observations Hugo concludes that the pegmatites appear to be genetically related to the grey gneisses. These examples again illustrate the validity of regional pegmatite zoning.

(c) Implications of the Present Investigation

(i) General

The results of a combined investigation by Smith (unpublished thesis, 1962) on the regional geological environment and by the author on the smaller scale relationships of complex pegmatites to their environment justify the recording of certain conclusions pertaining to the genesis of these complex bodies. It is well appreciated that a great deal more work is required on a regional scale encompassing larger sections of the Damara orogenic belt before a complete picture will be obtained which may well modify the present interpretations. Furthermore, more time data are required from particular regions, and the only manner in which this information can be obtained is by using modern methods of structural geology. Such information can give a near complete record of the sequence of structural, metamorphic and magmatic events of any particular area. It is regrettable that such statistical techniques are so time consuming.

(ii) Results Obtained

Smith (1961) has shown that although many granitic rocks occur within his area, Western Damaraland, South West Africa, the two most widely distributed types, can be related to their stratigraphical environment and are therefore products of in situ granitisation and gneissification. Furthermore, he has recognized a small group of intrusive granites and pegmatitic granites which are found in virtually all stratigraphic horizons. These non-foliated granites are distinctly transgressive with regard to the meta-sediments. The complex, internally zoned and economically mineralized pegmatites are related to such bodies.

Concerning pegmatites in general, Smith states that they are of varying ages with regard to structural and metamorphic events. Three main types of pegmatites can be recognised ranging from syn-tectonic to post-tectonic. The simpler types are early and by far the most abundant while the complex types are late-tectonic and similar to their parent bodies, much more sparsely distributed. Locally intrusive relationships are revealed by the earlier types although they are generally directly derived from the meta-sediments of their immediate environment. An intermediate group of pegmatites is considered to be of intrusive and secretive origin.

The first section of this memoir gave evidence in support of the late-tectonic behaviour of the pegmatites described and their relationships to late intrusive granites. (The granites and pegmatites sometimes clearly cross-cut the fabric and fold trends of the meta-sediments and in places are related to post-folding faults.

Most of the mineralised pegmatites lie in late-tectonic granite and pegmatitic granite massifs, e.g. Rubicon, Brockmans pegmatite in the Albrechtshöhe-Kolmanskop area. The pegmatites show no evidence of internal deformation).

From the field evidence the following important conclusions can be drawn:-

- The complex pegmatites are clearly magmatic.
- They are related in time and space to late-tectonic intrusive granites.
- They occur in a high grade metamorphic environment (amphibolite grades increasing until localised melting and mobilisation of rocks occurs).
- Earlier pegmatites, generally simple types, are often syntectonic.

(d) Towards a Regional Synthesis of Granitic Pegmatite Generation

(i) Interpretation of Previous Literature

One of the major difficulties of trying to bring pegmatites into line with Read's plutonic processes of orogeny is the lack of time data. Most investigations on pegmatite regions lack this, although by applying sound deductions it has been postulated that in other regions interior pegmatites are earlier than the exterior types. This sort of information is critical in relating pegmatites to metamorphic and igneous events during the formation of folded belts.

Another serious problem is the one of relating pegmatites to the various igneous and metamorphic rock types in the so-called "batholithic" regions. Possibly more detailed mapping of metamorphic-grade and the relationships of pegmatites to these rocks, as well as any truly mobilised rocks, could well give results similar to those obtained in South West Africa. Such mobilised and homogenised granites may have accumulated elsewhere as relatively smallish belts at the margin of batholiths. This phenomena is well documented by the contact region of the Cape Granite in the Barberton district of the Transvaal. Simple pegmatites (often exterior types) may therefore also be associated with this type of phenomenon.

(ii) Relationship of Pegmatites to High Level Granites

It should be repeated again that high level, intrusive granites are known to contain pegmatites which are usually rather simple in type. This point has been emphasised by Reeves (1936) who considered that "depth appears to be an important factor in the development of residual melts rich in volatiles ....". He pointed out that the non-orogenic Brongo granites of South West Africa solidified at very shallow depths (only a few thousand feet). In these granites pegmatites are rare, although small lenticular vugs and rather small lenses of pegmatite minerals and greisens occur. Black schorl in hairline veats, and lining fractures is widely distributed in the Brongo granites. Volatiles were, therefore, present in considerable quantity .... "but the absence of typical pegmatites is probably to be explained by the shallow depths of

solidification, the volatiles being rapidly distilled off and dissipated into the roof and atmosphere". This environment is identical with the shallow seated gem pegmatites of Ginsburg's classification. In Southern Africa other examples of high level granites also notably poor in the large complex type of pegmatite are the Bushveld granite in the Transvaal, Cape granite pluton (Schmitz 1946 ?, and the late Karroo granites of S.E. Rhodesia and the Lebombo range.

From the above therefore, it would seem that a direct correlation between Read's granite series and the transition from simple to complex pegmatites is not directly applicable (i.e. high level granites do not, in general give rise to the most complex pegmatites).

It is of interest to note that tin and Nb-Ta mineralisation may be associated with high level granites irrespective of their being late-orogenic or anorogenic types. Examples of the latter are the Bushveld and the younger granite province of N. Nigeria. The famous Cornish tinfields are related to the high level Hercynian granites.

(iii) Composition of Parent Source of Pegmatites

This very obvious factor has been mentioned in numerous publications. If, for example, a particular region is enriched in certain elements entirely by an effective sedimentary "differentiation", then, providing conditions are suitable for the formation of complex pegmatites, these will be characterised by a particular mineral suite. The other extreme case may possibly exist where conditions for the formation of pegmatites were ideal, but for some reason there was no enrichment of particular elements in that section of the earth's crust. Under such circumstances simple pegmatites could well appear in an environment where complex pegmatites should develop.

When viewed in terms of orogenic events the composition of the rocks undergoing simple melting and/or metamorphism, granitisation and mobilisation must have a profound influence on the composition of the derived granite magmas and may be responsible for differences in pegmatite compositions in different "mineralised provinces" on the earth's surface.

(iv) Bulk Compositions of Pegmatites

Jahns (1953) calculated the bulk composition of the complex Pidlite pegmatite and was able to show that it did not differ much from Daly's average granite composition. In contrast to this Brotzen (1959) suggests that there may be differences in bulk composition of his four pegmatite types. Orville (1960) has studied the modal and chemical composition of several simple pegmatites occurring in quartz-mica schist which are peripheral to the Harney Peak granite in the Keystone District, Black Hills, South Dakota. The pegmatites all have a similar composition which is very close to that of the Harney Peak granite. The Li_2O content in the pegmatites is 0.02 - 0.05% while that of the granite is 0.06%. Jahns, however, found a very much higher Li_2O content (0.7%) in the Pidlite pegmatite.

Inherent variations in the bulk composition of different pegmatites are to be expected; and this is possibly particularly true of the unusual elements.

Lack of world-wide chemical data makes further discussion rather speculative. However, it would seem necessary to consider the following points in future work of this kind-

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1. Is there any marked variation between the bulk chemistry of pegmatites and their parent granite masses? For simple pegmatites it would appear that there is none according to the work of Orville (1960). However, the same author states that the complex lithium-bearing pegmatites in the same district should differ in bulk composition from the simpler pegmatites and Harney Peak granite. Jahn's (1955) work, cited above, taking Daly's average granite composition for comparison, is not conclusive in demonstrating a close similarity in bulk composition between the Pidlite pegmatite and its actual parent body.

There is no satisfactory data to suggest that the unusual element content of granites and pegmatites is identical. Where it can be established that pegmatites are clearly related to granitic bodies, it is feasible to compare the bulk chemistry of the two, and establish if the pegmatitic fractionate is different.

2. Are there real differences in chemistry between simple and complex pegmatites? Brotzen suggests a true difference in composition from his first type pegmatites to his fourth type pegmatites. The depth facies of pegmatites as suggested by Ginsbourg (1960) runs parallel with a difference in unusual element content. The same viewpoint is suggested by Orville (op.cit) for pegmatites of the Keystone area. At present it would appear that true differences in unusual element content would distinguish simple from complex pegmatites. However, a great amount of more detailed chemical data is required.

(v) Cooling History of Pegmatites

Heinrich (1948) has made the suggestion that the mechanism of concentration of uncommon elements in pegmatites may have never come into operation and that these elements are distributed very widely in the more ordinary pegmatite minerals. Therefore "it may be possible that the differences between some complex and simple pegmatites are more mineralogical than chemical and more apparent than real". Considering the previous problem it would appear that basic differences in bulk chemistry, may in fact exist, between simple and more complex pegmatites.

Considering the more regional aspects of pegmatite genesis and their genetical relationships to parent granitic rocks the laws of Goldschmidt (1930, 1937) suggest that fractionation should in fact take place in the case of those elements which are rejected during the crystallisation of granite minerals and which should be enriched in pegmatites. This a priori requires that the cooling history of the magma to be sufficiently slow enough for these elements to concentrate in the pegmatite magma.

Therefore, in discussing the generation of pegmatites, the formation and the cooling history of the source rocks are also of prime importance. These points are discussed below.

(a) Conclusions

Regarding the generation of pegmatites it is known that at the various levels of present day erosion there exists a trend for different types of pegmatite to occupy definite zonal positions with respect to associated granitic rocks. In the central regions of pegmatite distribution simple pegmatites are found; if the parent source contained unusual elements these are frequently concentrated in more complex pegmatites which are usually marginal to the parent granite, often extending for many

gible beyond the latter. The greater degree of migration is no doubt due to the greater mobility of the final residual fractions rich in volatiles. Generally they are the youngest, while in the Karibib district it has been possible to demonstrate their direct relation with late- or post-tectonic granites. In many other regions this is unproved, either because of insufficient work employing modern techniques of structural geology, has been done, or because such granites are not exposed at the level of erosion. It is also possible that elsewhere conditions may be different.

In certain regions, however, a direct relationship of time and space between complex pegmatites and late-tectonic granites is quite clear. These regions generally display a high grade of metamorphism, usually of the amphibolite facies or higher, and frequently contain gneisses, migmatites and granites. In direct contrast to this, late- or post-tectonic or non-orogenic high level granites are not associated with complex pegmatites, but may give rise to Sn, Cb-Ta mineralisation.

It should not be forgotten that certain geologic terrains have revealed that secretion-diffusion mechanisms are also responsible for simple pegmatite formation e.g. Nasberg (1951, 1956), Reitan (1958, 1959). In general such pegmatites are formed in metamorphic grades varying from the epidote - amphibolite facies up to the granulite facies. These pegmatites represent local "sweats" of a mobile pegmatitic "disperse phase" which are generally concentrated into areas of low pressure leaving behind a zone enriched in ferro-magnesian minerals. It is proposed that pegmatites which are of such local origin, with respect to their surrounding metamorphic rocks, be regarded as the oldest and simplest types developed during processes of metamorphism and folding. This then establishes a definite starting point in pegmatite genesis. The localised nature of these pegmatites and the absence of complete melting of considerable fractions of the surrounding metamorphic rocks which formed magmas are considered the essential factors for the formation of these bodies.

In the metamorphic rocks surrounding simple granitic pegmatites, the rarer elements of, e.g. Li, may proxy for bivalent atoms occupying the octahedral sites in the micas. Cb and Ta may be widely dispersed in minerals like sphene and zircon while beryllium may go into a variety of silicates where it actually replaces Si (Rankama and Sahama, 1955), in such minerals as alkali felspar, micas, tourmaline, muscovite and biotite. In this manner there is no effective means of fractionation of these elements.

Complex pegmatites require a granite magma which cools slowly enough to give rise to complex fractionates. A melt is probably one of the most important factors in the mechanism of allowing a concentration of unusual elements into the pegmatitic fractionate. Under non-melting metamorphic conditions, the total diffusional distance limits for individual unusual element is probably very small; they are incorporated into new phases almost in situ. This state contrasts with the more truly magmatic or at least partially magmatic conditions where diffusion and migration of unusual elements can be extremely efficient, aided by the migration of water and other volatile compounds to low temperature and low pressure regions (Kennedy 1955).

The most suitable environment for the development of complex pegmatites is that where granitic magmas are injected into or generated within zones of active high grade metamorphism. Much of this magma would possibly owe its origin to the partial melting of geosynclinal sediments and underlying basement rocks. Because this magma cools in a moderate to high grade metamorphic zone it is given sufficient time to fractionate and the unusual elements which are rejected from the common rock-forming minerals

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are concentrated together with the volatile phases (H_2O is the main) and other pegmatitic constituents (granite).

As already stated high level granites do not give rise to complex pegmatites though their composition may not differ appreciably from that already described. Cevers (1936) suggested that the rapid cooling of these granites was responsible for this phenomenon. According to Marmo (1958) post-kinematic granite contains orthoclase while syn-kinematic and late-kinematic granites contain microcline. Where cooling takes longer time the lower the degree of symmetry of the K-felspar and the more ordered is the lattice. Recent work, however, by Mathias (1962) on various South West African disharmonious granite plugs has shown that the K-feldspar is microcline perthite. She suggested that in the case of porphyritic magmatic granites the phenocrysts may have formed at a late pegmatitic stage. In particular Mathias has been concerned with high level granites, e.g. Spitskop, Brandberg granites in South West Africa and the Cape granite. The prophyritic nature of these granites which must certainly be widespread, and thus the pegmatitic action itself, fairly evenly dispersed, indicates a poor degree of fractionation of the volatile material. The absence of marked concentration of volatiles may be due to these high level granites cooling comparitively rapidly, thereby preventing their diffusion to sites of low pressure and low temperature. Instead they, together with associated rarer elements were trapped in the ordinary granitic minerals.

In conclusion it may be stated that the generation of complex pegmatites can be intimately related to plutonic processes associated with orogeny. The essential factors for their formation are:

- An intermediate to high grade metamorphic environment.

- Complexity of pegmatites increases with the degree of mobilisation of the disperse phase (granitic material ultimately becoming a magma) of the active metamorphic zone. This increased mobilisation may occur marginally or externally to large areas of granitic rocks resulting in intrusive granitic and pegmatitic relationships being observed; otherwise it may occur within the central area of granitic rocks developed as homogenised granite plutons and associated pegmatites. Late tectonic granites will only fractionate to give complex pegmatites where the grade of active surrounding metamorphism is high enough to ensure slow cooling. High level intrusive granites tend to be devoid of complex pegmatites but may contain scattered gem-bearing pegmatitic druses and small lenses. Under these conditions complex mineralised pegmatites will form only if the rocks from which the mobile disperse phase is derived do in fact contain a significant amount of unusual elements.

- There would appear to be a continuous "pegmatite-series" associated with metamorphic and orogenic events. The simplest types are formed by almost in situ "secretion" or "sweating" out of the most mobile constituents. Complex pegmatites are derived from granitic magmas of which they represent true volatile-rich fractionates in the classical sense.

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Simple pegmatites however, may also be derived from these granitic magmas if unusual elements are not present, e.g. the Brockmann pegmatite reveals both simple and complex types in the same pluton. The simple pegmatites of this type are generally well fractionated and zoned.

Between these two extremes there probably exists a series of pegmatites of varying complexity. Pegmatites injected into less severe metamorphic environments, or generated in larger amounts directly by secretion-diffusion may be added to, or have added to them, small pegmatitic material derived from the adjacent metamorphic rocks. With increased metamorphism and development of palingenic granite the pegmatites are possibly more likely to be developed from residual fractionates of the granite magma.

6. [illegible]

(a) General Statement

The second section of this paper dealt with the detailed descriptions of the various pegmatites and ended with a summary and Table 1 in which an idealised zonal sequence of zonal formation was presented. This is based on the many fine exposures of mineral variation across, and also along the strike of the pegmatites. There are also numerous indications that fractionation of various mineral assemblages also takes place in a vertical direction, a point which has received very little attention in the past. In this section it is proposed to briefly review the generalised zone sequence and to ascertain to what extent this is in harmony with the findings of investigators in other pegmatites.

(b) [illegible]

The zonal pattern and time sequence of various pegmatite units were found as follows:

(i) Albite-perthite-muscovite; this zone may be subdivided into two units; albite-quartz-muscovite followed inwards by albite-perthite-quartz-muscovite; locally in some pegmatites, a giant perthite unit may follow the above sequences.

(ii) cleavelandite-rich unit with quartz and muscovite; accessory minerals are beryl, frondelite, columbite-tantalite and topas.

(iii) Li- and Na-mineralisation; these zones show distinct variations, but are normally symmetrically disposed about a quartz core; where they occur there often is a decided tendency for the petalite ores to be found in the upper part of the lithium zone, lepidolite being massed in the lower; below the latter sugary albite rock are often found capable of diapiric movement intruding and replacing earlier consolidated zones; three units may possibly be developed and although they are capable of overlap they also show a

definite time sequence of formation:

- Petalite-quartz-albite-amblygonite-columbite-tantalite.

- Lepidolite-albite-quartz.

- Sugary albite with minor lepidolite and quartz.

the main sequence of mineralisation is petalite ——→ lepidolite ——→ albite.

(iv) cleavelandite-beryl-columbite-tantalite-topaz ; cleavelandite predominates.

(v) quartz core; its boundary against neighbouring zones may be sharp and quartz apophyses from the core may cut into the adjacent lepidolite-bearing zones; elsewhere the quartz core may enclose marginally minerals of adjacent zones; the albite domes of Karlsbrunn definitely appear to have originated after the concentration of quartz in the core.

(c) Comparison with other Pegmatite Areas

One of the most thoroughly investigated lithium-bearing pegmatites is that of Varutrask, in Northern Sweden, recently fully described by Quensel (1955). Two main stages of crystallisation existed. The first was the pegmatitic stage when the border, wall, intermediate and quartz core zones were formed. The intermediate zone consists of an outer unit composed of perthitic quartz and muscovite, and an inner unit of the same constituents but also containing spodumene and montebrasite in addition to the previous zones. In this pneumatogenic stage an earlier lithium replacement unit comprises lepidolite, petalite and a second generation of spodumene. It is not clear what the age relationships of these individual minerals are; Quensel states, however, that spodumene and petalite appear to be contemporaneous. Next follows a caesium replacement unit composed of pollucite. The later age of this unit is indicated by pollucite being observed to replace petalite. The last significant replacement unit consists of almost pure albite, developed mainly in the form of cleavelandite though fine-grained albite also exists. Albite is found to replace and transect all other earlier mineral assemblages.

