THE ALLANITE DEPOSITS ON VREDE,

GORDONIA DISTRICT, CAPE PROVINCE

by

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ABSTRACT

Allanite deposits of an unusual nature occur in two types of granulite on the farm Vrede, portion of Cnydas West, Gordonia District, Cape Province. The granulites belong to the Archaean Complex which is also represented by schists and gneisses. These rocks, which are described in detail, have been correlated with the Kaaien Series of the Kheis System.

The ore-bodies are characterised by their distinct banding and the close connection between their distribution and the regional structure of the metamorphic rocks.

Allanite occurs with tourmaline, apatite, zircon and monazite in bands ranging from one sixteenth to two inches in thickness, parallel to the foliation of the granulites. The mineralisation, probably hydatopneumatolytic in nature, started with the introduction of zircon, monazite and tourmaline, after which apatite, allanite, magnetite and quartz followed in that order.

The optic axial angle of the allanite is $2V_\alpha = 60^\circ$ or more. A high magnesian variety, however, has a positive sign with $2V = 40^\circ$.

The range in refractive indices is:

$$n\alpha = 1.732 - 1.757$$

$$n\beta = 1.747 - 1.768$$

$$n\gamma = 1.759 - 1.779$$

This variation is probably due to differences in chemical composition.

The three analyses of allanite given have been recalculated on the basis of 13 (O, OH, F) atoms to the unit

cell and the formulae obtained conform closely to the formula $X_2\ Y_3\ z_3\ (O, OH, F)_{13}$ developed by Machatschki.

Chip sampling was done on all the deposits and the samples were radiometrically assayed against a standard uranium-thorium sample. The average values obtained are 0.096 per cent. U_3O_8 and 0.142 per cent. ThO_2. Allanite is, therefore, a prescribed material in terms of the Atomic Energy Act.

The other ore minerals are all normal in their properties.

A crystallising pegmatite is believed to have been the source of the mineralising solutions giving rise to these deposits. This pegmatite and those of the surrounding area are related to a younger granitic intrusion, probably the acid granite intruded into parts of Bushmanland.

The deposits opened up by 1960 occur intermittently over a total area of approximately 600 feet by 200 feet, but their extent in depth has still to be proved. Only the main deposit may perhaps be workable; if the allanite bands there extend to a depth of 200 feet, the ore reserve will be of the order of 1500 tons, assuming that the ore contains roughly 10 per cent. allanite.

I. INTRODUCTION

A. GENERAL

Allanite, a cerium-bearing epidote, is a common primary constituent of many syenitic and granitic rocks, in some of which it forms an important accessory mineral. It also occurs in gneisses and granulites. It attains its best development, however, in pegmatites associated with the above-mentioned rock-types in Canada, the United States of America, New Zealand, South Africa and Japan. It is seldom recovered in its own right, being usually a byproduct of workings for beryl, columbite, cassiterite and gadolinite.

Only a few occurrences of non-pegmatitic allanite present in more than minute amounts are mentioned in the literature. Baker (1937, pp. 47-58) noted the occurrence of allanite in basic schlieren in You Yangs granite (Victoria, Australia) "where orthite (i.e. allanite) locally constitutes 3.5 per cent. of the rock". In the granite itself allanite represents only a fraction of one per cent. Giroux (Hoffman, 1894, pp. 12-13R) recognised this mineral as "entering largely into the composition of a coarse granite occurring on the east shore of Lac á Bande, Champlain County, Quebec". Flat tabular crystals of allanite, constitutes "not less than close upon 56 per cent. by weight of the rock".

Söhnge (1944, pp. 157-181) found abundant allanite in a number of samples from the large mineralised pods exposed in the low-grade ore of the Zaaiplaats tin mine.

The allanite deposits to be described in this report are not of a common type, being in the form of epigenetic lodes in granulite. This sort of allanite deposit is believed to be hitherto undescribed.

Apart from the investigation of the deposits themselves, the surrounding area had to be examined so that controls for the mineralisation could be established. The information so gained was to be used if possible to locate further deposits of radioactive rare-earth minerals.

B. FIELD INVESTIGATION

The area (about 25 square miles in size) mapped during the period August to October 1958 constitutes the southeastern corner of Geological Sheet 2820A and was included in the original survey of the Gordonia District by Haughton in 1926. It adjoins the area mapped by Von Backström in 1945 to the south.

As no aerial photographs were available, mapping was done by means of a plane-table and telescopic alidade, using a base map supplied by the Trigonometrical Survey, Cape Town. The results of this survey are given on a scale of 1:50,000 (Folder 1).

C. LABORATORY INVESTIGATION

About 120 thin sections were prepared for petrographic work. The optic axial angles of some minerals and the optical properties of the feldspars were determined on a 4-axis universal stage.

In correlating the optical properties of the feldspars with their chemical compositions the orientation-composition charts of Reinhard (1936) and Nikitin (1936) were used for plagioclase. For potassium feldspar the charts of Emmons (1943) were used.

Refractive indices were obtained by the immersion method and the corresponding compositions of the respective minerals from the curves given by Winchell (1951). The refractive indices of the immersion media were measured after each determination on a Leitz-Jelley refractometer, using sodium light.

II. REGIONAL GEOLOGY

A. PHYSIOGRAPHY

Just off the western border of the area there is the prominent escarpment of the Nama Plateau consisting essentially of horizontal beds of Kuibis quartzite overlying the Archaean complex.

The central part of the area is mountainous. It is bounded on the east and south by the broad, flat valley of the Molopo River which lies about 1,000 feet lower than the Nama Plateau. The southeastern and northern parts of the area are characterized by inselberg topography.

The area is drained by the Molopo River and its tributaries. That the drainage is not influenced by the geological structure is illustrated by the fact that the river valleys trend across the strike of most of the rocks. The Molopo leaves the area in a southwesterly direction and joins the Orange River.

As the area receives about 5 inches of rain per annum, the rivers only flow after heavy downpours. The vegetation is typically that of a semi-arid region, being largely represented by various types of euphorbia and hardy stunted shrubs, and favours the hilly areas. Apart from the kokerboom (Aloe dichotoma) which occurs as isolated trees throughout the area, smaller types of aloe are also found, but less frequently. Although grass is usually sparse, it flourishes on the sandy flats after a good shower of rain.

B. GEOLOGICAL FORMATIONS

About one-sixth of the area mapped is covered by Recent deposits consisting of sand, surface-limestone and loose gravel. Horizontal beds of quartzite, which represent the base of the Kuibis Series of the Nama System, cap the highest hill in the area (Gryskop, 2926 feet above sea-level). All the other rocks belong to the Archaean Complex.

The Archaean rocks in the country surrounding the area can be classified, broadly speaking, into four main suites:-

(a) Schist, gneiss and granulite belonging to the Kaaien Series of the Archaean Kheis System. They represent original sedimentary formations and are predominantly arenaceous, but have some intercalated pelitic members.

(b) Amphibole-rich and pyroxene-rich granulite, schist and pyroxenite belonging to the Marydale Series of the Kheis System, and which predominantly represent metamorphosed lava.

(c) Metabasaltic rocks (ortho-amphibolite) which intrude the above, generally in the form of sheets.

(d) Scattered bodies of tonalitic to granitic, gneissic "autochthonous granite" (Read, 1957, p. 327) having diffuse borders, associated with migmatite. The rocks of this suite are collectively called Grey gneiss (Söhnge and De Villiers, 1946, pp. 263-272; Von Backström, 1955, p. 16).

Of these four subdivisions, only (a) and (c) are present in the area surveyed (see Table 1).

The original features of a large portion of the sedimentarily derived Archaean rocks have been more or less completely obliterated by the regional and contact metamorphism to which they have been subjected.

Table 1. - Formations present in the area surveyed

Formation	Correlation	Remarks
Sand, surface limestone, river gravel and alluvium	Early Tertiary to Recent deposits	Never attain great thickness
Quartzite with thin bands of grit and shale near the base	Kuibis Series, Nama System	Small patch only
Pegmatite veins		Probably associated with Bushmanland granite
Ortho-amphibolite (metabasalts)		Ancient basic intrusive in Kheis System
Quartz schist, pink aplogranite gneiss, granulite and other ultrametamorphosed rocks	Ultra metamorphosed Kaaien Series, Kheis System	Agent of metamorphism is the intrusive Grey gneiss. Further regional metamorphism has probably been active

C. DESCRIPTION OF FORMATIONS

1. KAAIEN SERIES OF THE KHEIS SYSTEM

The schistose rocks along the Orange River south of the Langeberg were originally named "Kheis Series" by Stow (1874). This name was retained by Rogers (1910) who worked out the details of the succession within what is now known as the type area between Prieska and Upington. He introduced the following threefold subdivision:-

(a) Wilgenhoutdrift Beds

(b) Kaaien Beds

(c) Marydale Beds

The Wilgenhoutdrift and Marydale Beds, where least altered, consist of lavas, usually basic in composition, and associated rocks.

The Kaaien Beds consist only of sediments, mainly quartzite and quartz-sericite schist which, in some places, are interbedded with thin layers of argillaceous and calcareous material.

Detailed studies by Poldervaart and Von Backström (1949) indicate that all the granitic rocks of the Kakamas area are of sedimentary origin, or represent migmatite formed by the injection of the sediments by granodiorite magma (Grey gneiss).

Seeing that there are no extrusive rocks in the Kakamas region the sediments, and the metamorphosed rocks which can still be linked with sediments of one kind or another, were correlated with the Kaaien Series.

Poldervaart and Von Backström (1949, pp. 436-438) give the following account of the geological history of the surrounding area (it differs in some respects from that given by previous workers in the Northwest Cape):-

"The Kaaien sediments represent the débris of older rocks which consisted largely of granite and quartzite. This material was transported over a considerable distance before it came to rest in the Kheis geosyncline.......

"After an unknown interval the beds were compressed into large, open folds. Shortly after, or during these movements, olivine-gabbro magma ascended into the crust, and intruded the lower Kaaien Beds at Kakamas, forming many sills, conformable with the folded structure.

"Folding movements continued and became more intense, leading to overfolding and internal thrusting. The basement rocks were regionally metamorphosed and thrown into the intricate plications observed today. This is the main period of Kheis orogeny.

"The grey gneiss was intruded after the peak of orogenesis, when folding movements were decreasing in intensity. Its intrusion was marked by a widespread migmatisation and transfusion of material from the igneous rock into the sediments and vice versa. Pegmatites were also associated with the grey gneiss".

The rocks here to be described grade into and are associated with quartz-feldspar rocks of varying appearance and composition. They are represented by schist, granulite and gneiss. The correlation of these rocks with the Kaaien Series of the type area is not at first sight an obvious one; the conclusion that they are of sedimentary origin, is based on the following evidence (Von Backström, 1953, pp. 31-32):-

(1) The foliation and lineation of the rocks are parallel to the foliation and lineation of associated, undoubtedly metasedimentery rocks;

(2) Pelitic intercalations are present;

(3) Gradual transition from one rock type into another is visible and can be correlated with the changes in metamorphic grade;

(4) Xenoliths are absent;

(5) Rounded zircon grains are present.

The reconstituted sediments have been subdivided into the following types:-

(a) Quartz schist

(b) Pink aplogranite gneiss

(c) Metasedimentary granulite

(i) Red granulite

(ii) Grey granulite

(iii) Leucocratic granulite

(a) Quartz Schist

This schist lies along the northern boundary of the farm Bb 24 and its strike follows the regional trend of the foliation, i.e. east-west. The foliation dips at about 75° to the north-east. The schist can be traced eastwards through Weltevreden and Biesjiespoort to the indisputably sedimentarily derived Baviaanspoort quartz schist of the Kakamas region. To the west it terminates abruptly on the eastern bank of the Molopo River on the farm Bb 25. This termination may be caused by a hidden fault running north-south in the bed of the Molopo River. The undisturbed continuation of the bands of grey and red granulite to the north, however, militates against that possibility.

Macroscopically the quartz schist varies greatly as regards colour, texture, structure and, to a lesser degree, mineral content.

The colour varies from pinkish-white on fresh surfaces to medium grey when altered. There are variations between even-grained, schistose, quartz-feldspar rocks and hard and compact, glassy metaquartzitic types, the latter forming small lenses in the former. Several bands rich in tourmaline, alternating with bands and lenses of light - to dark-grey schist, occur at the north-western and north-eastern corners of Bb 24 and Bb 25 respectively. The black tourmaline crystals lend a speckled appearance to the rock.

Microscopic examination of thin sections shows that the schist consists essentially of quartz, microcline ($2V_{\alpha}=81^{\circ}$) and turbid plagioclase with varying amounts of muscovite ($n_{\beta}=1.605$), sericite, biotite ($n_{\beta}=1.622$) magnetite and tourmaline (schorlite). Accessory minerals are apatite and zircon.

(b) Pink Aplogranite-gneiss

A fairly large proportion of the farms Bb 24, 25, 26 and 27, Vrede and Nauwpoort is underlain by pink aplo-granite-gneiss, which will be referred to as pink gneiss hereafter in accordance with the terminology used by Poldervaart and Von Backström. On the farms Bb 26 and 27 and Nauwpoort it builds fairly prominent hills, but in the rest of the area it is largely covered by surface-limestone and younger sand, and most of the outcrops are found along the dry watercourses.

Exposures of the rocks display well-developed cleavage. The foliation generally strikes west-northwest, but the dip varies greatly in direction and amount.

When fresh the gneiss is grey to pink, but it is friable and weathers easily to a characteristic orange-brown; fresh specimens are not easily obtained. It is a medium- to coarse-grained rock locally porphyroblastic or aplitic in texture. The composition is granitic. The foliation and lineation in the pink gneiss are due to the orientation of quartz, feldspar and mafic minerals and, where they are developed, by small porphyroblasts.

Microscopic examination showed that the pink gneiss is remarkably uniform in mineral composition consisting of quartz, potassium feldspar, plagioclase and subsidiary magnetite, amphibole and biotite. Accessories are apatite, tourmaline, zircon and sericite.

Microcline ($2V\alpha=80^{o}-84^{o}$) seldom exhibits the normal cross-hatching between crossed nicols and is more frequently present as untwinned crystals. The microperthite encloses grains of plagioclase, apatite, allanite and zircon, and is itself replaced by vermicular intergrowths of quartz. It is usually somewhat sericitised, the alteration proceeding from the exsolution plagioclase and inclusions.

Unaltered grains of microcline, anorthoclase and orthoclase are present as well.

The plagioclase is usually albite or oligoclase (An_{5-15}). Plagioclase showing kaolinised cores (An_{6-15}) (Poldervaart and Von Backström, 1949, pp. 456-457), surrounded by narrow, clear rims (An_{0-5}) was frequently observed. These zoned structures are best developed along junctions with microcline, and are generally absent when plagioclase borders on quartz.

The mutual relationship between the feldspars suggests that the first to form was probably oligoclase; the later feldspars became progressively richer in sodium and potassium through albite and microperthite to microcline and orthoclase.

The amphibole is a greenish-brown variety of hornblende; it is usually associated with magnetite and biotite and is enclosed by quartz. The biotite forms small, dark-brown flakes and has a refractive index $n\beta$=1.702. Zircon (rounded), apatite and allanite occur interstitially to other minerals but are enclosed by feldspar, biotite and magnetite. Zircon grains in biotite are usually surrounded by pleochroic haloes.

Quartz is the youngest mineral by virtue of its recrystallisation, and it has truncated or partly replaced all the other minerals. Grains exhibit undulose extinction or recrystallisation shadows between crossed nicols.

Northwest of the homestead on Vrede a typical flaser structure is developed in the pink gneiss. Augen 3-8 mm. in diameter are set in a sheared aggregate that fills the interstices between them. The augen are mostly of microperthite, and the aggregate consists of quartz, biotite, zircon, allanite, magnetite and apatite. The augen exhibit undulose extinction —evidence for the operation of stresses after their growth.

White aplogranite occurs in the vicinity of the boundary between Bb 24 and 25. Apart from the colour these rocks are identical with the medium-grained pink gneiss.

(c) Metasedimentary Granulite

There are several occurrences of rocks in the area which have been termed granulite on the basis of mineralogical composition, similarity of character and general field relationship. The following three types were distinguished:

(i) Red Granulite. - The rocks falling into this suite attain their greatest development in a band running nearly parallel to the southern boundary of Vrede. They also crop out on Weltevreden, Old Cnydas and Nauwpoort. When followed west-northwest along the strike, the red granulite grades into pink gneiss. Wherever the red granulite is present it constitutes hilly country.

This granulite is correlated with the medium- to fine-grained, grey or red granulite in the Kakamas region, called Aasvogelkop granulite by Poldervaart and Von Backström (1949, p.455).

In colour the red granulite ranges from greyish pink to dirty grey when weathered; on fresh surfaces it is typically reddish pink. The texture ranges from non-porphyritic in fine-grained varieties to porphyritic in coarse-grained ones.

Petrographic examination of a large number of thin sections revealed the variable character. The main constituents in order of abundance are quartz, potassium feldspar and plagioclase. Biotite and amphibole are present as dark minerals. Accessories are apatite, magnetite, sphene, allanite and zircon.

The potash feldspar forms crystals of varying size. Determinations by Poldervaart and Von Backström (1949,

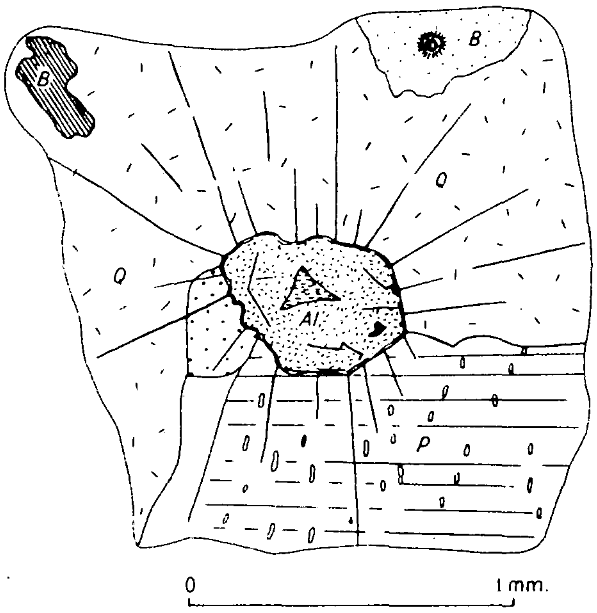

Fig. 1. - Cracks and fractures radiating from an allanite crystal in red granulite. Note the pleochroic halo caused by zircon in biotite (B). Other minerals are quartz (Q) and perthite (P).

p. 457) and the author show $2V_\alpha$ to range from 54°-85°. Typical anorthoclase twinning (Alling, 1921, pp. 193-294) is seen in some crystals having a low optic axial angle. Others with a somewhat higher $2V_\alpha$ exhibit the typical cross-hatch twinning of microcline. Some thin sections contain vein perthite as well as micro-perthite in conspicuous "patterns" (cf. Spencer, 1945, Plate vii-10).