There are certain similarities between the above sequence and that found in Karibib district where some of the albite is found to post-date the formation of lepidolite. Here the main Ne-rich phase can be subdivided into an earlier sugary albite stage and a later cleavelandite stage. The main difference in interpretation lies in Quensel assigning the quartz core to a pre-lithium and sodium mineralisation.

Heinrich (1948) proposed an essentially similar model of pegmatite crystallization for the Right Mile Park pegmatites of Colorado where an initial aqueatic stage gave rise to the border, wall, intermediate and quartz core zones followed by later secondary units which gave rise to fracture fillings, fracture and contact controlled replacement masses and other more irregular replacement masses. The major minerals belonging to the

secondary units are quartz, sodic plagioclase, sugary albite and/or cleavelandite, lithia micas, beryl, phosphates, columbite-tantalite, etc. It is quite clear that Heinrich considers the quartz core to have crystallised before the Li- and Be- mineralisation.

Similar sequences are indicated by Jahns (1952) who distinguished the following units in his study of the pegmatites of the White Picacho District, Arizona: border, wall, intermediate and core/replacement bodies and fracture fillings. Lepidolite occurs in replacement bodies which are found in the wall zones, outer intermediate zones as well as in the more central parts of the pegmatites. He found that the quartz core sometimes to have been replaced by albite as a post zonal phenomenon. In 1953 the same author made a quantitative assessment of the bulk chemistry and the amount of replacement in the Pidlite pegmatite, New Mexico. This body consists of border, wall, intermediate and quartz core zones and several "composite units" which owe their origin to a certain amount of replacement. Minerals due to replacement processes are albite (mainly cleavelandite), lepidolite and muscovite. Jahns is of the opinion that the actual amount of replacement is quantitatively small.

In his description of the crystallization sequence of the Namaqualand pegmatites Gevers (1936) stated that the magmatic and epimagmatic stages were followed by a number of replacement phases:- "albitization began earlier than muscovitization or lepidolitization, was in part contemporaneous with these, but ceased before the latter two processes were complete". This trend differs somewhat from that found in the Karibib pegmatites.

Page and others (1953) concluded from their investigation of the Black Hills pegmatites in South Dakota that most of the plagioclase and lithium minerals are not related to a hydrothermal stage, as thought by previous investigators, but belong to a magmatic stage, though "like other pegmatitic minerals they may also occur in units formed primarily by hydrothermal solutions". Crystallisation is considered to have taken place in an orderly manner from the walls inwards, the last two zones to form, being albite-lepidolite-plagioclase-lithia micas-quartz and the quartz core. This general sequence ending with the quartz core is in harmony with the present author's findings.

Possibly the most pertinent paper discussing the crystallisation sequence of pegmatites is that of Brotzen (1959) based on innumerable literature references and his own observations. He concludes:-

- lithium- and sodium-mineralisation may precede or post-date the quartz core.
- similarly the sodium-mineralisation (essentially cleavelandite-) may precede or post-date the lithium-mineralisation.
- in the very complex pegmatites (Brotzen's fourth stage type) the formation of lepidolite follows on that of spodumene and petalite; cleavelandite persists beyond lepidolite.
- the quartz core becomes brittle at about 270°C. Alkali replacements and core margin mineralisation preceded this consolidation.

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In these described sequences there are several points which are in full agreement with Karibib pegmatites.

The essential sequence of crystallisation of granitic pegmatites as envisaged by Ginsbourg (1960) is essentially controlled "by the part played by alkalis at differing stages of the process and the appearance of volatiles during the last stages". The sequence delineated by him, from oldest to youngest units is: calcium - sodium (plagioclase), potassium (microcline), lithium (spodumene), sodium (albite) and late lithium and potassium (lepidolite). Here again the period of albitisation precedes the lepidolite stage. It is not clear what exact relationship Ginsbourg considers the quartz core to have to the other zones.

The above review brings to light considerable variations either in the actual sequence of crystallisation in the various pegmatites or in the interpretation by different investigators of similar features. The main discrepancies concern the degree and extent of replacement of earlier by later phases. While some e.g. Cevers and Quensel, assign a major role to this process, others, particularly the authors of the classic memoir on the internal structure of the Black Hills pegmatites in S. Dakota, consider it to play an only insignificant role.

It would appear, however, that while a broad overall pattern seems fairly well established, there actually do exist considerable differences between the various pegmatite areas not only with regard to the perfection and symmetry of mineral zoning, but also in respect of late-stage processes. In all of the various interpretations listed, there are many that agree with the author's observations (and interpretations) in the Karibib district as already described in detail. One of the main differences would appear to be the relationship between the sodium and lithium stages of mineralisation. The broad overall sequence, as interpreted by the author for the Karibib district, contains in many essential aspects with that suggested for other areas. The author's own findings particularly support those of Brotzen (1959).

(d) The Conditions of Crystallisation within Pegmatite Bodies

Pegmatite literature abounds with terms designed to represent different stages of development. Often these are given rather rigorous temperature limits and the environment is suggested confidently in spite of the lack of experimental data on pegmatite processes. In most syntheses it is accepted that pegmatite formation covers the fields of magmatic crystallisation to hydrothermal mineralisation. This range is possibly a rational deduction for magmatic pegmatites but the assignment of rigid temperature ranges (often hundred degree intervals e.g. 600°C, 500°C, 400°C, 300°C etc.) to various stages of mineralisation can only be regarded as highly speculative. However, as Jahns (1953) has already pointed out, some of these overall temperature limits have stood up fairly well against new geothermometric data, even if one does not agree with the individual breakdown of the various stages.

Selected examples of these estimates of temperature and environment are given below as they serve to illustrate the overall impression of most pegmatite investigators that pegmatite mineralisation covers a wide range of processes.

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Goranson (1931) probably gave the most rigorous breakdown of pegmatitic processes, viz:-

800 - 700°C - epimagmatic	equilibrium between silicate-melt and crystalline phases
700 - 600°C - pegmatitic	
600 - 500°C - pegmatoid	essentially coexistence of crystalline, liquid and gas phases
500 - 400°C - hypercritical	
400 - 300°C - high hydrothermal	essentially equilibrium between crystalline, aqueous liquid and aqueous gas phases.
300 - 200°C - middle hydrothermal	
200 - 100°C - low hydrothermal	

Devers (1936) suggested the following main stages of mineralization to have been active in the Namaqualand pegmatites:-

above 600°C - epimagmatic and late magmatic replacements

about 600 - 500°C - early pneumato-hydatogenic stage. Replacements at high temperature with the formation of schorl, spessarite, beryl, fluor-apatite, columbite-tantalite and spodumene.

about 500 - 400°C - late pneumato-hydatogenic stage. In this stage the processes of albitisation, muscovitisation and lepidolisation take place.

about 400 - 269°C - initial hydrothermal stage. Vein formation; generally contain quartz tourmaline and apatite. Muscovite continues to form.

269°C and below - late hydrothermal stage. Formation of phyllosilicates essentially by replacements.

Quensel (1935) also differentiates various stages of pegmatite mineralisation at Varutrask, Northern Sweden, viz:-

around 800 - 600°C - pegmatitic stage with the formation of border, wall, intermediate and quartz core zones

around 600 - 400°C - pneumatogenic stage in which lithium and caesium replacement units represent a higher temperature stage while sodium replacement takes place during a lower temperature

around 400 - 100°C - hydatogenic stage, when numerous secondary minerals form e.g. kaolin, montmorillanite, cookeite etc.

Most later pegmatite investigations tend to formulate less precisely defined and fewer stages. The main stages postulated are : firstly a magmatic stage, followed by a stage when the residual fluids contain a tremendous enrichment of volatile constituents during which the vapour pressure reaches a maximum (pneumatolytic stage) and finally a hydrothermal stage starting

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near to the critical temperature of water. The assignment of individual rock groups to these main three stages must necessarily be somewhat speculative. The most significant criteria are the sudden appearance of numerous hydrous minerals and textural evidence, in which replacement features are the most important.

Among the later North American investigators (Heinrich 1948; Cameron et. al 1949; Hanley, Heinrich and Page, 1950; Page and others, 1953; Jahns, 1955), there is a noticeable reluctance to differentiate units into definite temperature groups. Jahns (1955) in his summary of the relevant literature on pegmatites pointed out that replacement processes in general have been attributed to one or more of the following:-

- rest liquid of progressively changing composition.
- vapours and their condensates derived from a rest liquid undergoing resurgent boiling.
- hydrothermal solutions formed by direct descent from the rest liquid.
- hydrothermal solutions immiscible with the rest liquid.
- liquid or gaseous solutions derived from sources outside the pegmatite body.

The same author favours the view that replacement takes place mainly as a result of the activities of condensed vapours formed by resurgent boiling of the rest liquid. Jahns (1953) have attempted a quantitative estimate of the amount of replacement that took place in the Pidlite pegmatite and concluded that some 75 per cent of the pegmatite had consolidated prior to the major period of replacement. The minerals formed during the latter stage are considered to have formed partially from the replacement of pre-existing consolidated material and partially from direct cyrstallization of the residual fluid.

Brotzen (1959) divided pegmatite crystallization into a series of mineralogical assemblages which represent their order of formation and are chosen because they represent significant genetical stages of the entire pegmatite process

- granitoid (border zone)
- zone of graphic granite
- pegmatoid zone
- core margin
- alkali replacements
- core ma[illegible]in products
- alteration products

The quartz core is left out because its position is difficult to [illegible]. However, Brotzen believes that quartz ceases to crystalise in the graphic granite zone (the microcline crystals thus [illegible] the pegmatoid zone) to make a late appearance in the quartz core as well as interstitial quartz of the pegmatoid zone and core margin. This is explained by the "ability of silica to polymerise and to form inert 'noncrystalline' matter such as glass and a silica gel". CO_2 is considered to play an important part

in this process.

Recent discussions of geothermometric data are given by Jahns (1955) and Brotzen (1959). Jahns concludes that pegmatites were formed in the range 700 - 250°C and that internally zoned pegmatites began to crystallise at temperatures not greatly in excess of about 550°C. Brotzen suggests that most pegmatites were emplaced at temperatures well above 600°C (graphic granite) and that feldspar and the earliest beryl crystallised at about 600°C (pegmatoid zone) that muscovite started to form at about 500° (core margin ?), that spodumene started to form below 500°C (alkali replacement and core margin) that beryl and muscovite continued to form until 300°C (the higher range about 500°C representing core-margin and equivalent assemblages and the lower range about 300°C, later groups including cavity fillings) and finally the quartz core was mainly at about 270°C.

Recent laboratory experiments have thrown considerable light on pegmatite crystallisation. Burnham and Jahns (1962) have shown that pegmatitic melts can dissolve as much as 30% H_2O at 675°C and 10,000 bars. The influence of water on the crystallisation processes has always been considered an important factor by all pegmatite investigators. This water however, is probably concentrated into the residual pegmatite fluids, the percentage thus steadily increasing with the time of crystallisation (assuming a closed system). The relative water content must obviously leave its imprint on the minerals formed at successive stages. A considerable amount will be incorporated in the hydrous silicates of which micas are the most important. Some water must be required to keep the final residual fractions in a non-crystalline state; this will be released only after conversion to the crystalline state. Numerous vugs, druses etc. give evidence of the presence of water. No quantitative data are available to give a rough estimate of the amount of water [illegible] the practical difficulties in obtaining such data are obvious. If the system is not a completely closed one, some of the water may escape into the country rock.

A serious problem that remains is the mechanism of [illegible] quartz in a non-crystalline state at low temperatures, about 300°C as estimated by Brotzen. This author suggests that increased activity of CO_2 may play on important role in this connection.

Jahns and Burnham (1961) have suggested a model of crystallisation for granitic pegmatites which is based on a threefold sequence:-

- crystallisation from a crystalline melt yielding granitoid pegmatite.
- crystallisation concomittantly from a silicate melt and from a co-existing gas phase, yielding giant textured pegmatite and fine-grained even aplitic aggregates.
- segregations of these products vary enormously. Partitioning of constituents between the two fluid phases, rapid diffusion of constituents through the gas, gravitational rising of this gas to form pods and zones of unusual composition.
- crystallisation in the absence of a silicate melt, yielding a wide variety of late stage products.

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They contend that the second stage is vital to all truly magmatic pegmatites. Processes included in the second and third stages are satisfactorily apparent for metamorphic pegmatites.

From the above interpretations certain generalisations can be made. Magmatic pegmatites are emplaced at a temperature of about 700°C. Crystallisation generally begins with a magmatic stage which is followed by stages in which volatiles (mainly water, but also F, Cl, CO_2) play a more important role. During the later processes a gas phase probably co-exists with the residual silicate melt.

(c) Conclusions Concerning the Crystallisation History of the Karibib Pegmatites

In this section an attempt is made to explain the field observations already described in detail, in terms of the current views on pegmatitic and petrological processes.

The following points are considered to be important with regard to the Karibib pegmatites:-

(i) The complex Li- and Be-bearing pegmatites are crystallisation products of a magma; they represent fractionates of late-tectonic intrusive granites emplaced into a region of moderate to high grade metamorphism.

(ii) These pegmatites appear to have crystallised under closed or restricted system conditions. Many of the bodies occur in dolomitic marbles and at the level of exposure reveal very little wall rock alteration. It is surprising that two incompatible phases such as a silicate magma and a dolomitic marble reveal only very narrow zones (inches in width) of reaction skarn (tremolite, scapolite, diopside). Furthermore the Ca content of the plagioclases practically nowhere attains the composition even of oligoclase (page 98) indicating that very little exchange took place.

The phenomenon of very restricted skarn formation is a useful guide in estimating the depths at which the pegmatites were emplaced. The following reactions are possible (Turner and Verhoogen, 1960):

$$2CaMg(CO_3)_2 + SiO_2 = 2CaCO_3 + Mg_2SiO_4 + 2CO_2$$

$$2CaCO_3 + SiO_2 = CaSiO_3 + CO_2$$

Assuming a temperature of 700°C for the pegmatite emplacement and taking into consideration that the carbonate phases remained essentially stable means that $P_{CO_2} = P_{FLUID}$ was equivalent to about 10 - 20 kms depth. (Turner and Verhoogen, 1960).

Another feature in favour of closed or restricted system conditions for the pegmatite crystallization is the fact that lepidolite rocks, petalite rocks, pollucite rocks, almost pure albite rocks, spodumene-quartz rocks etc. are completely confined to the pegmatite bodies themselves. Had any material been able to escape in significant amounts, at least some of the minerals, should also be found, or at least their characteristic elements be traceable, within the enclosing country rocks.

For other arguments concerning closed or restricted system conditions see Cameron et al. (1949), Jahns (1953, 1955) and Pretsen (1959).

(iii) There appears to be a direct relationship between the size and shape of a complex pegmatite and the degree to which it fractionates. Large lenscid bodies often attain a high degree of fractionation (e.g. Rubicon main ore body, Helicon I, Karlsbrunn) while narrow dyke-like bodies are not well fractionated particularly with respect to the lithium-bearing ore zones and the quartz core (e.g. Rubicon west, Durnburg, sections of Helicon II). The crystallisation of a magmatic pegmatite, as shown, is greatly dependent on the rate of cooling and the final proportion of volatiles in the residual melt. It is to be expected, therefore, that size in comparable environments of temperature and pressure will have a strong influence on the rate of cooling and consequent fractionation. It is well appreciated that this is not the only factor governing fractionation.

(iv) The crystallisation sequence of the Karibib pegmatites which is repeated fairly often from one body to the next indicates a fairly uniform set of thermodynamic conditions. Furthermore, there is the very important fact that fractionation particularly of the later lithium and sodium stages may take place in a vertical direction. This has obvious economic and genetical significance. The following conditions are thought to have controlled the development of the Karibib pegmatites.

- The first stage of crystallisation is one in which coarse-grained granite is formed, the main constituents being felspar (albite and perthite) quartz and muscovite. Crystallization probably is "magmatic" in that the mineral components crystallized directly from a silicate melt. Locally in some pegmatite bodies subtle interplay of thermodynamic conditions resulted in fractionation of these minerals (variation in initial partial pressure of water, temperature and pressure?). This stage closed with rather special conditions represented by the increasing stability of perthite which may develop an independent unit, viz. the activity of K increases; giant crystals are formed; the crystals are concentrated in the hangingwall side of a dipping ore body, e.g. Rubicon, Karlsbrunn. Page and others (1953) state that perthite is often concentrated in hooded zones. The formation of giant perthite crystals in the upper portions of unconsolidated pegmatites was probably due to the appearance of a gas phase. This would be concentrated in the upper portions of the residual chamber and allow the formation of giant crystals as the diffusion rates of the component perthite ions would then be high.

- The above stage is followed by a definite break in mineralization. Cleavelandite is the main mineral to form together with quartz, muscovite and numerous accessory minerals. Within this unit a peculiar texture is developed on the outer margin consisting of reniform nests of muscovite from which narrow tapering radiating spines of this mineral project corewards. The tips of the spines are often made up of pink lepidolite. This texture is considered

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significant, being interpreted as follows:-

(a) the residual pegmatite fluid was being enriched in Li, as Li micas tend to form instead of muscovite.

(b) micas are unable to form as crystallisation proceeds, their components being polymerized and concentrated in the residual fluids

The subsequent zones are lithium-bearing, indicating that the concentration of Li was achieving critical proportions. Silica was also being concentrated. Concurrently with this effect of concentration certain unusual elements precipitated together with the cleavelandite in the form of beryl, columbite-tantalite, Fe-Mn phosphates, topaz etc. Critical conditions must have prevailed; these unusual elements were unable to form stable complexes with the alkalis in the residual fluids and were thus eliminated while the alkalis were being stabilised. During this entire stage components of the cleavelandite zone were able to react and replace pre-existing consolidated phases.

The next stage is marked by the appearance of lithium- and sodium-bearing minerals which show a systematic spacial relationship about the quartz core. Whatever the actual state of the latter it must have been fairly well segregated at this stage. It is thus envisaged that a complex series of fractionations took place. The essential element diffusions are illustrated in fig. 49. Although a certain amount of over-lapping may take place in the crystallisation sequence it is quite clear that petalite is among the earliest minerals to form and is accompanied by amblygonite, minor albite, and quartz. The petalite and amblygonite tend to develop giant crystals again requiring rather specialised conditions. Furthermore a rather effective means of fractionating these components from the residual system is necessitated. Possibly a gas phase was involved, particularly since the first-formed petalite is found in the upper portion, viz. the hood of this zone. It appears that under ideal conditions lepidolite post-dated the petalite and itself was followed by the main portion of albite, which commonly is found in massive units below the lepidolite.

This vertical fractionation again poses certain problems. Liquid immiscibility could possibly be involved, but in general the lepidolite ores contain a certain amount of albite which probably crystallised together with the mica. Lepidolite is also slightly heavier than albite, making it difficult to understand why it should mainly collect above the latter, if both were crystallising from an undisturbed silicate melt. Possibly, however, much of the lepidolite may have been derived from the

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replacement of petalite. After petalite (anhydrous) had formed in the hood portion with the co-operation of a gas phase the residual system must have become progressively enriched in water and other volatiles. Under conditions of steadily mounting vapour pressure, conditions for replacement would be enhanced, and the increasing water content, with addition also of K, of which certain quantities must have been taken up into the residual fractions by the replacement of microcline perthite by albite in the earlier formed zones, would then convert the anhydrous petalite to lepidolite. (The footwall region at Rubicon contains very little petalite, probably due to its conversion into lepidolite. It is of interest in this connection that at Helicon I a small isolated body of petalite was found within the lepidolite-albite zone).

The residual fraction of the pegmatite after this stage consisted mainly of the components of albite, silica (already segregated) and volatiles. Another build up of vapour pressure probably enabled the albite residual fraction to behave diapirically intruding already consolidated surrounding rock types as so strikingly demonstrated at Karlsbrunn. When the vapour pressure was rapidly released the undercooled albite fluid crystallised into a sugary albite rock. During this stage of extremely high vapour pressure, already consolidated units, especially the adjacent lepidolite ores, could be fractured to produce the very common brecciated nature of the latter. This fracturing could bring about the rapid drop in vapour pressure of the residual system. In other cases lepidolite and albite may have separated out so close in time that the lepidolite mush became permeated with albite.

This analysis is largely subjective, but would appear to be most feasible in explaining the vertical fractionation observed in so many of these bodies. It is quite impossible to estimate exactly when a gas phase will be liberated in a pegmatite system. The rates of cooling and consolidation no doubt vary in individual bodies depending on the temperature and pressure of the surrounding rocks, and on the size of the particular body. Consolidation would lead to a build up of volatile constituents in the residual fraction and therefore its vapour pressure until the latter reached equilibrium with the surrounding rock pressure and allowed boiling. This effect of the rate of consolidation and vapour pressure build up may possibly be reduced by the rate of cooling which would tend to condense a gas phase. Latent heat of crystallisation probably extends the period of its presence. With the numerous components of the entire system a second, or even several, periods of boiling may occur. The details of the interplay of all these possible processes in a multi-component system cannot be

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evaluated at our present state of knowledge.

As shown by the usually Na-rich core margin mineralisation, the precipitation of albite usually continues well beyond that of lepidolite. Instead of sugary albite, however, the final product is cleavelandlite. This residual Na-rich fluid also contained those elements not incorporated in silicates formed at previous stages or which were able to form minerals of their own, e.g. Cb, Ta, Sn, Cl, Cs, Be, B etc. These now crystallized out in specific characteristic minerals together with cleavelandite which clearly replaces and veins the lepidolite ore zone. Table 1 suggests that this stage is particularly well developed in those pegmatites where these elements were not stabilized at an earlier period, i.e. preceding the Li- and Na-mineralization. (A basic difference in the behaviour of the unusual elements thus exists from one pegmatite to the other. A comparison of Rubicon and Helicon I illustrates this phenomenon). It would seem that very slight changes in the pegmatite system determine whether the unusual elements are concentrated with alkalis of the residual system which ultimately give rise to the Li- and Na- units or whether they are unable to form complexes with the alkalis and then form minerals of their own. Ginsbourg (1960) suggests that the stability of such complexes is determined by variations in the pH of the system. Slight variations in pH might therefore be a deciding factor as to whether mineral assemblage forms before or after the Li- and Na-mineralization.

The quartz core is probably the last unit to consolidate. This is quite a startling suggestion as it is difficult to understand how it would be possible to keep quartz unconsolidated at low temperatures e.g. 300°C as suggested by Brotzen. However, the author's findings are in agreement with Brotzen (1959). See page 121 . That small amounts of fluids were still available at least in portions of the pegmatite after the final consolidation of the quartz core, is indicated by its occasional veining by lithia mica as well as bismuth and associated minerals.

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. . . . . .



FIG. 1.

Showing field relations of pegmatitic and quartz bodies which are pre- or syn-tectonic.

FIG. 2.

Sub Area 1.

Fig. 2a





Fig. 2b



Fig. 2c

Fig. 2a: Poles to foliation and axial plane cleavage. (94 points). Contours at 1,2,3,4,5, 10 and 15 points per 1% area.

Fig. 2b: Lineation plot. (100 points). Contours at 1,2,3,4,5, and 10 points per 1% area.

Fig. 2c: Composite interpretation of figs. 2a and 2b. Great circles and poles to great circles shown in relation to statistically determined maxima.

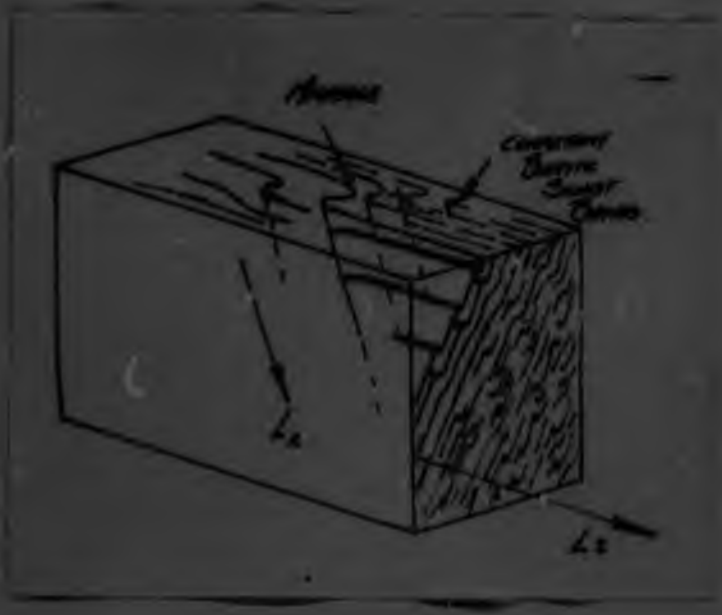

FIG. 3.

Sketch showing relationship of L_1 lineations to L_2 lineations as found in the field.



Fig. 4a



Fig. 4b



Fig. 4c

Fig. 4a : Poles to foliation (71 points). Contours at 1,2,3,4,5 and 10 points per 1% area.

Fig. 4b : Lineation plot (73 points). Contours at 1,2,3,4,5, 10 and 15 points per 1% area.

Fig. 4c : Composite interpretation of figs. 4a and 4b. Great circles and poles to great circles shown in relation to statistically determined maxima.



Fig. 5 : Fold limbs and axial planes having essentially the same orientation. Banded limestone-biotite schist.

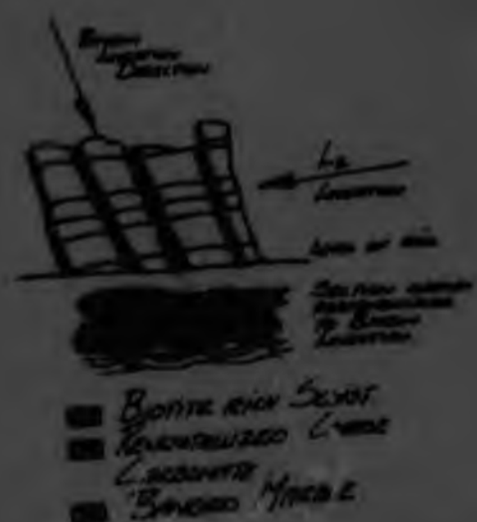

FIG. 6.

Formation of boudins almost at right angles to the micro-fold lineations L_2
1/4 natural size



Fig. 7. : Small tension joints developed perpendicularly to the lineations in a competent biotite schist intercalation in limestone.

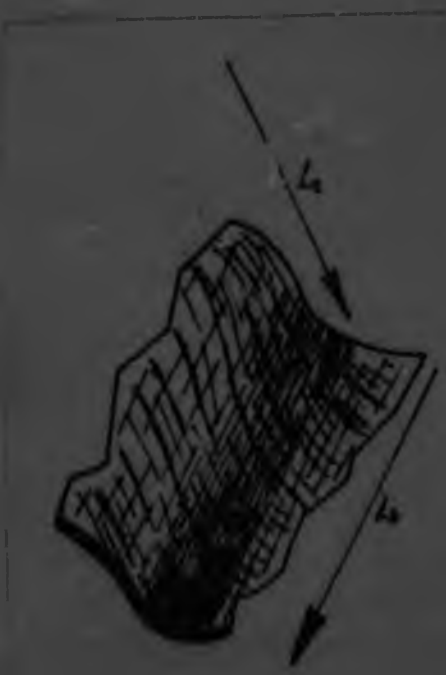

FIG. 8.

One set of lineations L_3 (micro-folds) folded by later L_4 smaller folds.
1/4 natural size

FIG. 9.

Sub Area III.

Fig. 9a



Fig. 9b



Fig. 9c



Fig. 9a : Poles to foliations and axial plane cleavages (53 points). Contours at 1,2,3,4,5 and 10 points per 1% area.

Fig. 9b : Lineation plot (34 points). Contours at 1,2,3,4 and 5 points per 1% area.

Fig. 9c : Composite interpretation of figs. 9a and 9b. Great circles and poles to great circles shown in relation to statistically determined maxima.

FIG. 10.

Sub Area II

Fig. 10a



Fig. 10b



Fig. 10c



Fig. 10a : Poles to foliations and axial plane cleavages (37 points). Contours at 1,2,3,4 points per 1% area. Remnant B$_1$ folds possibly present as indicated by the accommodation of the B$_1$ great circle determined in Sub Area I.

Fig. 10b : Lineation plot (39 points). [illegible] at 1,2,3,4,5 points per 1% area.

Fig. 10c : Composite interpretation of figs 10a and 10b. Great circle and poles to great circles shown in relation to statistically determined maxima.

FIG. 11

Sub Area V.

Fig. 11a

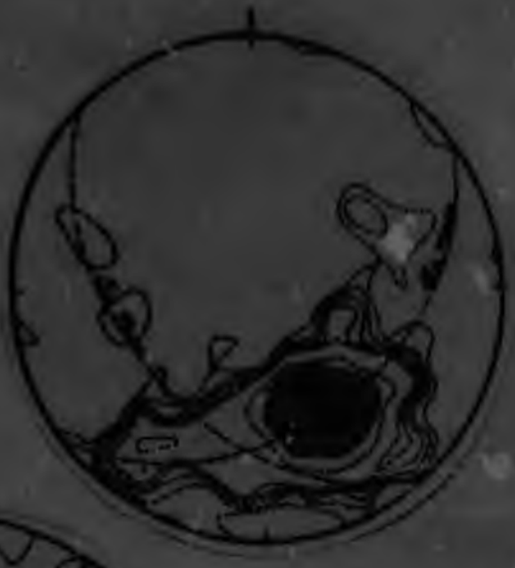



Fig. 11b

Fig. 11c



Fig. 11a : Poles to foliation and axial plane cleavage (251 points). Contours at 1,2,3,4,5,10,15,20,25 and 30 points per 1% area.

Fig. 11b : Lineation plot (286 points). Contours at 1,2,3,4,5,10, 15,20,25 and 20 points per 1% area.

Fig. 11c : Composite interpretation of figs. 11a and 11b. Great circles and poles to great circles shown in relation to statistically determined max'ma.

Fig. 12.

Sub Area VI.



Fig. 12a



Fig. 12b

Fig. 12a : Poles to foliations (small open circles) and lineation plot (contoured). The latter are contoured at 1,2,3,4,5, and 10 points per 1% area. 100 lineations.

Fig. 12b : N.W. isolated outcrop of banded limestone and biotite schist in this sub area. Small dots are lineations. Axial plane of L_2 folds of Sub Area II is shown with a pole to it. A great circle with its pole is drawn through the lineations. A mean idealized axial plane of L_2 folds has been constructed from the two observed axial planes. The pole to this shows the direction of the idealized force required to produce these folds. Large dots L_2 maxima from various sub areas indicated by Roman numerals.



FIG. 13

Sub Area VI : L_1 lineations (diagonal trending small folds across photo) folded by later L_2 fold.

FIG. 14



Fig. 14a



Fig. 14b

Fig. 14a : Albrechtshöhe - Kollombo Area.
Analysis of the third phase of phase of folding with kinematic axes.

Fig. 14b : Broekmanns pegmatite. Crosses are poles to foliations. Large black dot is the pole to the great circle drawn through the foliation poles. Medium black dot is a lineation measured right next to the pegmatite. Open circle is the pole to the plane containing the pegmatite. Small black dots are lineations.



FIG. 15.

Pictorial demonstration of the rotation of a stress field with intense folding. See Text.

FIG. 16.





These photos illustrate the permissive indtroduction of pegmatite into banded limestone biotite schist. The foliations are quite unaffected by the pegmatite.



Location of Brockmanns pegmatite in an anticline of Damara Quartzites on the farm Tsaobismund 85.



FIG. 18

A highly corroded perthite crystal in a matrix of albite (dotted). Drawing from a photograph.

Scale 1 in. = 1 ft.



FIG. 19.

"Nucleation" texture caused by the growth of albite (dotted) and then muscovite (striped) and quartz (white) about a nucleus of partly corroded perthite (crosses). Drawn from a photograph.

Scale 1 in. = 1 ft.



FIG. 20.

Beryl (wavy streaks) and columbite (black) occurring in albite (dotted) - quartz (white)- muscovite (striped) assemblage.

Scale 1½ ins. = 1 ft.



FIG. 21.

Beryl (wavy streaks) occurring in albite (white)- quartz (dotted) -muscovite (striped) assemblage.

Scale 1 in. = 1 ft.



FIG. 22.

Alteration of Lithiophilite (dashed) to an amorphous Mn - Fe - rich wad (White).

Scale -- 1: 2.5



FIG. 23.

Brecciation and veining of purer lepidolite masses (striped) by albite. Speckling indicates varying degrees of lepidolite concentration in the sugary albite phase. Drawing from a photograph.

Scale 1 in. = 1½ ft.

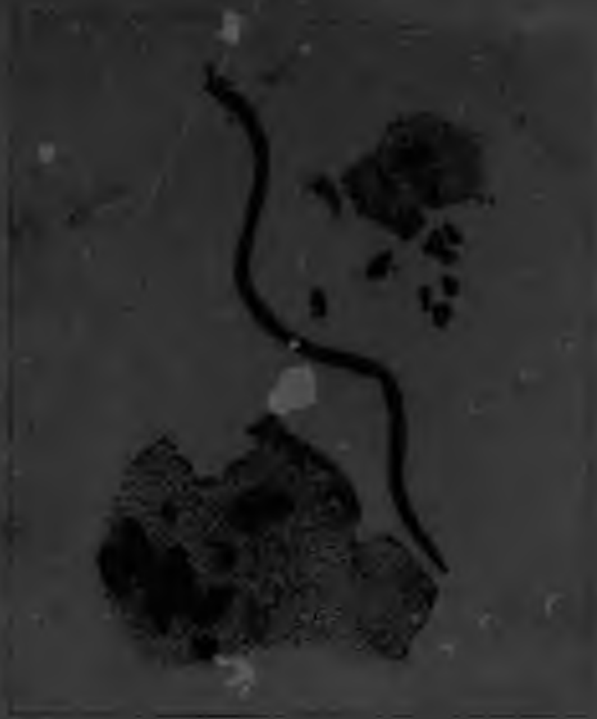

FIG. 24.

Showing an undulating vein of lepidolite-rich rock (dotted) lying in albite-rich rock (white). The speckling represents varying degrees of lepidolite concentration in the sugary albite phase. Drawing from a photograph.

Scale 1 in. = 3 ft.



FIG. 25.

Structures indicating rotation and movement within the lepidolite zone. The speckling represents varying degrees of lepidolite concentration in the sugary albite phase. Note the veining of certain lepidolite-rich blocks by albite. Drawing from a photograph.

Scale 1 in. = 1½ ft.



FIG. 26.

Showing pellucite (dotted) lying in quartz (white). Symmetrically in the centre of the quartz there occurs a narrow vein of grey mica (black). Natural size.



FIG. 27

Showing blocks of pure lepidolite (black) lying in a matrix of sugary albite (white) with varying proportions of lepidolite (speckling). Folded structures reveal that movement has taken place. Drawing from a photograph.

Scale 1 in. = 2 ft.



FIG. 28.

Massive fine grained purple lithia-mica (white) being surrounded, brecciated and replaced by cleavelandite (horizontal lines). Drawing from a photograph.

Scale 3/4 ins. = 1 ft.



FIG. 29.

An outer pegmatite zone of albite-quartz-muscovite (randomly oriented dashes) followed by a cleavelandite-rich (white) zone in which lie reniform nests of muscovite from which project narrow radiating lepidolite spines. Beryl (vertical dashes) is associated with this cleavelandite zone. The next zone is a massive fine grained lepidolite-albite rock (dotted) in which lie quartz blebs (crosses) and purer albite masses (dense dotting).

Scale 1 in. = 1 ft.



FIG. 30.

A quartz rich lense (circles and dots) occurring adjacent to the petalite (double crosses) rich core of the pegmatite in the Western part of Helicon II. Amblygonite crystals (white) occur in the quartz and are "brecciated" by quartz, grey mica and albite. The quartz is a smoky variety (dotted) in the region where the amblygonite is found while further away it grades into the milky variety (circles).