Potassium feldspar porphyroblasts are locally developed and contain inclusions of quarts, plagioclase and myrmekite. These porphyroblasts are sometimes surrounded by discontinuous rims of small oligoclase crystals, thereby forming imperfect rapakivi structures. These (Poldervaart and Von Backström, 1949, pp. 457-458) are believed to have been produced by a pushing aside of smaller oligoclase crystals during the growth of the porphyroblasts.

The plagioclase is albite or oligoclase (An_{5-25}). Several small crystals of composition An_{35-40} were also observed in some sections. Large plagioclase crystals sometimes include rectangular areas of potassium feldspar, while small rounded grains of the former mineral occur interstitially to, or are embayed in, potassium feldspar and quartz.

Amphibole and biotite occur as small grains interstitial to feldspar and quartz. The amphibole ($n_\gamma = \pm 1.734$) is believed to belong to the hastingsite group. The biotite is nearly always altered to chlorite.

Zircon and apatite are present as stumpy, rounded individuals in feldspar, biotite and magnetite.

The allanite has a brownish-yellow colour near the margins, where they are altered. Small cracks and fractures radiating from the allanite grains are nearly always present (see Fig. 1). They are evidently pressure cracks due to an increase in volume resulting from internal radioactive disintegration (Walker & Parsons, 1923, pp. 25-28).

The quartz is largely recrystallised. It is believed to be the latest mineral as it replaces and/or truncates all the above-mentioned minerals.

(ii) Grey Granulite. - The grey granulite attains its greatest development in a strip running south of the band of Red granulite. Other outcrops are on Weltevreden and in the Bokvasmaak Bantu Reserve. When followed along the strike it grades into red granulite, intercalations of the latter variety becoming increasingly prominent to the west. In the field it is sometimes difficult to distinguish between these two granulites on lithological characteristics alone.

The grey granulite is predominantly fine-grained. It is light grey in colour and weathers to greyish brown. It is composed of the following minerals in variable proportions:- quartz, potassium feldspars, plagioclase, amphibole, clinopyroxene, biotite, epidote, garnet, sphene, calcite, tourmaline, magnetite and accessory apatite and zircon.

The potash feldspars predominate over the plagioclase and consist essentially of microcline, anorthoclase and orthoclase in order of abundance. No perthite was observed. The feldspar grains contain inclusions of quartz, sphene, apatite and zircon. They sometimes show marked alteration to sericite.

The plagioclase is mostly andesine and occurs as small grains interstitial to quartz and potash feldspar. It is saussuritised, giving rise to distinct chlorite and epidote in some cases.

The amphibole is pleochroic hornblende. Clinopyroxene is sometimes present as euhedral crystals and is faintly pleochroic from neutral to light green. Polysynthetic twinning is frequently observed. The clinopyroxene is probably diopside ($2V\gamma=64^{\circ}$, $\gamma\wedge c=44^{\circ}$).

Biotite (usually altered to chlorite), calcite, tourmaline, sphene, garnet and apatite occur interstitially to all the above-mentioned minerals. Calcite commonly exhibits polysynthetic twinning with ($01\bar{1}2$) as twin-plane. The tourmaline is black schorlite. X-ray examination of the garnet showed it to be andradite-grossularite* (9:1) with unit cell dimension a=11.98 and refractive index 1.86. In some specimens epidote has formed at the expense of pyroxene, amphibole, biotite and calcite.

Apatite, zircon and quartz are sometimes enclosed by magnetite. Sphene wedges attain a length of more than 0.5 mm. in some cases; polysynthetic twinning parallel to (221) is present in the larger crystals.

Feldspar and amphibole seem to be the earliest minerals, being largely replaced by the later ones, especially quartz.

(iii) Leucocratic Granulite. - The main occurrence of the rocks comprising this group is a narrow strip running through the central part of Vrede from east to west. It separates the pink gneiss to the north from the red granulite to the south. Elsewhere in the area it occurs as lenses in the pink gneiss.

The rocks are all foliated; the general strike is to the northwest and the dip is usually vertical or nearly so. They are similar to the granulites described above except that they contain more quartz, which is present as characteristic lenticles. On weathered surfaces there is a thin veneer of black material, but on fresh breaks these rocks are invariably white.

Microscopic examination showed that the leucocratic granulite consists of quartz, oligoclase, a little an-

* Identification by Miss A. Marais, Geological Survey.

orthoclase and accessory sphene, biotite and zircon. Porphyroblasts may be of potassium feldspar or oligoclase. The latter sometimes include rectangular patches of potassium feldspar. At Kakamas (Poldervaart and Von Backström, 1949, p. 458) the evidence indicates that these are due to replacement of the plagioclase. Oligoclase, usually clouded, is the earliest mineral, being replaced and truncated by both sphene and quartz. In general the oligoclase grains are enclosed by foliae of quartz.

Seen under the microscope the thin quartz lenticles consist of numerous small intergrown crystals. Sphene, seldom less than 1 mm. in length, and zircon occur as inclusions.

2. Basic Intrusives

Bluish-black ortho-amphibolite occurs as lenticular bodies in the pink gneiss, red granulite and less often in the grey granulite. It is believed to be genetically related to the norite and basalt in the main zone of basic rocks in the Kakamas region.

The amphibolite seems to have been originally emplaced in the form of small sills in the Kaaien sediments. During the main period of the Kheis orogeny the sediments and sills were overfolded so that today they occur in a nearly vertical position, thus resembling dykes. The rocks are all foliated, the strike and dip of the foliation conforming to those of the country rock.

The amphibolite bodies are of uniform appearance and consist of equidimensional plagioclase crystals and bladed amphibole with accessory pyroxene, quartz, biotite, magnetite, sphene and apatite. The plagioclase, usually between andesine and labradorite in composition (An_{35-70}), and pleochroic hornblende ($\gamma \wedge c = 15\text{-}20^{\circ}$, $2V_{\alpha} = 60^{\circ}\text{-}70^{\circ}$) are intimately intergrown. The pyroxene is largely altered to a greenish-brown amphibole. Quartz, when present, is recrystallized and occurs together with magnetite, sphene, biotite (largely altered to chlorite) and apatite interstitially to the plagioclase and hornblende.

Minor variations were found in grain size, the relative proportions of the constituent minerals, the optical properties of the amphibole and the appearance of the biotite. Although the composition of the plagioclase, which invariably shows polysynthetic twinning, varies greatly in specimens from different localities, it remains uniform in any one hand specimen.

Only a few of the bigger amphibolite bodies are shown on the geological map (Folder 1), the smaller ones being too numerous to plot.

3. Pegmatites

The greatest concentration of pegmatites is in the southeastern corner of the area. They are invariably concordant with the regional gneissosity of the rocks in which they have been emplaced. Parallel pegmatite bands occur in the grey granulite near the contact with the red granulite giving rise to a typical lit-par-lit injection contact.

Two types of pegmatite have been recognised. The one comprises a uniform mixture of its component minerals and may be called a homogenous pegmatite in accordance with the terminology used by Cameron *et al.* (1949). Only a few of this type were noted during the survey.

The other type, in ideal development, exhibits zones or successive shells symmetrically developed with respect to an innermost zone or core. These are called inhomogenous pegmatites by Cameron *et al.* Most of the pegmatites in the area are of this type. Prospecting excavations in some of the larger ones on Bb 24 showed them to have a central core of colourless, pink or smoky quartz surrounded by a coarse-grained zone consisting of microcline, orthoclase, quartz and mica. Mineralisation by tourmaline and beryl is usually associated with this zone. The beryl crystals seldom exceed 1 inch in diameter, and have a yellowish-green colour. Pegmatites near the main allanite body contain ilmenite as well.

Only the larger pegmatites are shown on the map (Folder 1).

There is little evidence for the existence of a pegmatitic phase associated with the grey gneiss in the Kakamas region (Poldervaart and Von Backström, 1949, p. 491). It is clear that the main pegmatitic phase is younger than the grey gneiss, and hence may possibly be connected with a later granitic intrusion occurring outside the area. Exposures of such younger granite have been found in Bushmanland, Namaqualand and the Richtersveld, but their relative ages are as yet unknown as is their possible relationship to the pegmatites of the Kakamas-Vrede region.

4. Kuibis Series of the Nama System

Only a small patch of Nama rocks is present in the area. This occurrence, on top of Gryskop, rests unconformably on the red granulite and dips slightly to the south-east. The succession is arenaceous and about 20 feet thick; it consists of an unsorted grit and intercalated, very thin shale bands at the base, followed by red quartzite.

Just west of the area the Kuibis Series forms the escarpment of the Namaqua Highlands.

5. Recent Deposits

Nearly the whole bed of the Molopo River is choked with quartz-feldspar sand, containing occasional patches of alluvium. At places near the S-bend in the river small islands consisting of gravel are developed.

Just south of the southern boundary of Vrede a fairly large area is covered by wind-blown sand, surface limestone and loose rubble derived from the Kuibis Series and the pink gneiss.

III. THE ALLANITE DEPOSITS

A. HISTORY

Alluvial pebbles of allanite ore were discovered in the bed of the Molopo River by a Hottentot during 1955. He gave them to Mr. E. Botha, who was prospecting for base minerals in the northwestern Cape Province at the time. Mr. Botha traced them back to the exposures from which they had originated.

Commercial analyses of the ore undertaken for Mr. Botha indicated an unusually high yttrium-earth content, and he thus commenced to prospect the area in September, 1956 with a view to marketing the allanite as an ore of the yttrium-earths. The occurrence was reported to the Geological Unit of the Atomic Energy Board and samples were subjected to X-ray and spectrographic analysis. The spectrographic analysis showed the allanite ore to contain Fe, Ca, La, Dy, Nd as well as traces of Y, U and Th. Later on it was discovered that the high yttrium value, as given in one of the commercial analyses, was attributable to the fact that only cerium had been quantitatively determined, and that the rest of the rare earths were taken to be yttrium.

As far as is known*, this is the only occurrence of non-pegmatitic allanite in South Africa that is present in more than minute amounts, and so a closer examination was recommended. A reconnaissance survey of the deposits

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*Mr. J.W. von Backström of the Geological Survey (personal communication) found similar lumps of eluvial allanite at Noordvoor to the north of Kakamas village, which he could not trace back to the exposures (pegmatitic or otherwise) from which they originated. They may be of the same type as described in this report.

discovered by Mr. Botha was conducted by Mr. D.R. Pike of the Geological Unit in December, 1957. During the first half of 1958, Mr. Botha discovered several new deposits on Vrede. As there was no demand for allanite at that time, the prospecting was stopped temporarily. The author investigated all the deposits and mapped the farm Vrede and its surroundings during the period August to October, 1958. Surreptitious prospecting subsequently took place and a small pegmatite vein that, for its size, contains a remarkably large quantity of allanite was exposed (see Folder 2).

B. LOCATION OF THE DEPOSITS

The principal deposits occur in the northeastern corner of the farm Vrede on either side of the Molopo River. Allanite is also found near the top of a hill south of the homestead (see Folder 1). This farm forms the southern portion of the original farm Cnydas West, Gordonia District. It is about 36 miles by road from Kakamas, and 23 miles from the nearest railway station, Lutzputs.

C. STRUCTURE AND SIZE OF THE DEPOSITS

The allanite deposits of Vrede are in the form of epigenetic lodes in two types of granulite (i.e. red and leucocratic granulite). The allanite occurs as stringers and lenses in these lodes, which conform to the strike and dip of the foliation of the wall rocks. In some places the stringers pinch out altogether.

In addition, thin veinlets and stringers of allanite, tourmaline and iron oxides are developed in the wall rock parallel to the lodes, adding to its banded appearance. These veinlets are usually confined to a width of about 9 inches on either side of the lode.

The contact between wall rock and lode is thus somewhat gradational. Only a few of the thin sections made, show a well-defined contact, but in these the sharpness is quite striking.

Small xenoliths of wall rock in the lode are not uncommon near the contacts, and the ore often contains quantities of chlorite and chloritic material, most probably representing altered biotite and feldspar. The epigenetic character of the lodes is therefore clearly illustrated.

That the shape and form of the ore bodies were controlled by the foliation of the wall rock is quite obvious. The ore bodies have also been affected by post-mineralisation stresses and/or movements. This is revealed by the numerous cracks and veinlets, filled with epidote and quartz, which cut through both the ore stringers and the enclosing wall rock.

As the deposits in the red granulite are limited to the eastern half and those in the leucocratic granulite to the western half of Vrede (Folder 1), the distribution and size of the deposits will be described in that order.

1. Eastern Occurrences

At the main deposit, which is situated on the west bank of the Molopo River, there are no less than 16 bands of allanite which vary from one-sixteenth to 2 inches in thickness (see Plates I, II and III). At the time of the investigation there were only a few shallow prospecting pits so that the persistence in depth of the deposit could only be surmised (Folder 2). The lodes, for all practical purposes, strike northwest and have a distinct vertical dip. They occur intermittently over a total area of approximately 600 feet by 200 feet. They disappear towards the west as a result of an abrupt change in the strike of the foliation, and to the east are covered by sand (see Folder 3).

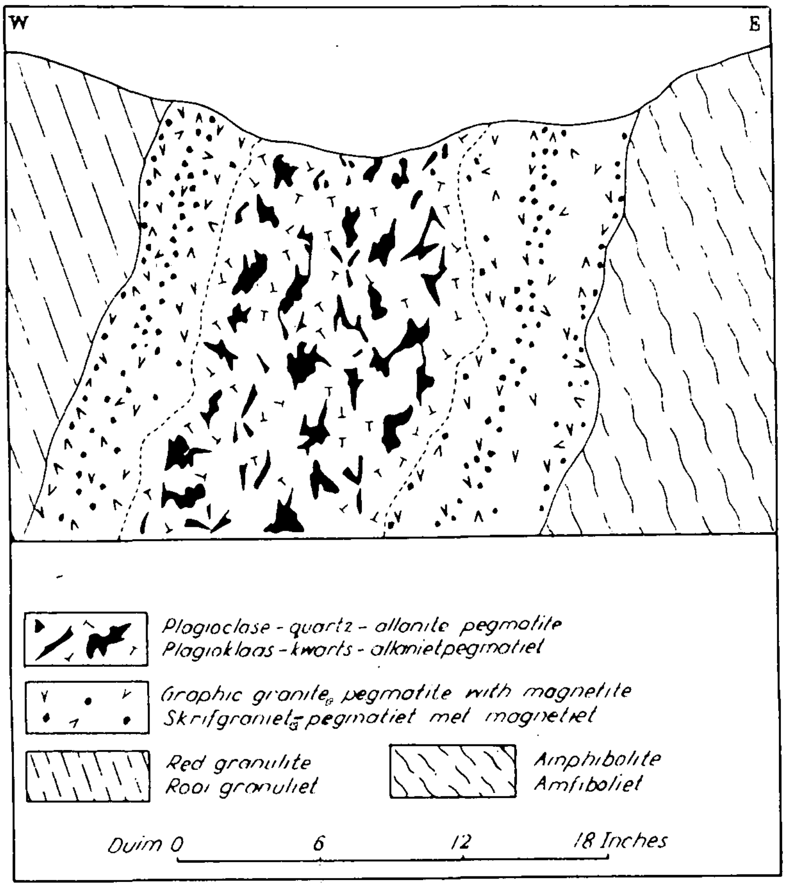

Fig. 2. - Section through allanite-bearing pegmatite north of main deposit (eastern occurrences).

Allanite ore also crops out for about 180 feet on the eastern side of the river, directly opposite the main occurrence, but not in the same line of strike (see Folder 2). The mineral forms 3 bands each about one-quarter of an inch thick. They follow the east-west strike of the red granulite where it constitutes the southern limb of a small anticline. The dip is approximately 60° S. The bands peter out to the east where the granulite apparently passes into metaquartzite. The bands are repeated on the northern side of this structure, but their total length is only about 20 feet (see Folder 2).

About 1500 feet north of the main occurrence, coarsely crystalline allanite occurring next to an amphibolite body was opened up by Mr. Botha (Folder 2). He believed it to be of the usual type of occurrence. The more recent surreptitious prospecting previously mentioned, however, revealed that the allanite originates from a small pegmatite emplaced between the red granulite and amphibolite. The pegmatite is only visible for about 30 feet and does not exceed 2 feet in width (see Fig. 2).

2. Western Occurrences

These are situated 4 miles due west of the eastern occurrences in a narrow band of leucocratic granulite south of the homestead, near the summit of a hill, which is approximately 130 feet high.

A few sparsely distributed, discontinuous bands ranging one-quarter to 1½ inches in thickness occur parallel to the foliation. The dark-brown mineralised bands are easily distinguished in the white granulite and their vertical dip is clearly seen in the excavation.

The ore-bodies occur over a total area of 360 feet by 150 feet. To the east and west they are covered by débris.

D. PROSPECTING

At the main deposit (eastern occurrences) a prospecting trench six feet deep and 60 feet long was cut parallel to the strike of the bands by Mr. Botha (Folders); it shows the allanite to persist to at least that depth (see Plate VI). For the rest prospecting was restricted to the making of shallower trenches across the strike of the bands. The ore did not stand out from the country rock and in general it was difficult to trace it on the surface of the ground because the mineralised zones in the granite gneiss evidently weather more readily than the country rocks, so that the bands are mostly covered by decomposition products. It is also difficult to distinguish the dark-brown bands of allanite from the chocolate-brown, weathered, mineralised zones in which they occur.