Scale 3/4 ins. = 1 ft.



FIG. 31.

Petalite zone. Petalite (diagonal dashing) and amblygonite (dotted) being replaced by lithia-mica and quartz (black). White grains in amblygonite are quartz.

Scale 1.5 ins. = 1 ft.



FIG. 32.

Large perthite crystal (dotted) lying in quartz (white) and bordered by reniform muscovite nests plus larger muscovite concentrations (striped) in which greenish tourmaline (black) is intergrown. Locally the tourmaline forms an independent border around the perthite where it clearly veins and corrodes the perthite.

Scale 1 in. = 7 ins.

FIG. 33.



FIG. 33 a.
Scale 1 in.= 3 ins.



FIG. 33 b.
Scale 1 in.= 4 ins.

Core margin associations. Dotted is cleavelandite while the crystals with dashed lines are amblygonite. The black crystals are pink tourmaline (rubellite) and are surrounded by muscovite (dense hatching).



FIG. 34.

Nucleus of perthite (diagonal dashing) and quartz, muscovite and minor albite (randomly oriented double dashes) surrounded by a concentric unit of quartz (white) and cleavelandite (dotted) with small conical nests of pink lithia-mica. The perthite is veined by the cleavelandite. This unit in turn is surrounded by a spherical zone of lithia-mica and albite (dashed). Surrounding this is another unit of cleavelandite. The entire spheroid is enveloped by the main quartz core of the pegmatite which connects up with the interior quartz by means of a narrow quartz vein.

Scale 1 in.= 1 ft.



FIG. 35.

Petalite (striped) systematically veined and corroded by quartz (black) and albite-lepidolite (white).

½ Natural size.



FIG. 36.

Block diagram illustrating the emplacement of an albite dome. White-sugary albite; speckling represents lepidolite rocks with varying concentrations of sugary albite. Black represents purer lepidolite bands. Quartz fragments (striped) are also found in the dome. Veining of the lepidolitic masses by albite from the domes may be systematic giving the rock a banded appearance.

Scale 1 in. = 1 ft.



FIG. 37.

Core margin mineral associations.
Dotted = grey lepidolite-albite rock;
black = columbite;
vertical lines = beryl;
squares = apatite;
white = quartz.

Natural size.

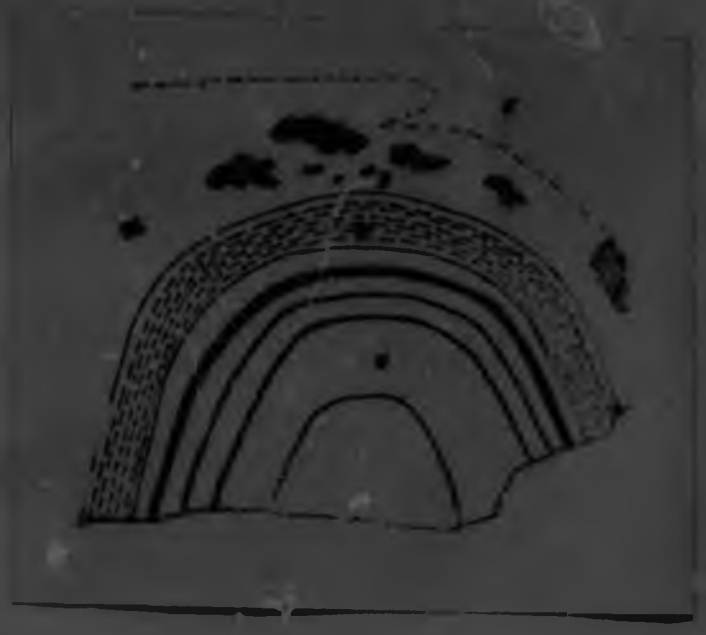

FIG. 38

An example of a well exposed albite dome (unit 4) with a capping consisting mainly of quartz (3). For a full description see the text on page 61.

Scale 1 in. = 3 ft.

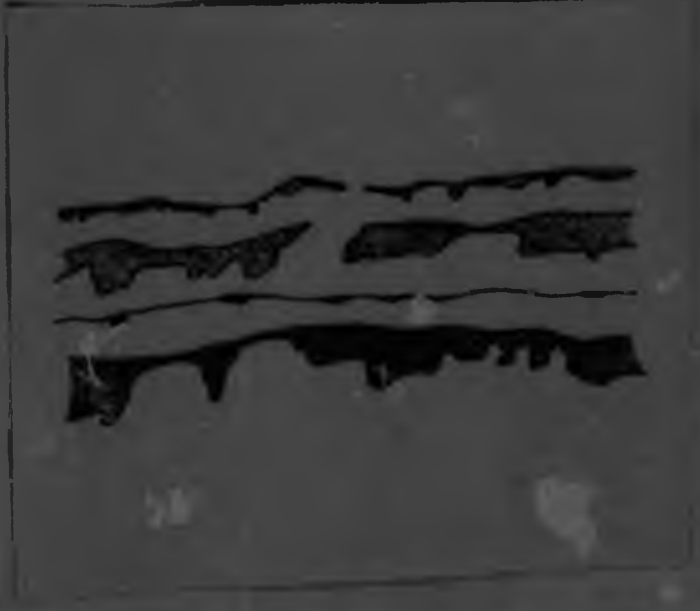

FIG. 39.

Showing detail of the symmetrical quartz capping of the albite dome in fig. 14. White is quartz while the speckled aggregates represent fine grained lepidolite-albite.

3/4 Natural size.



FIG. 40.

Showing the emplacement of a small dome. White = sugary albite with speckling denoting degree of disseminated lepidolite content. Striped area is a highly weathered and broken zone.

Scale 1.1/4 ins. = 2 ft.



FIG. 41.

Skeletal crystals and shells of beryl (dotted) lying in a matrix of cleavelandite (white) and muscovite (striped).

Scale 1 in. = 3 ins.



FIG. 43.

Quartz (white) being veined by a greenish lithia-mica.

½ Natural size.



FIG. 44.

Tourmaline (black) occurring in albite-quartz and muscovite.



FIG. 45.

Showing the relationship of Li, R^{+2} (Fe, Mn^{+2}, Mg) and octahedral R^{+3} (Al, Fe^{+3}) + Ti^{+4} in micas from the Karibib District.



FIG. 46.

Irregular lenses of albite (light grey), as well as cross-cutting veinlets of the same mineral, occurring in microcline (grey).



FIG. 47.

Two types of albite occurring in microcline (grey); coarse replacement perthite and fine film perthite.



FIG. 48.

Brecciation of quartz (white) by native bismuth and bismuthite.

½ Natural size.

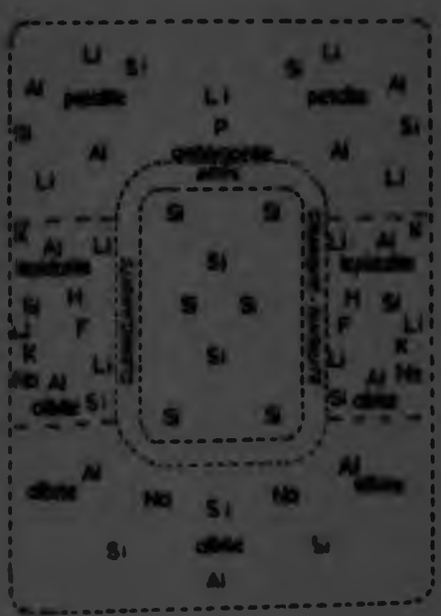

FIG. 89.

Idealized diagram showing distribution of major elements in the Na- and Li- mineralization, core-margin, and quartz core of the Karibib pegmatites.

TABLE 2

DESCRIPTION OF VARIOUS MICAS
SUBJECTED TO CHEMICAL AND X-RAY ANALYSES

K51	MASSIVE FINE GRAINED PURPLE ORE WITH ALBITE. LEPIDOLITE ZONE. RUBICON.
K52	MASSIVE FINE GRAINED BROWNISH PINK MICA. LEPIDOLITE ZONE. RUBICON.
K78	COARSE PLATY GREY MICA FROM THE BERYL ZONE. RUBICON.
K[illegible]	MASSIVE FINE GRAINED MAUVE. LEPIDOLITE ZONE. RUBICON.
K87	FINE GRAINED MASSIVE MAUVE. LEPIDOLITE ZONE. RUBICON B.
K93	COARSE PLATY MICA FROM OUTER PEGMATITE F/W. HELICON I.
K98	MASSIVE FINE GRAINED GREY FROM EASTERN F/W CORE MARGIN. HELICON I.
K99	MASSIVE FINE GRAINED MAUVE FROM LEPIDOLITE ZONE. HELICON I.
K101	MASSIVE FINE GRAINED MAUVE FROM LEPIDOLITE ZONE. HELICON I.
K141	MASSIVE FINE GRAINED PURPLE. LEPIDOLITE ZONE. EASTERN QUARRY. HELICON II.
K142	MASSIVE FINE GRAINED MAUVE. LEPIDOLITE ZONE. EASTERN QUARRY. HELICON II.
K170	MASSIVE FINE GRAINED PURPLE. LEPIDOLITE ZONE. CENTRAL PORTION. HELICON II.
K226	MASSIVE FINE GRAINED PURPLE. LEPIDOLITE ZONE. PETALITE QUARRY. HELICON II.
K330	BIOTITE PLATES IN GRAPHIC GRANITE ZONE. OTJUA.
K396	MASSIVE FINE GRAINED DENSE MICA BELOW CORE - KARLSBRUNN.
K486	MASSIVE COARSE WHITISH GREY POD IN PEGMATITE GRANITE. BERGERS CLAIMS.
K498	MASSIVE DENSE FINE GRAINED GREY. CORE MARGIN. BERGERS CLAIMS.
HELICON II	MASSIVE FINE GRAINED PURPLE. LEPIDOLITE ZONE. PETALITE QUARRY. HELICON II.
BROCKMANNS	MASSIVE FINE GRAINED PINK. LEPIDOLITE ZONE. BROCKMANNS PEGMATITES.
86	MASSIVE FINE GRAINED GREYISH GREEN. CORE MARGIN. VAN DER MADE.
819	LARGE PINKISH GREY BOOKS UP TO 12" IN SIZE. VAN DER MADE.
825	MUSCOVITE-QUARTZ-ALBITE ZONE. VAN DER [illegible]E.
832	FINE GRAINED BROWNISH PINK. REPLACEMENT BROWN MICA ZONE. WESTERN SECTION. VAN DER MADE.

TABLE 2

STRUCTURAL TYPES IDENTIFIED SELECTED AREAS
(by the author)

Specimen No.	Description	Structure Identified [illegible]	[illegible]	Classification Based on Composition of Orthoclase Cotions
[illegible] K151	Massive Fine-Grained Purple	x	x	Mixed Form
[illegible] K262	Massive Fine-Grained Brownish Pink	-	x	No Chemical Analysis
[illegible] K78	Coarse Grey Platy	-	x	No Chemical Analysis
[illegible] K282	Massive Fine-Grained Mauve	-	x	No Chemical Analysis
[illegible] K283	Coarse Platy Grey	-	x	No Chemical Analysis
[illegible] K285	Fine-Grained Massive Whitish Grey	-	x	Lithian Muscovite
[illegible] K301	Massive Fine-Grained Purple	x	x	No Chemical Analysis
[illegible] K142	Massive Fine-Grained Mauve	x	x	Mixed Form
[illegible] K170	Massive Fine-Grained Purple	x	x	No Chemical Analysis
[illegible] K226	Massive Dense Fine-Grained Grey	x	x	Plots close to "Indefinite" Boundary of Mixed Forms and Lithian Muscovite
OTJUA K330	Dark Brown Platy Mica	x?	x	No Chemical Analysis
KARIBURN K396	Massive Dense Grey Mica	?	x	No Chemical Analysis
[illegible] CLAIMS K488	Massive Coarse Whitish Grey	x	x	No Chemical Analysis
[illegible] K498	Massive Dense Grey	x	x	Mixed Form
[illegible] II WEST QUARRY	Fine-Grained Massive Purple	x	x	No Chemical Analysis
[illegible]	Fine-Grained Pale Pink	x	x	No Chemical Analysis
[illegible] K8	Massive Fine-Grained Greyish-[illegible]	-	x	Lithian Muscovite
[illegible] K89	Large Grey Plates	-	x	Lithian Muscovite

x Structure Present

- Structure Absent

TABLE 3

MICA ANALYSES

	3 K142	3 K141	1 K51	3 K498	3 K87	1 K226	3 K99	1 E6	2 E32	1 C35	2 K19	3 K98
SiO_2	48.88	50.95	48.84	49.80	54.54	50.83	62.44	50.46	46.12	49.29	49.06	51.9[illegible]
TiO_2	0.01	0.01	0.00	0.01	0.01	0.00	0.01	0.00	0.10	0.[illegible]5	0.15	0.01
Al_2O_3	28.92	27.38	29.34	27.74	25.78	28.84	20.64	27.39	30.23	33.91	32.19	33.04
Fe_2O_3	0.14	0.69	0.07	0.91	0.57	0.38	0.87	0.57	3.89	1.76	5.07	0.42
FeO	0.02	0.02	N.D.	0.97	0.04	1.15	0.05	2.22		2.08		0.27
MnO	0.28	0.27	0.60	0.75	0.60	0.45	0.30	0.94	0.87	0.67	0.40	0.14
MgO	0.03	0.04	0.03	0.02	0.03	0.00	0.06	0.10	0.18	0.08	0.11	0.02
CaO	0.02	0.14	0.00	0.00	0.31	0.02	0.51	Tr	[illegible]	Tr	0.01	0.02
Li_2O	4.20	3.77	3.42	3.34	3.27	2.93	2.48	2.45	2.24	1.75	0.85	0.58
Na_2O	0.30	1.06	0.85	0.20	1.00	0.58	2.90	2.56	0.71	1.13	0.66	0.52
K_2O	9.28	8.55	11.43	9.46	7.71	10.84	5.06	11.56	11.08	11.14	10.50	8.07
Rb_2O	1.81	1.33	2.08	1.04	1.14	0.80	0.87	0.44	0.51	0.18	0.22	0.35
Cs_2O	0.31	0.31	0.11	0.55	[illegible]5	0.12	0.21	0.18	0.34	0.02	0.11	0.25
P_2O_5	0.10	0.10	N.D.	0.00	0.30	N.D.	0.30	N.D.	N.D.	N.D.	N.D.	0.10
H_2O^-	0.08	0.10	0.24	0.19	0.36	0.29	0.26	1.01	0.13	0.37	0.21	0.04
H_2O^+	2.00	2.53	1.54	2.09	1.57	1.84	1.60	1.09	1.89	1.09	3.50	4.02
F	6.10	5.06	4.04	4.95	4.40	4.65	3.14	3.73	0.60	2.50	0.60	1.46
Cl	N.D.	N.D.	0.12	N.D.	N.D.	Tr	N.D.	Tr	0.[illegible]	Tr	0.01	N.D.
TOTAL:	102.37	102.20	102.71	102.01	102.28	103.72	101.99	104.70	98.99	102.12	100.03	101.15
O ≡ F	2.57	2.13	1.70	2.09	1.85	1.96	1.45	1.[illegible]	0.25	1.05	0.25	0.61
	99.80	100.07	101.01	99.92	100.43	101.76	100.54	103.13	98.74	101.07	99.78	100.54

Analyses undertaken by: 1. Government Metallurgical Laboratory 2. Goldfields Laboratory
3. Dr. J.C. Dunne

TABLE 4

UNIT CELL DATA OF MICAS
(by the author)

Spec. No.	Adjusted Total	Al	Ti	Fe^3	Fe^2	Mg	Mn	Li	Total	Octa-hedral Charge	Tetra-hedral Charge	Composite Layer Charge	Inter Layer Cation Charge	Inter Layer Cation Position
K142	99.80	3.085	-	0.013	0.004	0.008	0.032	2.256	5.398	-0.362	-1.469	-1.831	1.830	1.826
K143	101.37	3.022	-	0.069	0.004	0.008	0.032	2.005	5.140	-0.634	-1.253	-1.887	1.886	1.886
K498	99.92	3.021	-	0.091	0.108	0.004	0.085	1.799	5.118	-0.441	-1.341	-1.782	1.782	1.782
K226	101.75	3.101	-	0.037	0.126	0.004	0.051	1.541	4.860	-0.683	-1.349	-2.032	2.036	2.036
E6	103.13	2.765	-	0.055	0.243	0.195	0.105	1.284	4.647	-1.172	-1.435	-2.607	2.603	2.603
K99	100.34	2.963	-	0.083	0.004	0.011	0.030	1.257	4.318	-1.605	-0.133	-1.738	1.741	1.673
E32	98.74	3.054	0.010		0.439*	0.037	0.101	1.219	4.860	-1.763	-0.425	-2.198	2.167	2.170
E25	101.07	3.160	0.016	0.176	0.228	0.158	0.075	0.920	4.733	-0.066	-2.072	-2.158	2.163	2.163
E19	95.78	3.215	0.017		0.578*	0.025	0.045	0.467	4.448	-0.221	-1.857	-2.078	2.089	2.089
K98	100.43	3.748	-	0.041	0.031	0.004	0.015	0.303	4.142	-0.230	-1.286	-1.516	1.515	1.511

* Total Fe as Fe^2

TABLE - 5.