As the ore contains traces of uranium and thorium, the author tried to locate further deposits with the aid of a portable Geiger-Müller counter. Traverses 15 feet apart and about 600 feet in length were made across the strike on all the known deposits, but the radioactivity of the ore is so little different from that of the wall rocks that no anomalies were obtained. Subsequent experiments showed that a cover of sand only 4 inches thick is sufficient to mask radiation from the allanite ore.

Pieces of ore up to 2 lb. in weight have been picked up at various places on the farm, but prospecting trenches dug in the vicinity of the finds failed to reveal their source. Similar finds have also been reported from Nauwpoort by Mr. Botha.

E. COUNTRY ROCKS

1. Red Granulite

(a) General

The red granulite which forms the country rock of the ore bodies of the eastern occurrences is fairly typical of that occurring throughout the area. It differs from the typical red granulite in that it is somewhat more brown than reddish-pink in colour. The texture varies from equigranular at the main deposit to porphyroblastic in the vicinity of the deposit on the eastern bank of the Molopo River.

The foliation is provided by the arrangement of magnetite grains and biotite flakes. The direction of strike is nearly east-west and the dip varies from 60^{o} to the south to 90^{o}. Near the deposit on the eastern bank of the river the granulite locally resembles augen-gneiss. This is due to the separation of flow layers of quartz by sub-orientated porphyroblasts of feldspar.

Pegmatites in the granulite near the main deposit are all of the homogeneous type. They are never more than 5 feet in length and consist essentially of medium- to coarse-grained masses of quartz and feldspar. The general foliation of the granulite apparently controlled their emplacement, as they are all parallel to the foliation (see Folder 3).

(b) Petrography

The altered granulite which the ore stringers replace is confined to a narrow zone parallel to and surrounding the ore bodies. These rocks consist of albite, microcline and recrystallised quartz. Accessory minerals are zircon (rounded), magnetite, apatite, allanite (primary) and a small amount of biotite.

Of the feldspars, microcline is the least altered. It is usually untwinned and shows a distinct cleavage in most cases. Alteration (usually sericitisation) took place along some of the cleavage planes. Inclusions in the feldspar are quartz, zircon, primary allanite (usually isotropic as a result of alteration), apatite and microscopic needle-like crystals of an unknown mineral. These needles become more prominent in the vicinity of the allanite stringers.

Plagioclase (An_{6-10}) largely predominates over the potash feldspar, and is recognised by its characteristic polysynthetic twinning, even when highly altered. The twin lamellae are sometimes distorted and bent due to deformation of the rock.

Apatite occurs with biotite and magnetite, interstitially to the main constituents. The biotite is usually present in small flakes and is often altered to chlorite. Zircon usually occurs in clusters of three or more individual grains. These clusters are found between quartz and feldspar crystals and are always surrounded by alteration products of unknown composition.

Secondary iron minerals have separated out between all the other mineral grains, adding to the yellow-brown colour of the altered rock.

Quartz is the latest primary mineral. It occurs as irregular lenses and replaces the earlier minerals extensively. Near to the stringers of ore these quartz lenses abound with the needle-like inclusions mentioned above.

2. Leucocratic Granulite

The leucocratic granulite in which the thin lenticles of allanite occur differs somewhat from the granulite described under the section Geological Formations, in that it is finer grained and the quartz lenticles are thinner. The greyish-black weathering differs from the usual black coating of the typical granulite, and, in general, the rock is not as much weathered as is the red granulite.

The leucocratic granulite consists essentially of plagioclase (An_{35-40}) and recrystallised quartz. The plagioclase is largely altered. Sericite occurs in the cleavage planes and in some cases replaces some of the thin twin lamellae. Grains altered to a dense aggregate of saussurite frequently occur near the mineralised zone.

Zircon, usually in the form of rounded or stumpy individuals, and magnetite are sometimes present as inclusions in the feldspar.

The only other accessory mineral observed is sphene. It forms subhedral crystals, sometimes up to 2 mm. in length.

Quartz is the latest of the two main constituents as it replaces feldspar. Needle-like inclusions occur throughout the quartz.

F. MINERALOGY OF THE DEPOSITS

1. Appearance and Texture of the Ore

Thin sections were made of samples from all the different ore deposits on Vrede. In order of average abundance the ore consists of quartz, allanite, tourmaline, apatite, magnetite, monazite, zircon and ilmenite (see Plate IV). The only significant differences observed in samples taken from the various localities are in the relative proportions of the constituent minerals, especially tourmaline, monazite, magnetite and ilmenite.

Megascopically the ore is dark brown to black; the colour depends largely on the quantity of wall rock material enclosed. The allanite weathers much more easily than the enclosed wall rock and the weathered ore therefore has a pitted surface with the inclusions standing out in relief. A veneer of black material, which is probably an oxide of iron, covers the allanite.

In thin sections the ore is largely translucent to transparent. Allanite is greenish brown, tourmaline bluish black and magnetite opaque. Alteration products of iron oxide are found along cleavage-planes of the enclosed feldspar, giving the inclusions a brownish colour.

The ore is fine grained. The crystals of allanite, tourmaline and apatite are about the same size and have an average diameter of between 1.5 and 2 mm. The grains of quartz, magnetite and zircon vary considerably in size.

The ore is holocrystalline. The degree to which crystal forms have developed varies in all the minerals, depending upon their mode of emplacement, paragenesis or alteration. Allanite and monazite usually show the best crystal form both in prismatic sections, the outline of which is determined by cleavage, and in basal sections in which the outline is determined by crystal faces. Tourmaline is generally anhedral.

Euhedral apatite is rare. Zircon grains, usually forming clusters of 5 or more, are all well rounded. Magnetite interstitial to, or replacing the other minerals, is usually irregular in form.

Quartz constitutes more than 50 per cent of the material of the lodes. The thin bands of allanite and other minerals are enclosed by thicker bands of quartz. In the western occurrence veinlets of quartz up to 10 cm in length are present in the allanite ore.

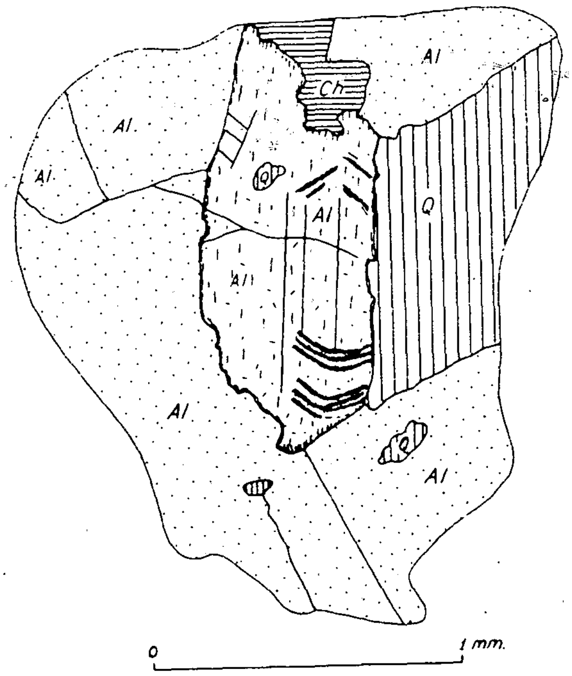

Fig. 3. - A prismatic crystal of allanite showing "chevron-like" zoning. Other minerals are quartz (Q), chlorite (Ch) and allanite (Al).

2. Constituent Minerals

(a) Allanite

(i) Morphology. - Grain size ranges from 0.1 mm., to 4 mm., 2 mm. being a fair average. The allanite is subhedral to anhedral in places where later minerals, i.e. quartz and magnetite, have rounded or replaced it along cleavage planes.

Where allanite is replaced by quartz, small rounded relics remain in the quartz. Pike (1959, p. 65) mentions a similar replacement of monazite by quartz in the Steenkampskraal deposit.

Small idiomorphic crystals of allanite, which are probably recrystallised, are found in some of the quartz veins in the ore body (see Plate V). These crystals are all elongated along the crystallographic b axis, a feature very typical of all the minerals belonging to the epidote group.

The idiomorphic grains mentioned above are too small for their interfacial angles to be measured on a goniometer.

Cleavage parallel to (001) is imperfect. Numerous cracks and fractures in the crystals obscure the true cleavage. These cracks and fractures are all irregular and do not show any particular orientation.

The allanite sometimes exhibits well-developed simple and polysynthetic twins parallel to (100). Twinned crystals are usually found in association with distorted grains of wall rock feldspar, exhibiting numerous cracks as well as undulose extinction. The twinning probably took place as a result of stresses which occurred in the mineralised zone after the main period of mineralisation.