QUALITATIVE SPECTROGRAPHIC ANALYSIS
OF CERTAIN SELECTED AREAS

Elements	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
As	-	-	•	•	•	•	-	-
Ba	•	•	-	•	-	-	-	-
Be	•	•	•	•	•	•	•	•
Bi	-	•	-	-	•	-	-	•
B	•	•	•	•	•	•	•	•
Cr	•	•	•	•	•	-	-	•
Co	-	-	•	•	-	-	•	•
Cu	-	-	•	-	-	•	•	-
Ge	-	-	•	•	•	•	•	•
I	•	•	•	•	•	•	•	•
Mo	-	-	-	-	-	-	-	-
Ni	•	-	•	•	•	•	•	•
Nb	-	-	-	-	-	-	-	-
Ag	•	•	•	•	-	-	-	•
Te	-	-	-	-	-	-	-	-
Sn	•	•	•	•	•	•	•	•
V	-	-	•	•	•	•	•	•
Zn	•	•	-	•	•	-	-	•

• Element detected

- Not detected

TABLE 6

FELSPAR ANALYSES

	K224	K298
SiO_2	63.99	67.29
TiO_2	0.00	0.00
Al_2O_3	18.95	20.15
Fe_2O_3	0.18	0.18
FeO	N.D.	N.D.
MnO	0.00	0.00
CaO	0.19	0.31
MgO	0.05	0.05
BaO	0.10	0.10
Li_2O	0.09	0.02
Na_2O	2.43	11.66
K_2O	13.55	0.29
Rb_2O	0.26	0.10
Cs_2O	0.05	0.01
P_2O_5	0.76	0.00
H_2O^-	0.11	0.12
H_2O^+	0.25	0.33
F	0.00	0.00
TOTAL	100.86	100.62

Number of Cations Based on 80

	K224			K298	
Si	2.926			2.951	
Al	1.028	3.955		1.041	3.998
Fe^{+3}	0.006			0.007	
K	0.972			0.016	
Na	0.216			0.991	
Ca	0.009			0.015	1.035
Mg	0.003	1.048		0.004	
Ba	0.002			0.002	
Li	0.017			0.004	
Rb	0.008			0.003	
Cs	0.001			Tr	

Analyst : Government Metallurgical Laboratory.

K 224 - Potash feldspar Horizon II Petalite quarry albite-perthite-quartz-muscovite zone.

K 298 - Sodic plagioclase core margin Bechers pegmatite on Otjua.

TABLE 7

SHOWING ANORTHITE CONTENT OF PLAGIOCLASE IN CERTAIN PEGMATITE BODIES
(by the author)

		An
RUBICON	7 ft. from contact with quartz-diorite. South side of pegmatite	5
	12 ft. from contact with quartz-diorite. South side of pegmatite	9
	18 ft. from contact with quartz-diorite. South side of pegmatite	5
	39 ft. from contact with quartz-diorite. South side of pegmatite	7
	Cleavelandite - footwall beryl zone	3
RUBICON	1 ft. from hanging wall beryl zone. North side of pegmatite	2
	21 ft. from hanging wall beryl zone. North side of pegmatite	3
	33 ft. from hanging wall beryl zone. North side of pegmatite	4
	43 ft. from hanging wall beryl zone. North side of pegmatite	3
HELICON I	11 ft. from quartz core contact. North side of pegmatite	6
	14 ft. from quartz core contact. North side of pegmatite	2
	25 ft. from quartz core contact. North side of pegmatite	3
	32 ft. from quartz core contact. North side of pegmatite	3
	39 ft. from quartz core contact. North side of pegmatite	3
HELICON II	6 ins. from northern contact with Damara dolomitic marble	3
	1 ft. from northern contact with Damara dolomitic marble	2
	5 ft. from northern contact with Damara dolomitic marble	2
	14 ft. from northern contact with Damara dolomitic marble	2
	20 ft. from northern contact with Damara dolomitic marble	3
	31 ft. from northern contact with Damara dolomitic marble	4
	34 ft. marks the southern contact with the marble.	

Plagioclase all from albite-quartz-muscovite rock with or without perthite unless otherwise indicated.

TABLE 8

PETALITE ANALYSES

	1 K230	1 K336	2 K338a
SiO_2	76.49	76.88	76.79
TiO_2	0.01	0.01	0.00
Al_2O_3	17.10	17.15	17.02
Fe_2O_3	0.09	0.25	0.29
FeO	0.32	0.34	N.D.
MnO	0.01	0.01	0.00
CaO	0.13	0.11	0.12
MgO	0.04	0.00	0.10
Li_2O	3.88	4.52	4.44
Na_2O	0.36	0.27	0.51
K_2O	0.36	0.09	0.06
Rb_2O	0.06	0.07	N.D.
Cs_2O	0.05	0.11	N.D.
P_2O_5	0.00	0.00	0.10
H_2O^-	0.17	0.05	0.18
H_2O^+	1.20	0.37	0.59
F			0.03
TOTAL	100.41	100.22	100.23
less O ≡ F			0.01
			100.22

Cations related to 10 Oxygens							
	K230			K336		K338a	
Si	3.975	4.000		3.958	4.000	3.959	4.000
Al	0.025			0.042		0.041	
Al	1.027	1.025		0.999	1.008	0.991	1.002
Fe^{3+}	0.003			0.009		0.011	
Li	0.811	0.918		0.985	0.994	0.921	0.991
Na	0.036			0.027		0.051	
K	0.024			0.006		0.004	
Rb	0.002			0.002		N.D.	
Cs	0.001			0.002		N.D.	
Ca	0.007			0.006		0.007	
Mg	0.009			-		0.007	
Fe^{2+}	0.014			0.015		N.D.	

K230 Dull waxy petalite from Helicon II Western petalite quarry.

K336 Rubicon Main petalite zone. Clear White

K338a Karlsbrunn Main petalite zone. Clear White

Analysts: 1. Dr. J.C. Dunne

2. Government Metallurgical Laboratory.

TABLE 9

REFRACTIVE INDICES OF COLOURED TOURMALINES FROM BECKER'S PROMOTION ON OBJUA

	Colour	Pleochroism	E	W	No. of ($Fe^2 + Fe^3 + Mn$) Ions on the Basis of 31(OH,F) E
Same Crystal	Black	Blackish Green to Khaki	1.64	1.67	2.25
	Dark Blue-Green	Pale Bluish Green to Colourless	1.623	1.642	0.80
	Green Shell	Pale Greenish Yellow to Colourless	1.[illegible]	1.641	0.95
	Blue-Green Core	Pale Greenish Yellow to Colourless	1.624	1.638	0.95
	Rather Opaque Pale Pink	Very Pale Pink to Colourless	1.621	1.639	0.60
	Pink From Core of Zoned Pink and Green Tourmaline	Very Pale Pink to Colourless	1.625	1.624	1.00

Refractive indices accurate to 0.003 and determined in Na light.

The number of ($Fe^2 + Fe^3 + Mn$) ions related to 31(OH,F) were obtained from curves of Deer, Howie and Zussman (1962).

TABLE 10

BERYL ANALYSES

	1 K49	2 [illegible]	3 K72	4 K125	5 K223	6 A
SiO_2	64.96	65.09	63.15	64.47	64.20	64.24
TiO_2	0.00	<0.01	<0.01	0.00	<0.01	<0.01
Al_2O_3	17.70	19.67	19.94	17.88	18.49	18.44
Fe_2O_3	0.40	0.10	0.05	0.40	0.44	0.64
FeO	N.D.	0.13	0.13	N.D.		
BeO	12.78	12.51	11.85	12.80	12.52	12.56
MnO	0.00	<0.01	<0.01	0.00	<0.01	<0.01
CaO	0.03	0.01	0.02	0.25	0.49	0.15
MgO	0.04	0.02	0.04	0.03	0.01	0.04
Li_2O	0.2C	0.40	0.89	0.27	0.59	0.59
Rb_2O	0.49	0.51	1.19	0.40	1.10	0.96
K_2O	0.07	0.07	0.08	0.14	0.07	0.07
Rb_2O	0.05	0.03	0.04	0.04	0.05	0.04
Cs_2O	0.03	0.14	0.94	0.16	0.21	0.15
P_2O_5	N.D.	0.01	0.01	N.D.	N.D.	N.D.
H_2O^-	0.17	0.07	0.09	0.01	0.02	0.02
H_2O^+	2.51	1.33	1.04	2.32	2.25	2.24
TOTAL	99.43	100.06	99.46	99.17	100.44	100.15

Analysts : 1. Government Metallurgical Laboratory (No. 1)

2. Gold Fields Laboratories (Nos. 4, 5, 6)

3. Dr. J. C. Dunne (Nos. 2, 3).

K49 : Rubicon Footwall Beryl Zone, transparent orange rose colour

K68 : Rubicon "anticlinal" beryl-rich zone : transparent white

K72 : Rubicon D ore : Hangingwall beryl zone : white colour

K125 : Rubicon I : Hangingwall beryl-columbite zone : white colour

K223 : Rubicon II : Petalite Quarry. White colour. Margin of quartz core lying in lepidolite ore.

A : Berger's pegmatite on Kalomba. Beryl green. Pale pink colour.

TABLE 13.

RECALCULATION OF BERYL ANALYSES
NUMBER OF CATIONS RELATED TO 36 OXYGENS

	[illegible]		[illegible]		K72		K135		[illegible]		A	
Si	12.092		11.915		11.750		12.017		11.[illegible]		11.907	
Ti	0.000		-		-		0.000		-		-	
Al	3.881	3.937	4.244	4.258	4.373	4.380	3.928	3.984	4.036	4.036	4.029	4.029
Fe^{+3}	0.056		0.014		0.007		0.056		-		-	
Be	5.715		5.502		5.297		5.731		5.569		5.590	
Mg	0.011		0.006		0.011		0.008		-		0.011	
Li	0.150		0.295		0.666		0.251		0.439		0.[illegible]	
Fe^{+2}	N.D.		0.019		0.020		N.D.		0.[illegible]		0.[illegible]	
Na	0.177	5.384	0.181	6.032	0.429	6.526	0.144	6.234	0.[illegible]	6.608	0.345	[illegible]
Cu	0.005		0.002		0.004		0.050		0.097		0.008	
K	0.017		0.016		0.019		0.033		0.016		0.016	
Cs	0.002		0.011		0.075		0.012		0.017		0.012	
Rb	0.006		-		0.005		0.005		0.007		0.[illegible]	
E	1.577		1.574		1.584		1.576		-		1.579	
U	1.584		1.580		1.587		1.584		-		1.582	
O	2.67		2.65		2.71		2.67		-		2.65	

	Si	(Ti + Al + Fe^{+3})	(Be + Mg + Li + Fe^{+2} + Na + Cs + K + Cs + Rb)
[illegible]	12.092	3.937	5.084
K135	12.017	3.984	6.234
[illegible]	11.915	4.258	6.032
A	11.907	4.029	6.526
[illegible]	11.887	4.036	6.608
K72	11.750	4.380	6.526

TABLE 12

X-RAYS OF LITHIOPHILITE FROM RUBICON

1 I	1 d(Å)	2 d(Å)	2 I
30	5.22	5.21	M
80	4.29	4.31	M
30	3.95	3.98	S
80	3.51	3.507	M
10	3.33		
		3.194	M
		3.151	M
80	3.03	3.041	V.S.
40	2.79	2.801	M
		2.625	M
90	2.54	2.542	M
20	2.47	2.484	M
10	2.39	2.396	M
20	2.29	2.296	M
10	2.15	2.156	M
10	1.86		
10	1.81		
50	1.75	1.756	M

1. d-values of Triphyllite after Quensel (1935)

2. d-values of partially altered lithiophilite from Rubicon C orebody.

TABLE 13

PHOSPHATE ANALYSES

	1 K21a	2 K21b
SiO_2	0.30	0.52
TiO_2	0.00	
FeO	10.71	
Fe_2O_3	3.03	19.88
P_2O_5	43.74	8.40
Al_2O_3	1.43	0.98
CaO	0.00	1.34
MgO	0.03	0.30
MnO	31.86	4.51
MnO_2		48.77
Li_2O	7.38	Nil
K_2O	0.04	0.60
H_2O^-	0.13	4.92
H_2O^+	2.73	8.39
	101.23	98.90

Cations Based on 4 Oxygens

K21c

Mn	0.721	1.070
Fe^{+2}	0.239	
Mg	0.001	
Fe^{+3}	0.061	
Al	0.045	
Si	0.003	
Li	0.793	0.797
Na	0.003	
K	0.001	
P	0.990	

Analysts : 1. Government Metallurgical Laboratory

2. Gold Fields Laboratories.

K21a — Partially altered yellowish brown lithiophilite

K22a — Amorphous blank mud derived from the alteration of lithiophilite

TABLE 14

AMBLYGONITE ANALYSES

	1 M54	2 K123	3 K154
SiO_2	0.65	0.52	0.60
TiO_2	0.00	0.01	0.01
Al_2O_3	36.68	36.17	33.83
Fe_2O_3	0.19	0.06	0.52
FeO	N.D.	0.14	0.06
MnO	0.01	0.01	0.01
CaO	0.00	0.72	0.31
MgO	0.00	0.00	0.00
Li_2O	8.34	9.58	8.73
Na_2O	0.54	0.68	1.02
K_2O	0.02	0.05	0.05
Rb_2O	N.D.	0.03	0.03
Cs_2O	N.D.	0.05	0.05
P_2O_5	46.80	45.80	46.80
H_2O^-	0.23	0.12	0.10
H_2O^+	4.26	3.98	4.80
F	5.79	4.94	5.68
TOTAL	109.51	102.76	102.56
F_2O	2.44	2.08	2.39
	101.07	100.68	100.17

Cations Related to 9 Anionic Charges							
	M54		K123		K154		
P	0.929		0.973		0.992		
Al	1.014		1.014		1.000		
Ti	-	1.032	-	1.058	-	1.026	
Fe^{+3}	0.003		0.001		0.009		
Si	0.015		0.013		0.015		
Li	0.786		0.945		0.879		
Na	0.024		0.032		0.050		
Ca	-		0.019		0.008		
K	Tr		0.002		0.001		
Mg	-	0.810	-	1.001	-	0.939	
Fe^{+2}	N.D.		0.003		0.001		
Mn	Tr		-		-		
Rb	N.D.		-		-		
Cs	N.D.		-		-		
(OH,F)	1.095		1.036		1.250		

Analysts : 1. Government Metallurgical Laboratory

2 & 3. Dr. J. C. Dunne

M54 Rubicon. In main petalite zone

K123 Helicon I Main amblygonite zone on Mangingwall core margin

K154 Helicon II Western petalite quarry. Complex Transition zone.

TABLE 15

COLUMBITE-TANTALITE ANALYSES

	K128[2]	K135[1]	K346[1]
Nb_2O_5	49.10	53.30	51.00
Ta_2O_5	27.40	25.88	27.90
Al_2O_3	1.05	0.49	0.12
TiO_2	0.14	0.12	0.15
SnO_2	0.32	0.08	0.20
FeO	0.18	0.30	0.10
MnO	17.22	17.56	17.56
CaO	0.00	0.13	0.08
MgO	0.42	0.01	0.01
SiO_2	2.63	0.65	1.10
Na_2O	0.40	N.D.	N.D.
K_2O	0.05	N.D.	N.D.
H_2O^-	0.08	0.06	0.05
H_2O^+	0.32	0.62	0.44
TOTAL:	99.31	99.44	98.72

Cations Associated with 6 Oxygens					
	K128		K135		K346
Nb	1.366		1.510		1.465
Ta	0.439		0.441		0.482
Sn	0.008	2.001	0.002	2.002	0.015
Ti	0.006		0.006		0.007
Si	0.162		0.043		0.070
Al	0.076		0.036		0.009
Fe	0.009		0.026		0.005
Mn	0.898		0.932		0.945
Mg	0.039	1.074	0.000	1.003	0.000
Ca	0.000		0.009		0.005
Na	0.048		N.D.		
K	0.004		N.D.		

2.029

0.965

Analysts: 1. Gold Fields Laboratories

2. Government Metallurgical Laboratories

K128 : Helicon I — Beryl-columbite zone on the hanging wall core-margin.

K135 : Helicon II — Western petalite quarry, beryl columbite paragenesis on margin of large quartz bodies.

K346 : Karlsbrunn — Columbite [illegible] mine dumps.

TABLE 16

QUALITATIVE SPECTROGRAPHIC ANALYSIS OF SELECTED COAL SAMPLES

	KL36	KL45
As	-	-
Be	-	-
Ba	•	•
Bi	-	•
B	-	-
Cd	-	-
Cr	-	•
Co	-	-
Cu	-	-
Ga	-	-
Pb	•	•
Li	-	-
Mo	-	•
Ni	•	•
P	-	-
K	•	-
Rb	-	-
Ag	-	-
Sn	-	-
V	•	-
Zn	•	-

Analyst : Gold Fields Laboratory

• Element present

- Not detected.

PEGMATITE INVESTIGATIONS
IN THE KARIBIB DISTRICT.
S.W.A

C. KOERING . VOL 2.



Geological Map of part of the Mineralized Pegmatite Area.

KARIBIB DISTRICT.

South West Africa.

0 10 20 30 40,000 Feet.
0 ½ 2 4 6 7 Miles

REFERENCE.

- Railway
- Main & Subsid. Roads
- River Beds & Water Courses
- Farmhouse & Windmill
- Strike of Vertical, Dipping & Flat Bedding
- Strike & Dip of Overturned Drag Folded Bedding & Foliation
- Strike & Dip of Foliation
- Plunge of Lineation
- Fault & Breccia Zones
- Mines & Prospects

Li = Lithium Be = Beryl Ta = Tantalite Co = Columbite To = Tourmaline M = Marble Cu = Copper.

- Superficial Deposits: Alluvium, rock debris, aeolian sand, calcrete
- Karroo: Dolerite Dykes
- Karroo: Shale & Extrusive Lava.

	Metasediments (early syntectonic)	Granitized Products in Situ (mid-syntectonic)	Intrusive (late tectonic)
Damara System	Khomas Schist Series Quartzo felspathic biotite schist with variable content of garnet, cordierite & amphibole	Diorite (Di) & Diorite Gneiss (Dign) with orthoamphibolite; Salem Gneiss (Sgn); Salem Granite (Sgr) Porphyritic & non-porph: biot. granite — Salem Granite Group	Red Homogeneous Granite & Pegmatite.
Damara System	Upper Marble Series Massive blue & white marbles occasionally cont. intercalated KS & amphibole schist & calc. silicate bands.	Biotite (KS) Schists → Sgn other intercolations unaffected	
Damara System	Chuos Tillite		
Damara System	Chuos Quartzite Series Red felspathic quartzites & quartz biot schist Sillimanite sometimes developed ho = hornfels	Red gneissose granite frequently porphyroblastic	
Abbabis System	Abbabis Gneiss Quartzo felspathic muscovite gneiss.	Abbabis rocks generally unrecognisable in granitised environment.	

N.B. 1 Early to mid-syntectonic pegmatites are ubiquitous in all metasediments
2 Metasediment remnants are abundant in their granitised equivalents

Map compiled by D.A.M. Smith - 1961.

PLATE I

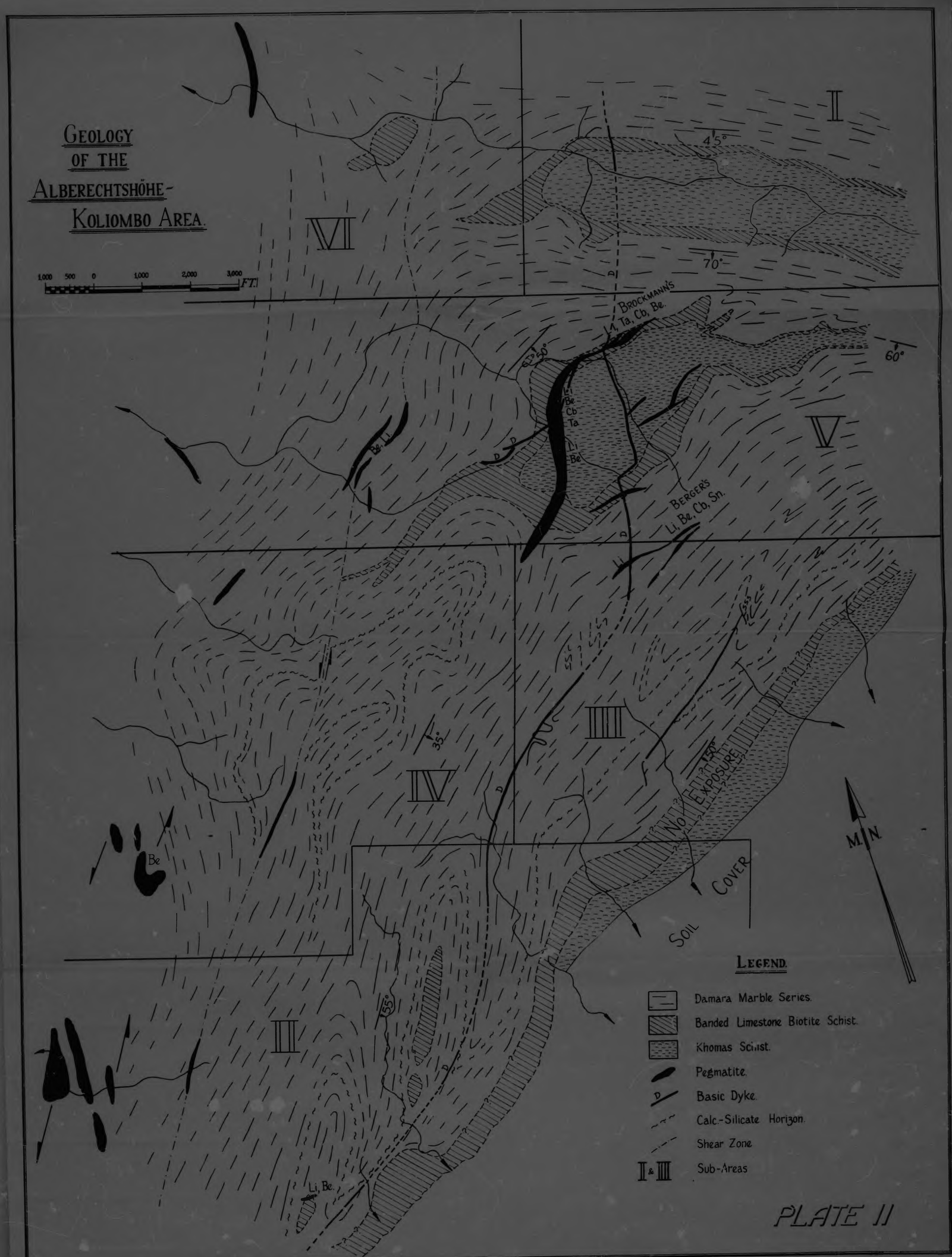
GEOLOGY OF THE ALBERECHTSHÖHE-KOLIOMBO AREA.
1,000 500 0 1,000 2,000 3,000 FT.
I
II
III
IV
V
VI
45°
70°
60°
50°
35°
55°
BROCKMANN'S Li, Ta, Cb, Be.
Li Be Cb Ta
Li Be
BERGER'S Li, Be, Cb, Sn.
Be. Li.
Be
Li, Be.
NO EXPOSURE
SOIL COVER
M.N.
LEGEND.
Damara Marble Series.
Banded Limestone Biotite Schist.
Khomas Schist.
Pegmatite.
Basic Dyke.
Calc.-Silicate Horizon.
Shear Zone
I & III Sub-Areas

PLATE II

Author Roering C
Name of thesis Pegmatite Investigations in the Karibib district, South West Africa 1963

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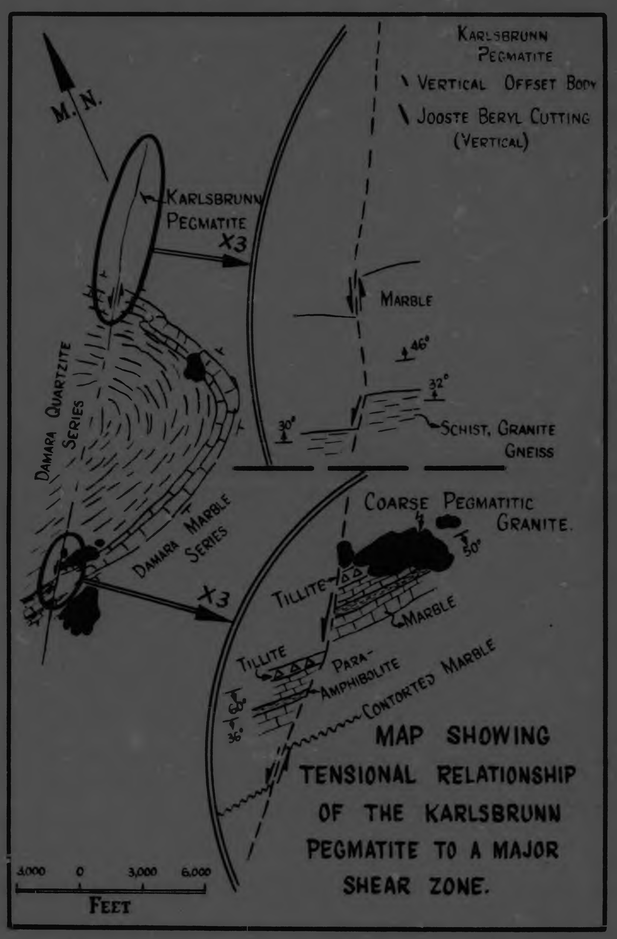


MAP SHOWING TENSIONAL RELATIONSHIP OF THE KARLSBRUNN PEGMATITE TO A MAJOR SHEAR ZONE.

PLATE III

Structural Map Of The Alberechtshöhe-Koliombo Area Showing Orientation Of Lineations

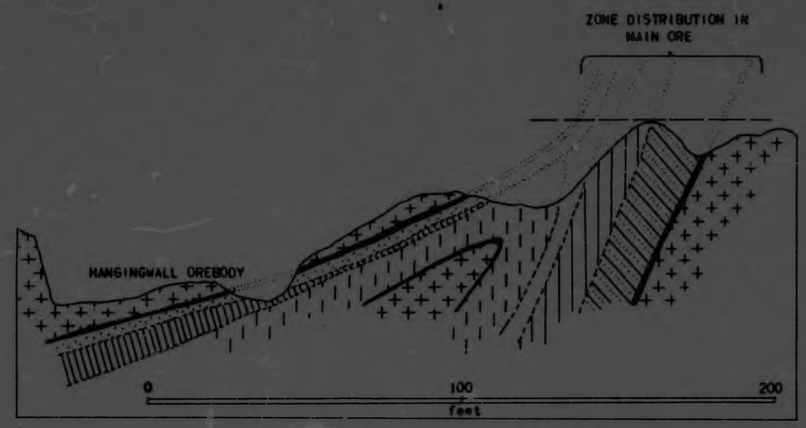
1,000 500 0 1,000 2,000 3,000 FT.

L1 L2 L3

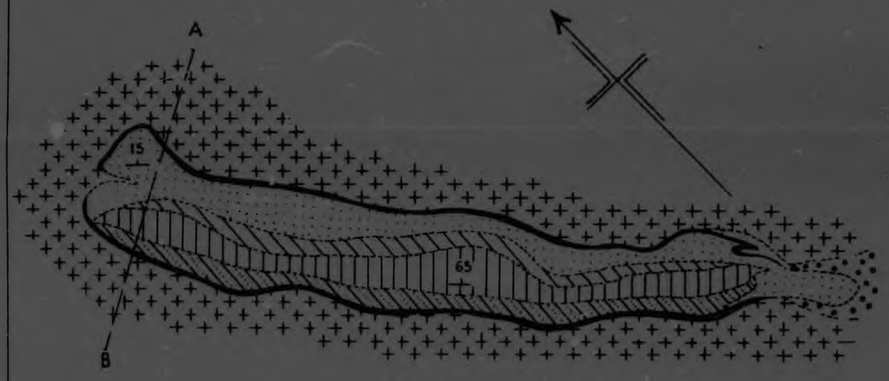
M. N.

PLATE IV

RUBICON PEGMATITE



IDEAL SECTION OF RUBICON ORE-BODY



PLAN OF THE RUBICON PEGMATITE AT THE GENERAL LEVEL OF THE MAIN ORE

- albite-perthite-quartz-muscovite
- quartz muscovite
- giant perthite
- beryl bearing zone
- petalite rich zone
- mixed lepidolite albite and petalite
- low grade lepidolite ore
- high grade lepidolite ore
- quartzose core zone
- massive quartz

PLATE V

0 300 600
FEET

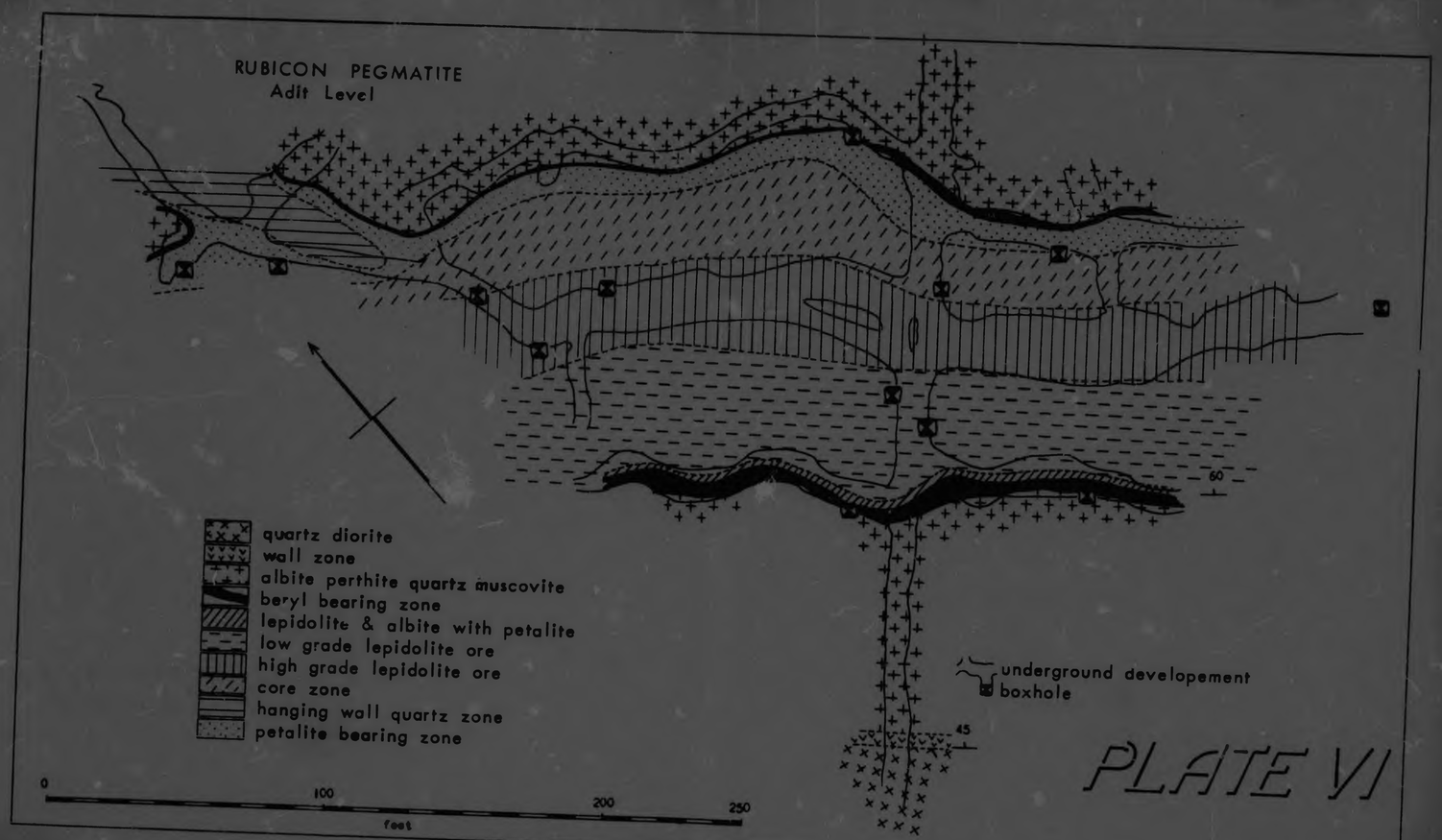
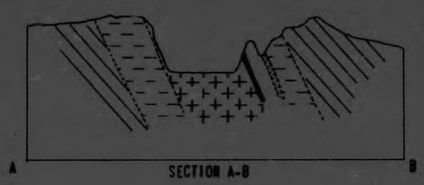
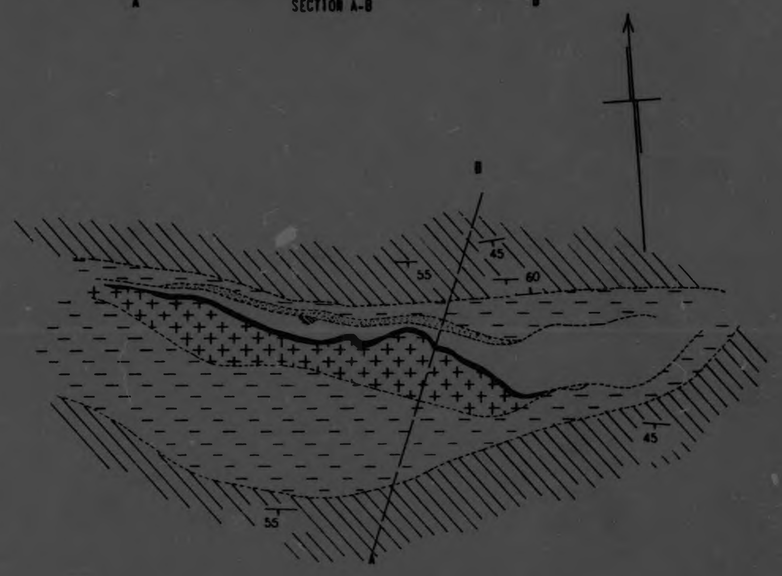

RUBICON PEGMATITE
Adit Level
quartz diorite
wall zone
albite perthite quartz muscovite
beryl bearing zone
lepidolite & albite with petalite
low grade lepidolite ore
high grade lepidolite ore
core zone
hanging wall quartz zone
petalite bearing zone
0
100
200
250
feet
60
45
underground developement
boxhole

PLATE VI

HELICON PEGMATITE



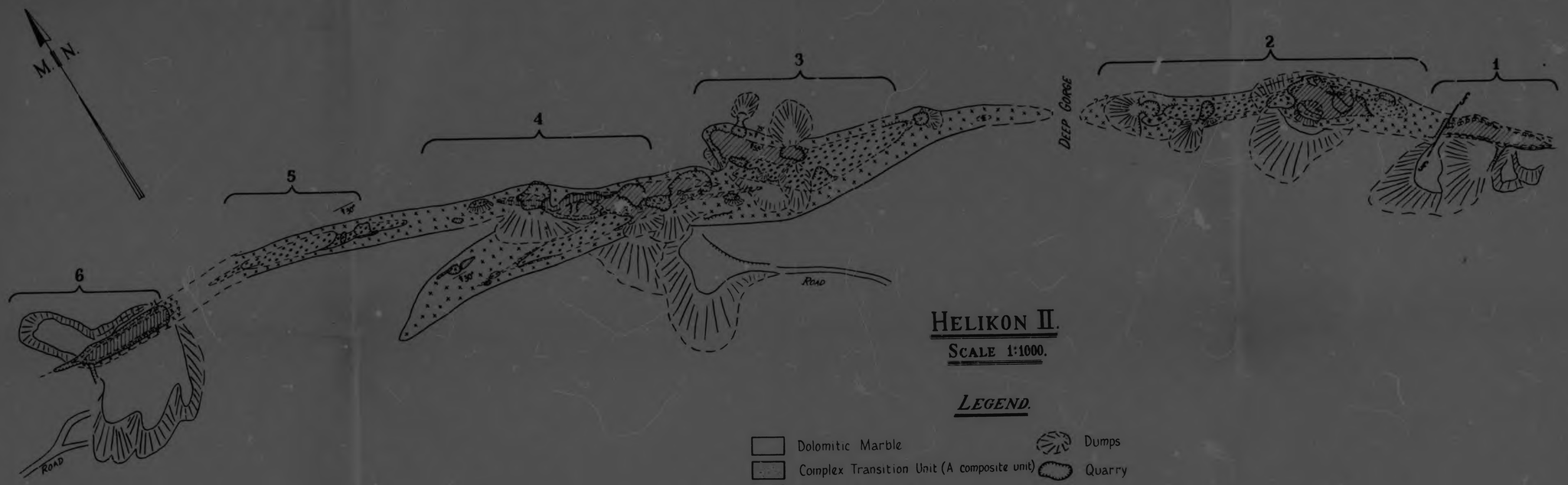
SECTION A-B



- banded dolomitic marble & biotite quartz schist
- albite-quartz-muscovite (perthite)
- lepidolite-albite
- cleavelandite beryl
- quartz
- hangingwall mineralized units
- pollucite unit

PLATE VII

0 500
Feet



HELIKON II.