Zoning occurs parallel to the outline of some crystals, but is also often "chevron-shaped" as indicated in Figure 3. Baker (1937, p. 50) found similar zoned and "chevron-shaped"

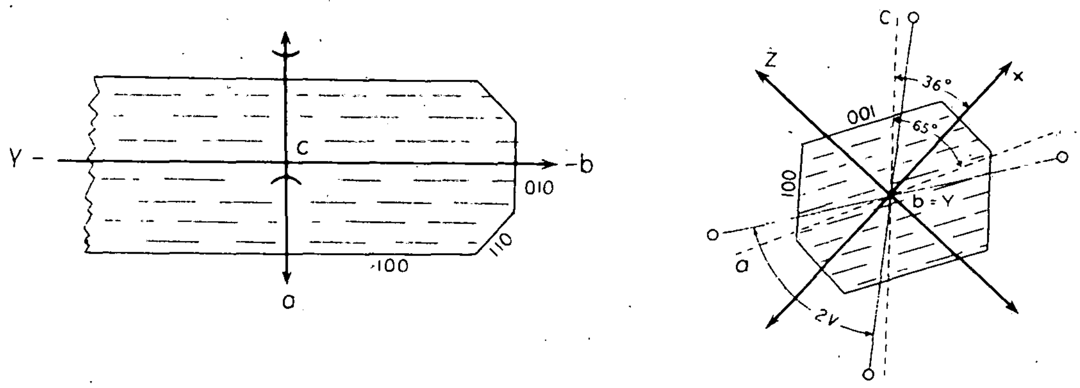

Fig. 4. - Optical orientation of allanite.

orthite in granite in Victoria, Australia.

(ii) Colour and lustre. - Seen under a pocket lens or binocular microscope, the allanite is brownish black in colour. It has a resinous lustre and is sub-translucent. In thin sections it is yellow to greenish brown and is pleochroic with absorption X>Y>Z. The twinned crystals all have a characteristic brown colour; their relief and birefringence are moderately high, but the interference colours are usually masked by the brown colour.

(iii) Specific gravity. - To determine the specific gravity, allanite crystals were cut to a suitable size and weighed in air and when suspended in boiled distilled water. Three determinations were made:-

(1) Sample from main deposit - $D_4^{21} = 3.550 \pm .020$

(2) Sample from western deposit - $D_4^{22} = 3.595 \pm .020$

(3) Sample from pegmatite deposit - $D_4^{23} = 3.519 \pm .020$

(iv) Optical properties. - The generally accepted optical orientation of allanite is shown in figure 4. The γ ray vibrates parallel to the crystallographic b axis, and the angle $c \wedge \beta$ is 65° (Hintze, 1897, p. 257; Rogers and Kerr, 1942, p. 326; Ford, 1945, p. 624).

The extinction is usually parallel but the orientation is difficult to determine.

$n\alpha$ and $n\gamma$ were measured in basal sections and $n\beta$ in prismatic sections. To determine $n\beta$, grains exhibiting centered optic figures were chosen and the lowest figure obtained for $n\beta$ from a number of determinations was accepted.

For the measurement of $n\alpha$ and $n\gamma$ grains showing the highest interference colours were chosen. The highest and lowest values obtained from a large number of determinations were accepted as $n\alpha$ and $n\gamma$ respectively. It was found that the refractive indices of the allanite vary for samples from the different localities, probably due to differences in chemical composition. The range in refractive indices is as follows:-

$$n\alpha = 1.732 - 1.757$$

$$n\beta = 1.747 - 1.768$$

$$n\gamma = 1.759 - 1.779$$

Attempts were made to measure the optic axial angle of allanite accurately by means of the universal stage but they met with no success. Examination of a number of optic axial figures of allanite, however, suggests an axial angle of 60° or more (with the exception of a high magnesian variety which has an axial angle of 40°). The sign is negative. A decolorized allanite, to be described later, however, has a positive sign.

(v) Inclusions. - When the ore contains small inclusions of primary allanite from the wall rock, the mineral is recognised by the alteration products surrounding the grains and by its isotropism. The nature of the alteration products is uncertain; Clarke (1916, pp. 15-17) considered that they consist of carbonates of the cerium group, but Watson (1917, p. 498) found only traces of carbonate in the outer zone of altered allanite.

Besides the primary allanite from the surrounding granulite, the following inclusions are found in the allanite of the ore body: zircon (rounded), apatite, chlorite and magnetite.

Many of the allanite grains are cut by minute veins of quartz and also of epidote. When viewed in thin section the contact between allanite and epidote is gradational, suggesting a parallel growth between the two

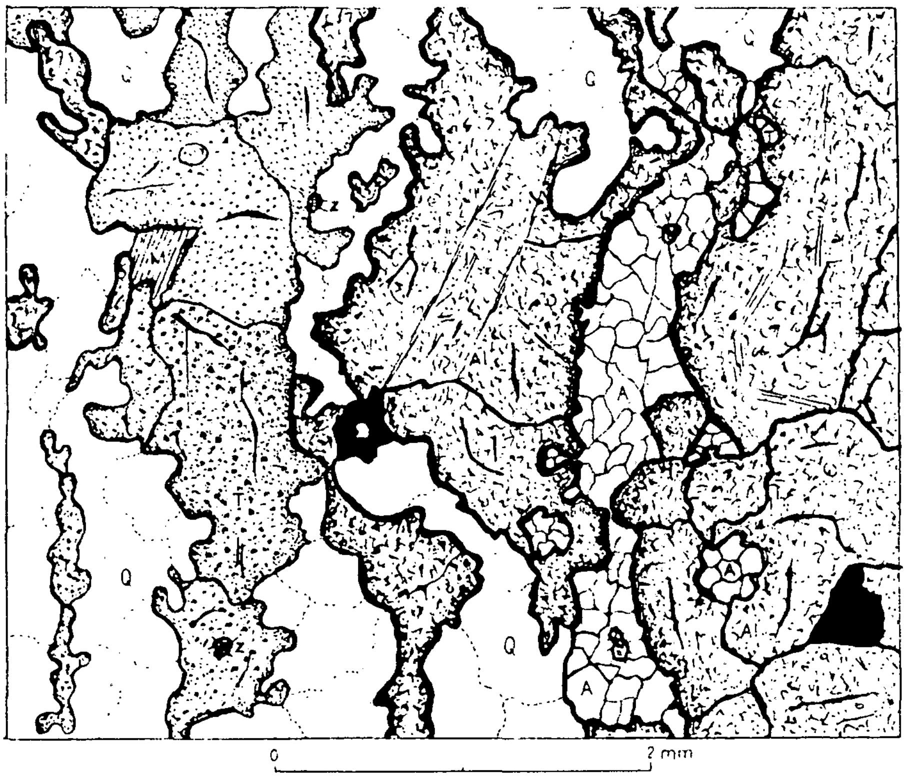

Fig. 5. - Irregular bands of allanite (Al), tourmaline (T) and apatite (A) in the ore. Other minerals are quartz (Q), magnetite (black), zircon (Z) and monazite (M). Note cracks radiating from allanite and zircon crystals.

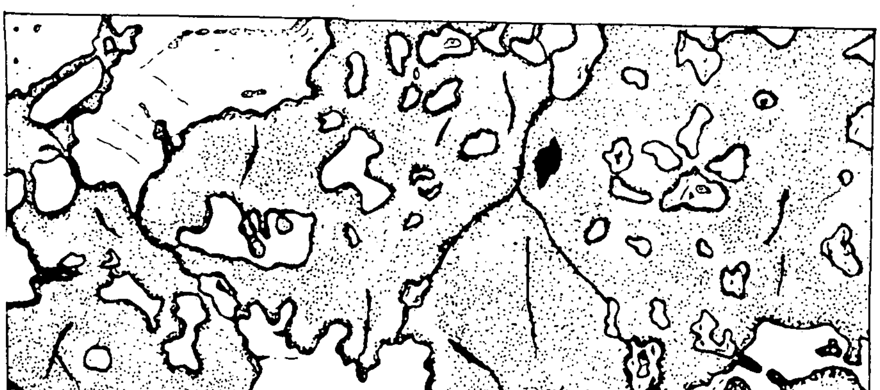

Fig. 6. - Replacement of tourmaline (stippled) by quartz (clear). Accessories are zircon (cross-hatched) and magnetite (black).

minerals as described by Hobbs (1889, pp. 223-238). This epidote is sometimes altered to chlorite.

(vi) <u>Alteration</u>. - "Allanite is easily altered and then the mineral usually becomes isotropic" (Ford, 1945, p. 625). Nowhere, however, was the allanite of the ore found to be isotropic. In some cases crystals have been partially decolorized, probably due to leaching out of iron or to physical disruption of the crystal lattices. The hydroxides removed by leaching were deposited in the peripheral zones of the crystals. The decolorized crystals sometimes show anomalous interference colours similar to those of chlorite.

(b) Tourmaline

Tourmaline occurs in bands (see Fig. 5) parallel to those of allanite. The two minerals are seldom in contact with each other, but where they are, it can be seen that the allanite is the later of the two. Several grains of tourmaline, however, with inclusions of apatite, primary allanite, zircon and monazite were observed.

The grain size does not exceed 2 mm. As in the case of allanite, tourmaline is rounded and replaced by later minerals and is therefore frequently anhedral. This replacement and embayment of tourmaline by quartz is illustrated by figure 6.

Subhedral grains are usually found in the wall rock about 1 cm. from the contact with the lode.