SCALE 1:1000.

LEGEND.

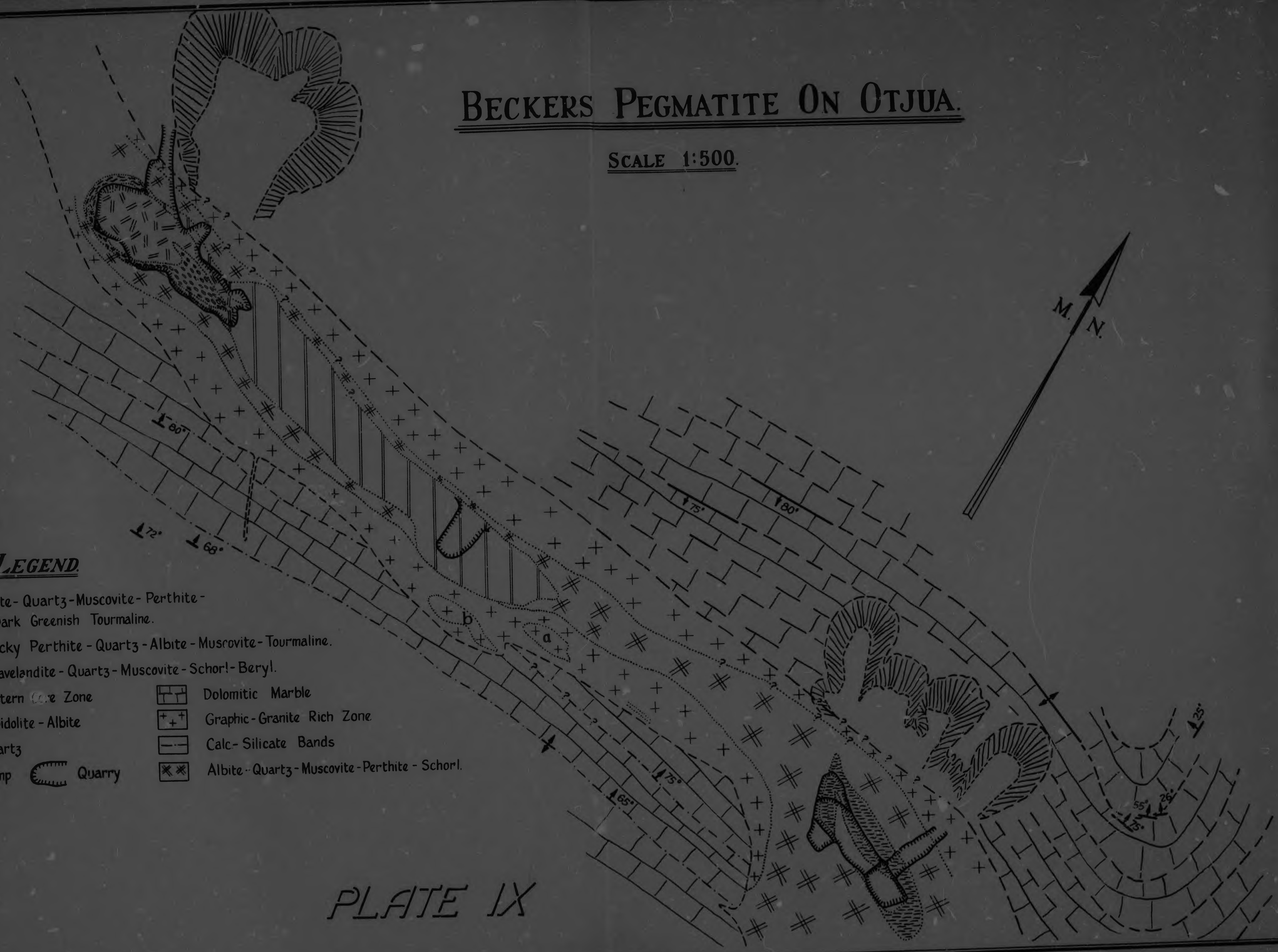
- Dolomitic Marble
- Complex Transition Unit (A composite unit)
- Petalite Bearing Zone
- Lepidolite-Albite-Quartz
- Sugary Albite Rock
- Quartz
- Albite-Quartz-Muscovite
  Albite-Quartz-Muscovite-Perthite
- Dumps
- Quarry
- Outcrop
- 1to6 Sections used to describe Pegmatite in text.

Narrow 1-2 ft units mainly of cleavelandite with minor Muscovite, Quartz, Beryl and Columbite-Tantalite often occur on the outer contacts of the Li-bearing zones or on the Quartz ore margin.

PLATE VIII

BECKERS PEGMATITE ON OTJUA.

SCALE 1:500.



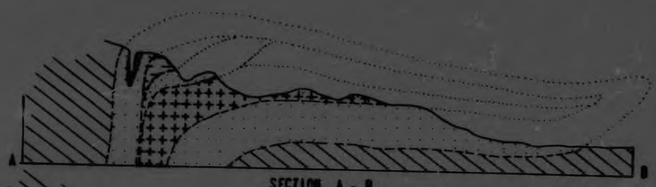
LEGEND.

- Albite - Quartz - Muscovite - Perthite - Dark Greenish Tourmaline.
- Blocky Perthite - Quartz - Albite - Muscovite - Tourmaline.
- Cleavelandite - Quartz - Muscovite - Schorl - Beryl.
- Eastern Core Zone
- Lepidolite - Albite
- Quartz
- Dump
- Quarry
- Dolomitic Marble
- Graphic - Granite Rich Zone
- Calc - Silicate Bands
- Albite - Quartz - Muscovite - Perthite - Schorl.

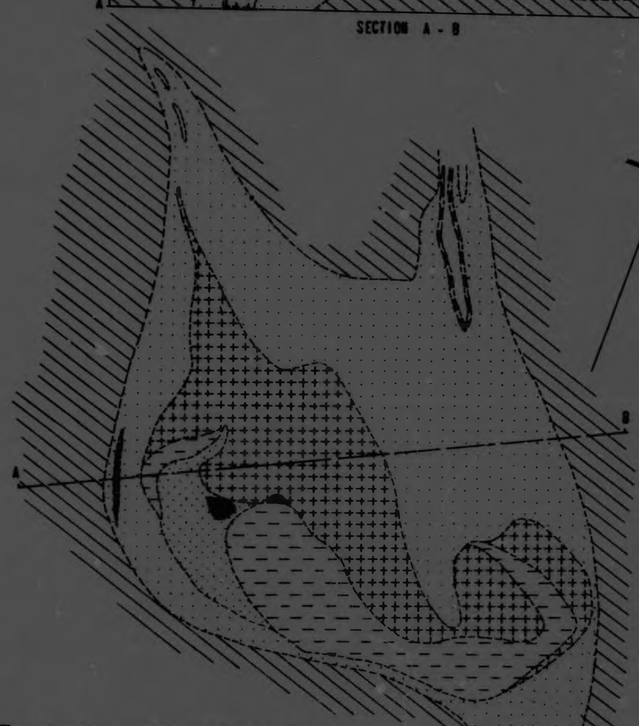
PLATE IX

PLATE X

KARLSBRUNN PEGMATITE



SECTION A - B



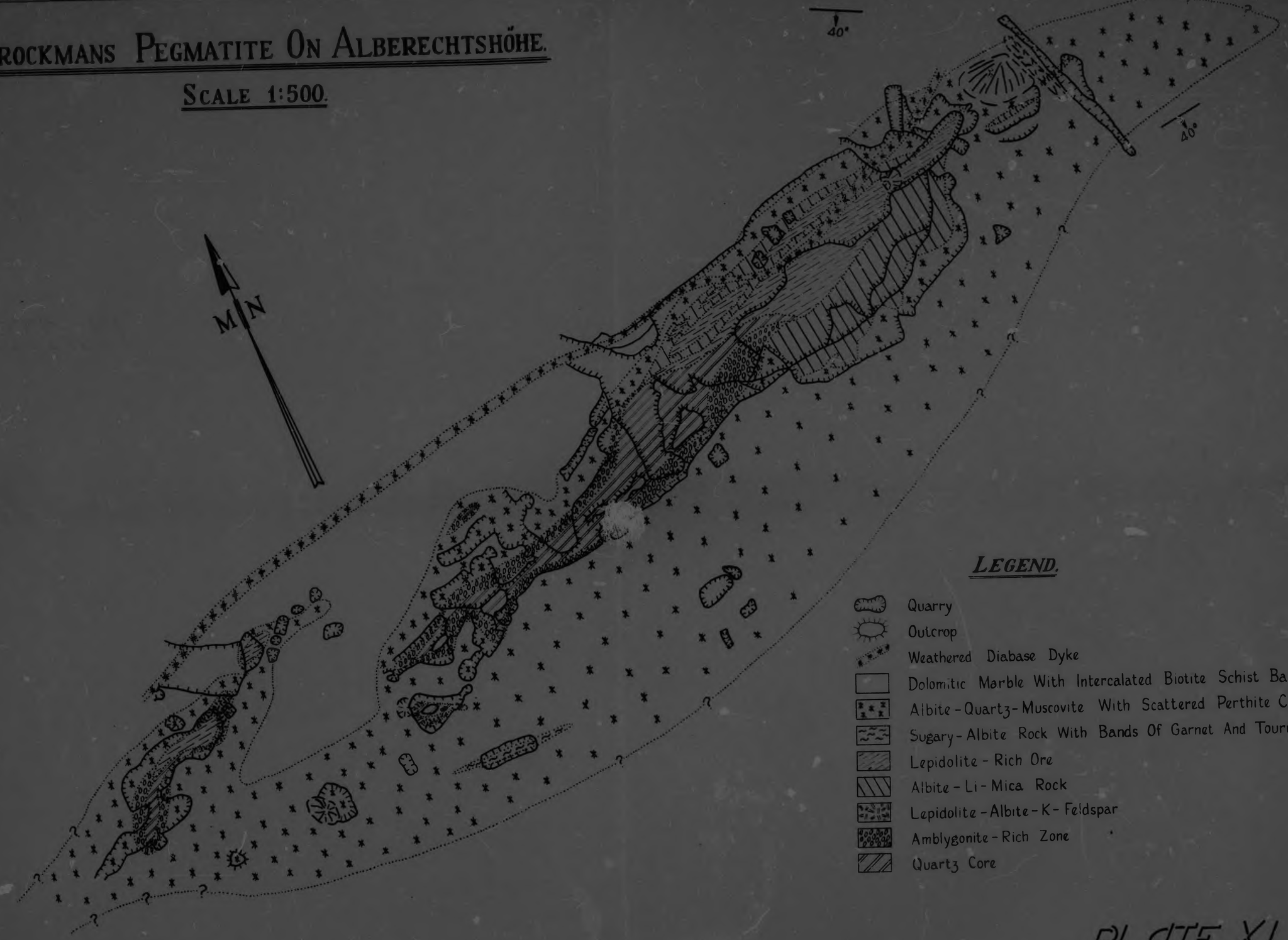
dolomitic marble with tremolite
outer pegmatite unit
beryl rich zone
lepidolite albite zone
petalite amblygonite rich zone
cleavelandite quartz muscovite beryl
quartz
mixed core zone
albite rich domes

0 100 200 300 400

Feet

BROCKMANS PEGMATITE ON ALBERECHTSHÖHE.

SCALE 1:500.



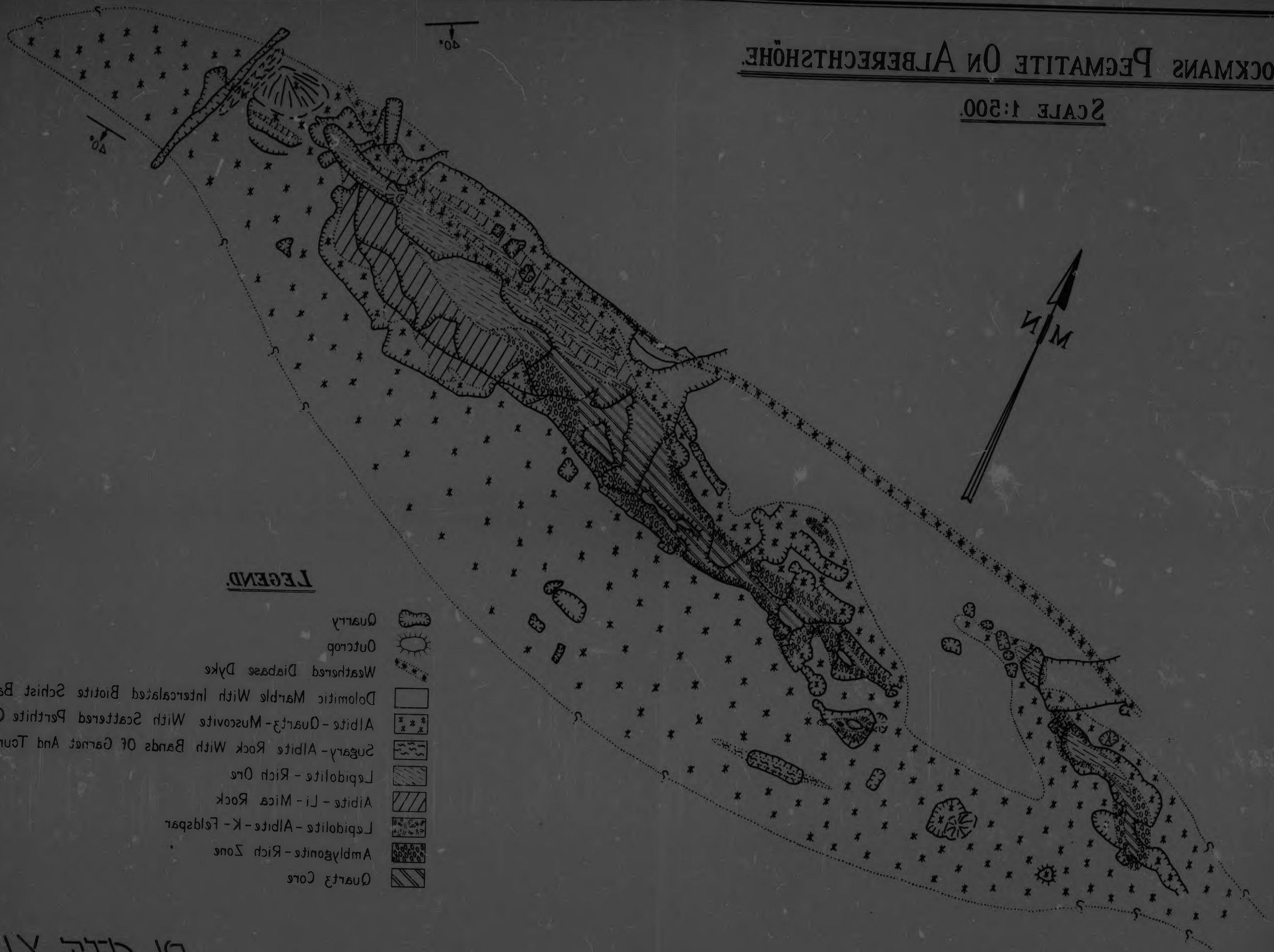
LEGEND.

- Quarry
- Outcrop
- Weathered Diabase Dyke
- Dolomitic Marble With Intercalated Biotite Schist Bands
- Albite - Quartz - Muscovite With Scattered Perthite Crystals
- Sugary - Albite Rock With Bands Of Garnet And Tourmaline
- Lepidolite - Rich Ore
- Albite - Li - Mica Rock
- Lepidolite - Albite - K - Feldspar
- Amblygonite - Rich Zone
- Quartz Core

PLATE XI

Brockmans Pegmatite On Albrechtshöhe.

Scale 1:500.



Legend.

- Quarry
- Outcrop
- Weathered Diabase Dyke
- Dolomitic Marble With Intercalated Biotite Schist Bands
- Albite – Quartz – Muscovite With Scattered Perthite Crystals
- Sugary – Albite Rock With Bands Of Garnet And Tourmaline
- Lepidolite – Rich Ore
- Albite – Li – Mica Rock
- Lepidolite – Albite – K – Feldspar
- Amblygonite – Rich Zone
- Quartz Core

PLATE XI

PLATE XII

BERGER'S PEGMATITE ON KOLOMBO

SCALE 1: 520

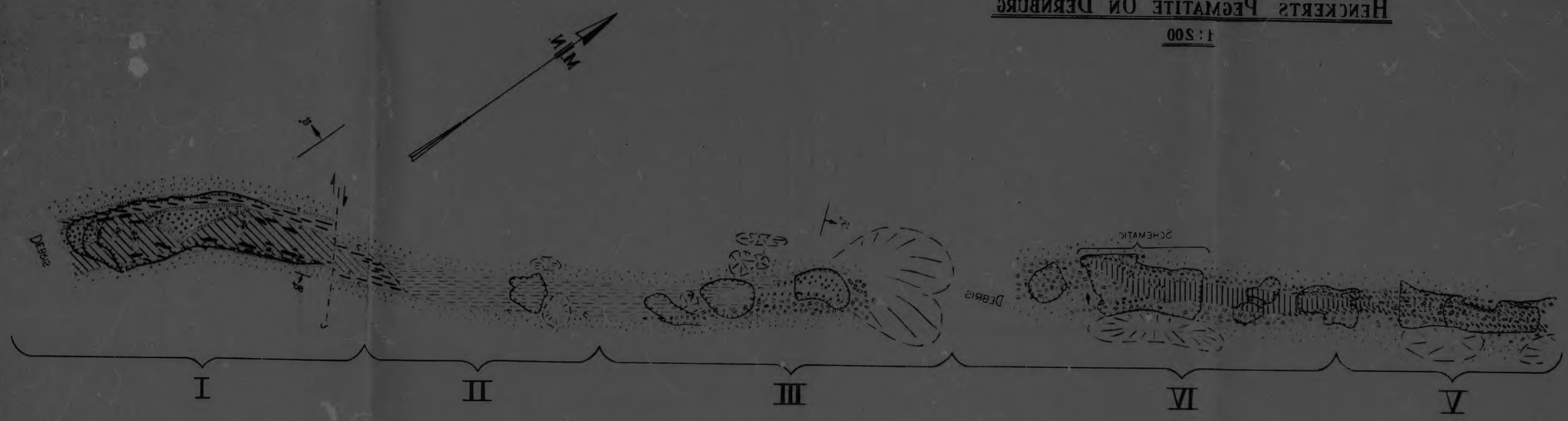
M. N.