No cleavage was observed, but cracks and fractures occur in most of the grains.

In hand specimens, the tourmaline is black, opaque and has a resinous lustre. In thin sections under the microscope the mineral is strongly dichroic, the colour ranging from blue-black to fawn with absorption $O > E$.

The relief and birefringence are moderate to high.

Basal sections of standard thickness give a negative uniaxial figure with one or two rings. Occasionally basal sections transmit so little light that they fail to give a figure at all.

Grains showing centered optic axial figures gave $n\omega = 1.653 \pm 0.003$. Indices measured from prismatic sections gave $n\epsilon = 1.636$.

The optical properties compare well with those of the iron-rich tourmaline, schorlite.

(c) Apatite

As in the case of tourmaline, apatite occurs as bands parallel to the allanite. The only differences are that there is much less apatite than tourmaline, and that the apatite grains are often in contact with those of allanite. The average grain size is about 1.5 mm. Allanite grains which enclose small crystals of apatite indicate the allanite to be the later.

The apatite is usually rounded, and here and there quartz clearly replaces it. Cleavage is absent but irregular cracks and imperfect to perfect parting parallel to the length of the crystals are common. The optical properties are perfectly normal and typical of apatite. The refractive index $n\omega = 1.635 \pm .003$. According to Winchell (1951, p. 199) this indicates a fluorapatite.

(d) Monazite

Monazite occurs in the massive allanite ore of the eastern occurrences. The grains which are on the average 0.5 mm. in diameter, are disseminated through the ore in an irregular manner. They are equant and euhedral, and are generally polysynthetically twinned parallel to (100).

In thin sections the monazite has a pale fawn colour and is faintly pleochroic. Its relief and birefringence are very high. Basal sections display very low birefringence, and those which yield well-centered interference figures are almost dark between crossed nicols. The interference figure is biaxial positive with a small axial angle (14^{o}).

(e) Zircon

Zircon is nearly always present in the ore, either in the form of aggregates or as individual grains. It is frequently found near the tourmaline bands, i.e. near the contact between the lode and the wall rock.

The zircon apparently crystallised first, because it is sometimes included in large allanite or tourmaline crystals, or is tightly surrounded by other minerals which are not replaced or fractured. It has in rare cases been replaced by apatite.

The grain size ranges between 0.1 and 0.3 mm. The crystals are all rounded, probably due to resorption before crystallisation of the other minerals.

No cleavage was observed; irregular cracks run the whole length of the grains or radiate from the centre outwards.

The relief is very high and so is the birefringence. The interference figure is uniaxial positive.

(f) Opaque Minerals

Magnetite occurs interstitially to allanite or replaces it. In some places it is present in the form of streaks in the quartz of the lode. In thin sections the replacement of tourmaline, allanite, apatite and monazite by magnetite is very apparent. Some of the magnetite occurring in allanite masses is cut by veinlets of quartz which are evidently younger than the quartz of the ore.

In polished sections the magnetite is recognised by its reflectivity and isotropism. It is martitised along fractures and cleavage planes.

In some samples small quantities of ilmenite are intergrown with magnetite or replace it (see Plate VI). In polished sections the ilmenite exhibits characteristic anisotropism and reflection pleochroism. Polysynthetic twins are common. The presence of ilmenite was confirmed by X-ray diffraction.

(g) Quartz

In thin sections the replacement of allanite, tourmaline, apatite, zircon, and the wall-rock by quartz is very evident. Where thin veins of quartz cut through a mineral, small sub-to anhedral crystals of that mineral are found in the veins.

The grain-size varies appreciably, but it seldom exceeds 2 mm. The large quartz bodies as a rule consist of aggregates of several smaller intergrown crystals. The individuals can be distinguished between crossed nicols by differences in the direction of extinction. This gives the impression of undulose extinction instead of which it is actually sympathetic extinction of similarly orientated crystals. The optical properties are typical of quartz.

This lode-quartz differs from the wall-rock quartz in the following respects:-

(i) The wall-rock quartz is largely recrystallised while the lode-quartz is not.

(ii) The lode-quartz is clear and replaces tourmaline whereas the wall-rock quartz contains

Table 2. - Analyses of Allanite

No.	1	2	3	4	5	6	7	8	9
SiO_2	31.12	31.72	31.76	30.97	27.7	30.22	28.80	30.60	32.20
Al_2O_3	15.23	16.75	19.15	16.04	13.2	16.94	10.0	16.18	17.18
Fe_2O_3	17.73	10.07	10.46	10.49	4.3	2.97	10.25	3.52	3.79
FeO	0.57	7.90	6.11	5.29	14.2	10.50	7.33	8.60	10.38
MgO	2.54	2.39	4.06	0.49	-	0.05	0.58	0.46	0.69
CaO	15.0	11.6	12.4	9.16	10.4	10.39	10.08	7.76	11.95
K_2O	-	0.04	0.12	-	-	-	-	-	0.02
Na_2O	0.15	0.08	0.10	-	-	-	-	-	trace
MnO	0.22	0.14	0.21	-	-	1.58	6.74	4.48	0.26
H_2O^-	0.20	0.24	0.12	-	-	0.33	-	0.22	0.29
H_2O^+	3.74	2.44*	1.31	7.99	0.80	2.19	1.32	5.07	1.89
Ce_2O_3	4.51	7.56	5.76	17.22	28.5	7.50	9.06	19.36	9.06
La_2O_3	6.44	5.57	6.43	-	-	11.50	13.36	-	9.24
Dy_2O_3	0.21	-	0.14	-	-	-	-	-	-
Nd_2O_3	1.56	2.54	1.42	-	-	-	-	-	-
Y_2O_3	0.38	0.34	0.04	-	0.4	3.43	-	2.22	0.72
Ho_2O_3	0.17	0.42	0.33	-	-	-	-	-	-
ThO_2	0.41	-	-	1.70	-	1.53	0.95	1.02	1.05
BeO	-	-	-	-	0.13	-	-	-	-
TiO_2	-	-	-	-	0.38	-	2.02	0.36	0.74
Total	100.18	99.80	99.92	99.35	100.01	99.13	100.49	99.85	99.46

1. Pegmatitic allanite (north of eastern occurrences), Vrede. Analyst: C.E.G. Schutte; Division of Chemical Services, Department of Agricultural Technical Services.

2, 3. Samples from main (eastern) deposit, Vrede. Analyst: C.E.G. Schutte.

4. Bokseputs, Gordonia. Analyst not given (Mountain, 1931, p. 133).

5. Zaaiplaats Tin Mine, Transvaal. Analyst: C.F.J. van der Walt (Söhnge, 1944, p. 172).

6. Osawa, Japan. Analyst: S. Hasegawa, 1957, p. 360).

7+. Ragged Peak, Yosemite National Park, California. Analyst: M. Johnson (Hutton, 1951, p. 238).

8. Woodstock, N.W. Division, Western Australia. Analyst: D.G. Murray (Simpson, 1931, pp. 137-148).

9. Willmot Pass, Fiordland, New Zealand. Analyst: F.T. Steele (Hutton, 1951[a], p. 210).

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* contains CO_2

+ Analysis includes 0.015 UO_2

Table 2.

minute needle-like inclusions and is replaced by tourmaline.

(h) Chlorite

Chlorite occurs interstitially to the allanite and encloses small grains of quartz which are apparently not related to the lode-quartz. The chlorite and associated quartz grains seem to be relics of the wall-rock that were trapped as xenoliths in the lodes. If this is the case, chlorite represents altered biotite.

In thin sections the chlorite is pleochroic from green to nearly colourless. It has a fairly high relief but the birefringence is low, and the anomalous interference colour is typical. Cleavage is present in some crystals.

The interference figure appears to be uniaxial but is actually biaxial with an extremely small axial angle. The optical character is usually positive, but sometimes it is negative.

The mineral is probably penninite.

G. COMPOSITION OF THE ALLANITE

1. Chemical Analyses

The chemical analyses of pure allanite separated from the ore are given in table 2. The samples were crushed and ground to -100, +120 mesh (Tyler). The superpanner was used to obtain a preliminary concentrate. After drying, the strongly magnetic fraction was removed by means of a hand magnet. Successive fractions of the remainder were then separated on a Franz Isodynamic Separator, each fraction being examined under the binocular microscope, and the process repeated until a pure allanite fraction was obtained.

Table 3. - Recalculation of Analysis (2) of Allanite on the basis of 13(O, OH, F) atoms to the unit cell.