LEGEND

- Albite - Quartz - Tourmaline
- Albite - Quartz - Muscovite - c. glassy andalusite, p. petyl
- Complex Albite - Quartz - Muscovite - Unit
- Albite - Lithia - Mica - Quartz
- Beryl Bearing Zone - Not Depicted At Outer Contact
- of Quartz Core or Lithia - Mica Unit
- Complex Clay Mineral Units
- Damara Marble
- Dump
- Quarry
- Outcrop

Henckerts Pegmatite On Dernburg

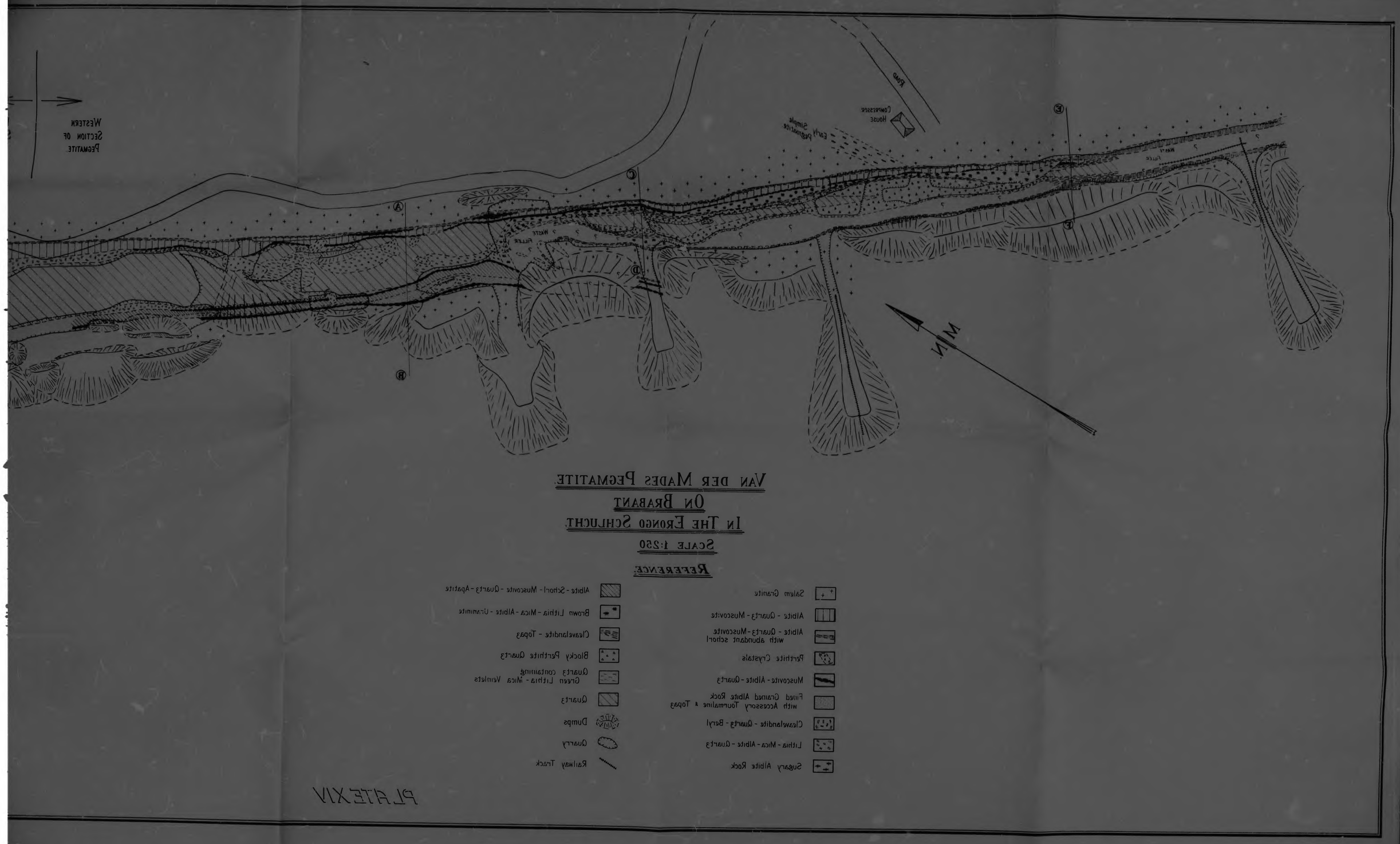
1 : 200

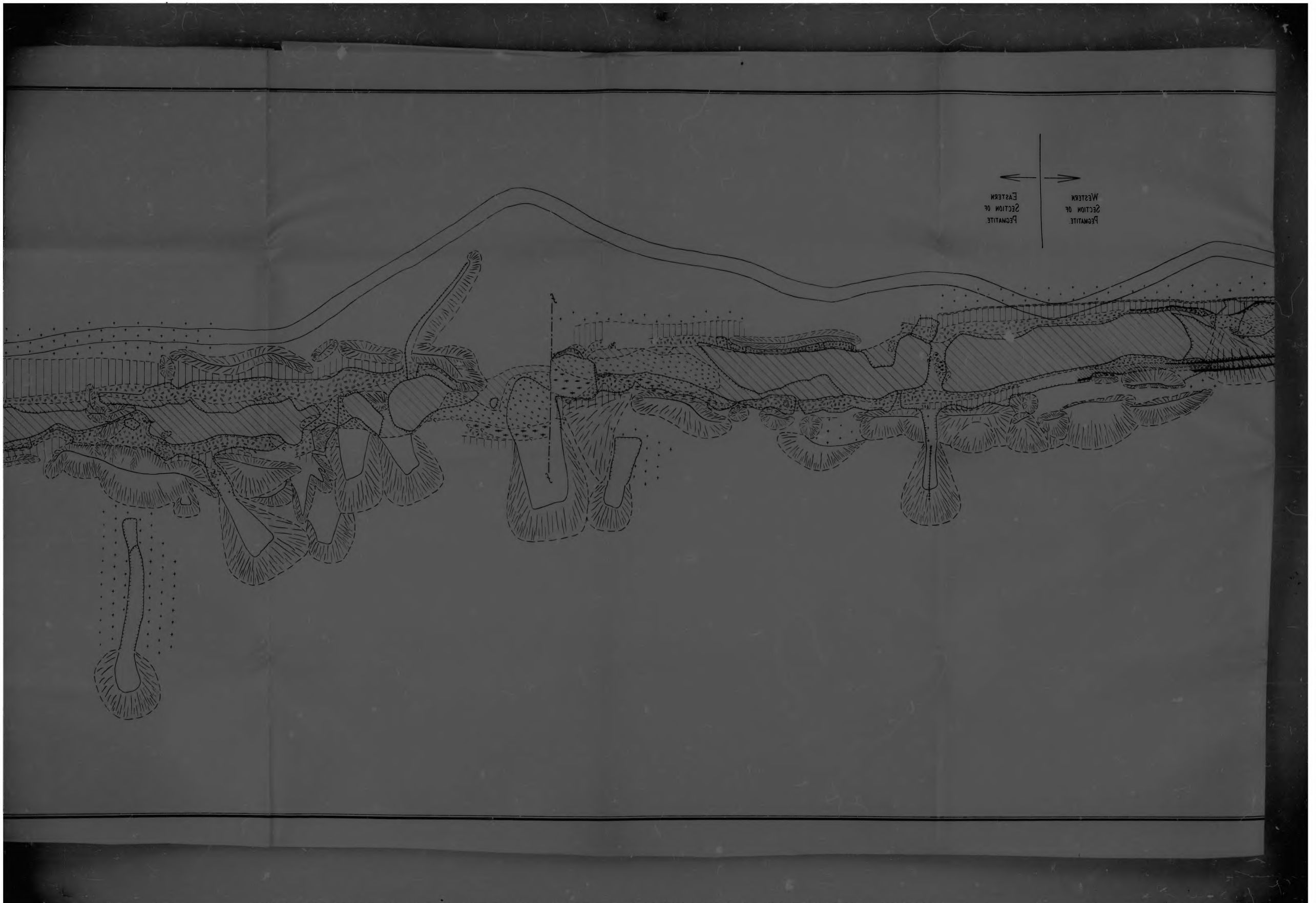


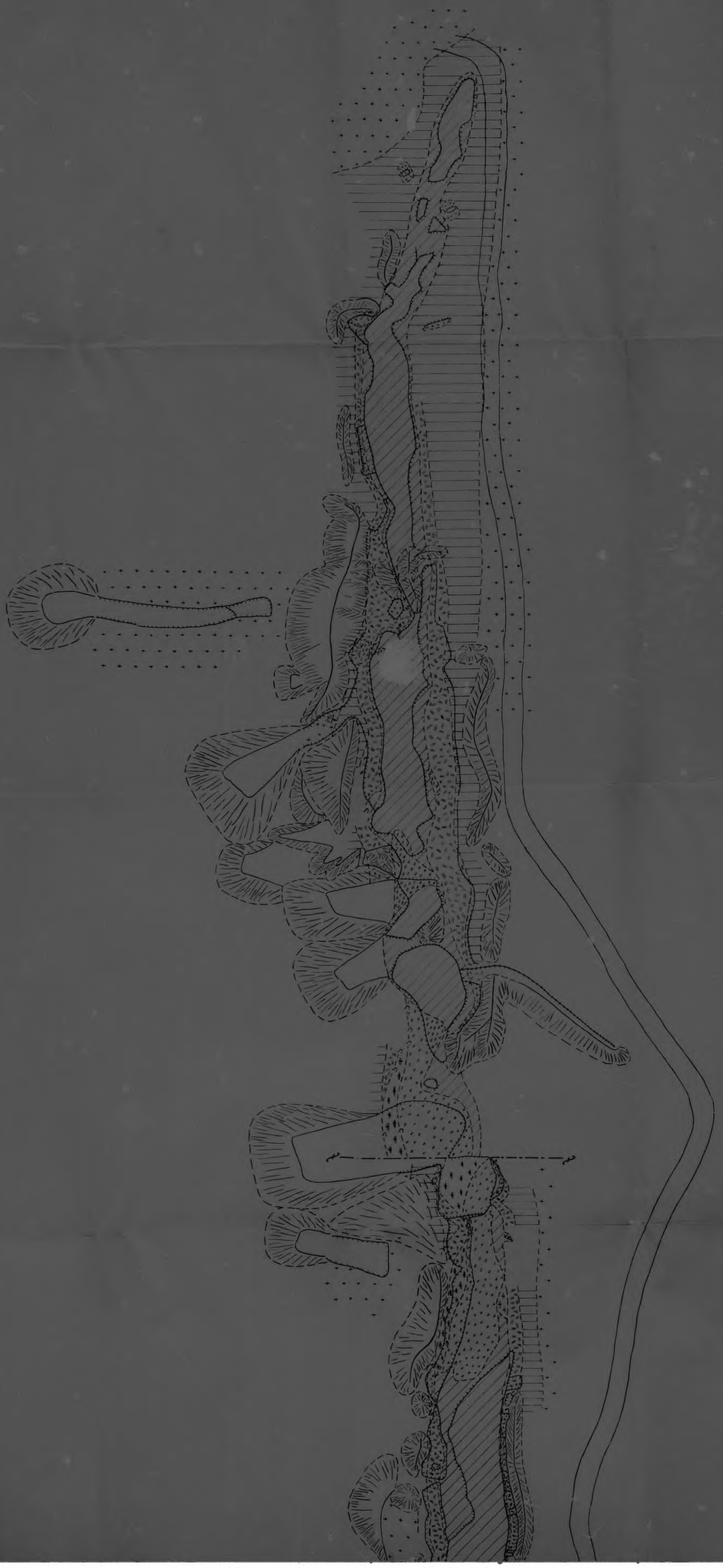
Legend

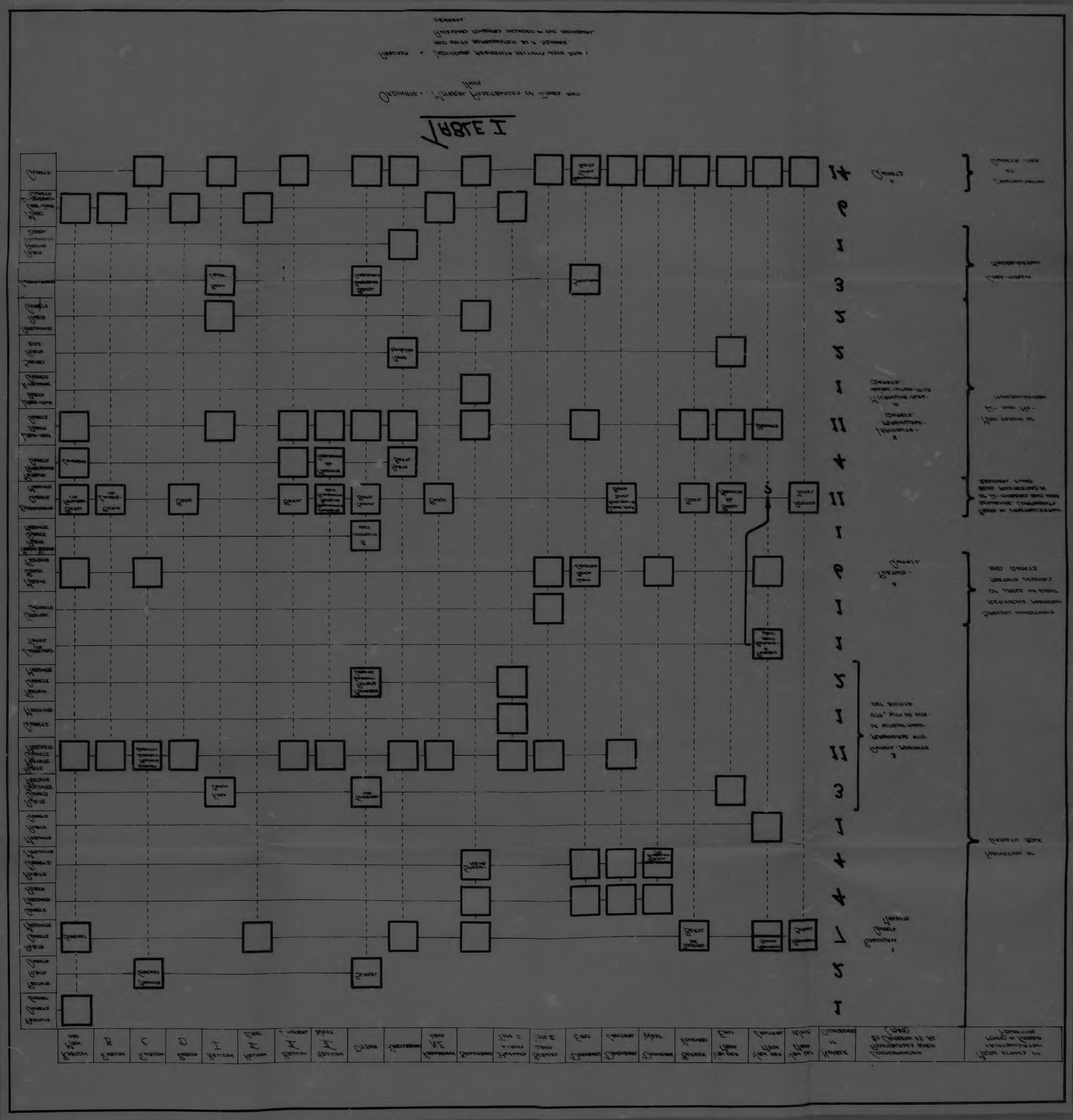
- Quartz - Muscovite - **Albite**
- Albite - (Quartz)-(Muscovite)
- Perthite - Quartz - Albite - Muscovite
- Albite - Quartz - Muscovite
- Albite - Quartz - Muscovite - Beryl - Amblygonite
- Perthite
- Beryl
- Quartz - Amblygonite - Topaz
- Lithia - Mica - Albite - Quartz - Columbite - Tantalite
- Cleavelandite - Spodumene
- Cleavelandite - Lithia - Mica - Spodumene - Topaz - Amblygonite - Beryl
- Perthite - Cleavelandite
- Cleavelandite
- Cleavelandite - Coarse Lithia - Mica
- Quartz - Blocky Perthite
- Quartz
- Jamara Quartzite
- I-X Pegmatite Subdivisions used in Text
- Dump
- Quarry

PLATE XIII


Western Section of Pegmatite
Road
Compressor House
Early Pegmatite
Simple
Waste Filler
Waste Filler
N
Van der Mades Pegmatite
On Brabant
In The Erongo Schlucht
Scale 1:250
Reference
Salem Granite
Albite - Quartz - Muscovite
Albite - Quartz - Muscovite with abundant schorl
Perthite Crystals
Muscovite - Albite - Quartz
Fined Grained Albite Rock with Accessory Tourmaline & Topaz
Cleavelandite - Quartz - Beryl
Lithia - Mica - Albite - Quartz
Sugary Albite Rock
Albite - Schorl - Muscovite - Quartz - Apatite
Brown Lithia - Mica - Albite - Uraninite
Cleavelandite - Topaz
Blocky Perthite Quartz
Quartz containing Green Lithia - Mica Veinlets
Quartz
Dumps
Quarry
Railway Track
PLATE XIV


WESTERN
SECTION OF
PEGMATITE
EASTERN
SECTION OF
PEGMATITE





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Name of thesis Pegmatite Investigations in the Karibib district, South West Africa 1963

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