	Mol. weight	Weight per cent.	Mol. prop.	(O, OH)	Metals	Balancing
CaO	56.08	11.6	.2068	.2068	1.0712	
MnO	70.93	0.14	.0019	.0019	0.0098	
ThO_2	264.12	-				
U_3O_8	842.21	-				
K_2O	94.192	0.04				2.134
Na_2O	61.994	0.08				
Ce_2O_3	328.26	7.56	0.23	0.69	0.714	
La_2O_3	325.84	5.57	0.017	0.051	0.0264	
Dy_2O_3	372.92	-				
Nd_2O_3	336.54	2.54	0.0075	0.0225	0.232	
Y_2O_3	225.84	0.34	0.0015	0.0045	0.0466	
Ho_2O_3	377.80	0.42	0.0011	0.0033	0.034	
FeO	71.85	7.90	0.1099	0.1099	0.5692	
MgO	40.3	2.39	0.0592	0.0592	0.3066	2.964
Fe_2O_3	159.7	10.07	0.0630	0.1890	0.652	
Al_2O_3	101.94	16.75	0.1643	0.4929	1.702 (1.437; .265)	
SiO_2	60.06	31.72	0.5281	1.0562	2.735	3.00
H_2O^+	18	0.24	0.1355	0.244	1.263	1.263
Total		99.80				

The formula derived is:

$(Ca, Ce, La, Nd, Y, Ho, Mn)_{2.134}(Al, Fe^{3+}, Fe^{2+}, Mg)_{2.964}[(SiAl)_3O_{12}](OH)_{1.263}$

The formula conforms closely to the formula $X_2\ Y_3\ Z_3(O, OH, F)_{13}$ developed by Machatschki (1930, p. 96) for allanite.

In the analysis of allanite by Schutte (personal communication), the usual analytical procedure for silicates as described by Hillebrand _et al._ (1953), was modified for the separation of the rare earths. After the determination of SiO_2, the rare earth group was separated by the oxalic acid method. Any occluded Ca was removed by dissolving the rare-earth oxalates in hydrochloric acid and reprecipitating with oxalic acid. After ignition the rare-earth oxides were weighed. The oxide mixture was retained for the individual determination of each rare-earth element present by the tablet technique described by Gum (1957, p. 184), for which a Philips X-ray fluorescence spectrograph was used.

The two filtrates from the oxalic acid precipitations were combined, sulphuric acid was added and the mixture then evaporated until SO_3 fumes envolved. Fe_2O_3, Al_2O_3, TiO_2, CaO and MgO were then determined according to the conventional methods.

For the purpose of comparison, the three analyses of allanite from Vrede are given in table 2 with 6 analyses of samples of allanite from localities in South Africa, New Zealand, Australia, the United States of America and Japan.

Although the last 5 analyses are in some respects incomplete and therefore not altogether satisfactory, they help to illustrate the wide variation in the composition of the mineral.

Special attention is directed to

(i) The low percentage of cerium in the Vrede allanite, by comparison with the others (save Japan).

(ii) The unusual richness of the Vrede samples in magnesium.

(iii) The absence of thorium in samples 2 and 3

(main deposit, eastern occurrences,
Vrede).

2. Chemical Formula

The analyses of allanite from Vrede have been recalculated (for example see table 3) on the basis of 13(O, OH, F) atoms to the unit cell to conform to the formula evolved by Machatschki (1930, p. 96) for other allanite, viz.

$X_2\ Y_3\ z_3\ (O, OH, F)_{13}$, where

X = Ca, Ce, La and other rare earths, Mn, K, Na

Y = Al, Fe^{3+}, Fe^{2+}, Mg, Ti

z = Si, and Al in part (probably also Be in part according to Quensel, 1945, pp. 1-7).

The X-group thus includes cations with ionic radii of about 1.0 - 0.10A°, the Y-group ions of intermediate size, and z silicon (although aluminium and, rarely beryllium may be present in the tetrahedra). In this connection one point deserves comment. The low figure for Si^{4+} (see table 3) is balanced by an appreciable quantity of aluminium in the silicon-oxygen tetrahedra; it should be observed that fourfold coordination of aluminium, normal in a great many silicates, is usually of little moment in allanites, as Lokka (1935, pp. 11-12) has made clear for some Finnish occurrences.

The purity and freshness of the samples analysed appear to be satisfactory because analyses of metamict (i.e. altered) allanite often show an excess of silicon over that required structurally. The negligible quantity of alkalies is also indicative of an unaltered condition since appreciable quantities of both sodium and potassium are often present in metamict varieties (Hutton 1951, p. 211).

The formulae obtained for the other two analyses were:-

(1) $(Ca_{1.396}, RE_{1.268}, Mn_{0.016})_{2.6}\ (Al_{1.259}Fe^{3+}_{1.158},$

$Fe^{2+}_{0.040}, Mg_{0.328})_{2.78}\ \left[(Al_{0.3}Si_{2.7})_3\ O_{12}\right]\ (OH)_{1.08}$

(3) $(Ca_{1.224}, RE_{0.378}Mn_{0.016})_{1.61}\ (Al_{2.01}Fe^{3+}_{0.724},$

$Fe^{2+}_{0.470}, Mg_{0.554})_{3.74}\ \left[(Al_{0.08}Si_{2.92})_3O_{12}\right]\ (OH)_{0.402}$

The figure for hydroxyl in analyses 1 and 2, is however, slightly greater than the theoretical requirements.

Ueda (1955, pp. 145-163) has recently reported that the crystal structure of allanite is of the mixed silicate type, being the same as that of epidote, and gives the chemical formula as

$$OH(Ca, Ce)_2\ (Fe^{2+}, Fe^{3+})\ Al_2O\ Si_2O_7\ SiO_4$$

For the purpose of substituting other atoms in this formula, there can be no objection to the use of the simplified formula $(Ca, Ce)_2(Fe^{2+}, Fe^{3+})Al_2Si_3O_{12}(OH)$, which closely resembles that proposed by Machatschki.

The formula obtained for analysis 2 according to Ueda's method is as follows:-

$(Ca_{1.07}Ce_{1.05}Mn_{0.01})_{2.13}(Fe^{2+}_{0.569}\ Fe^{3+}_{0.089}Mg_{0.306})_{0.964}$

$(Al_{1.437}Fe^{3+}_{0.563})_2\ (Al_{0.265}Si_{2.735})_3\ O_{12}(OH)_{1.263}$

Ce includes all of the rare earths.

In order to satisfy the requirements of the Ueda structural formula the following assumptions were made:

(i) Part of the Ca is replaced by Mn.

(ii) Part of the Si in the tetrahedra is replaced by Al.

(iii) A considerable quantity of Al is replaced by Fe^{3+}.

(iv) Part of Fe^{2+} is replaced by Mg.

As no chemical analysis was made of the ore of the western occurrence, a spectrographic examination was made to determine the rare earth content. The results of this examination are tabulated below (Table 4), with results obtained from the spectrographic examination of pegmatitic allanite, for the sake of comparison.

Table 4. - Spectrographic analyses of allanite

Sample No.	Locality	Large amounts $\pm$> 10%	Notable amounts $\pm$5-10%	Small amounts $\pm$ 1-5%	Very small amounts	Traces
1	Western occurrence, Vrede, Gordonia	Si,Fe	Ce,Al, Ca	La,Pr Nd	Th, Be,Y, Ho	U,Ti
2	Steynputs, Kenhardt	Si,Fe	Ce,Al, Ca	Pr,Nd	Gd,Y,Ti	U
3	Klein Mottles River, Kenhardt	Si,Fe	Ce,Al, Ca	La,Pr	Na,Mn,Gd	Ti
4	Bokseputs, Gordonia	Si,Fe	Ce,Al, Ca	Pr,Mg	Gd,Ti,Th	U

The rare-earth assemblage of the sample from Vrede therefore corresponds well with that for pegmatitic allanite, except in respect of the minor elements, which appear to be extremely variable.

3. Relationship Between the Chemical Composition and the Optical Properties

Hata (1939, pp. 124-128) has attempted to correlate chemical composition with optical properties for allanite from Kido, Japan (Hata, 1939, p. 127). He plotted the percentages of Fe^{2+} + Fe^{3+} in the Y-group against the percentage of rare-earth elements in the X-group and some relationship would seem to exist between these data and the beta refractive indices of the allanites concerned. Hutton (1951, p. 243) disagreed with Hata and considered that any relationship is entirely coincidental. He showed that if Hata's analysis (No. 13) is treated by Machatschki's method (1930) the results do not agree with the formula $X_2\ Y_3\ z_3\ (O, OH, F)_{13}$. Instead, "... the [sum of the] X- and Y-groups are 1.52 and 3.46 respectively if manganese is placed with the ions of higher coordination, or 1.39 and 3.58 respectively if manganese is placed in six-fold coordination". The allanite used by Hata must therefore either have been impure or considerably oxidized. Factors other than those considered by Hata must therefore be taken into account.

Hutton (1951, p. 243) described a manganoan allanite from Yosemite Park with refractive indices distinctly higher than any previously recorded for allanite. These high values are undoubtedly a reflection of the unusually high percentages of Fe^{3+}, Mn^{2+} and Ti^{4+} in the mineral. The considerable variation in the refractive indices of the Vrede allanite may likewise be caused by the high percentage of Fe^{3+}, Mg^{2+} and the variable percentage of

Fe^{2+}.

It has already been mentioned that a positive optic sign was observed in some of the Vrede allanite. This appears to be unusual for the mineral, since only a few samples of optically positive allanite have been recorded. (Hutton 1951[a], p. 211; Goddard and Glass, 1940, p. 398; and Geijer 1927, p. 1-32). It is interesting to note that three of these allanites have an abnormally high magnesium content:

Vrede 2.54-4.6 per cent

Colorado (Goddard and Glass) 1.4 per cent

Östanmasso (Geijer) 7.42-14.15 per cent

The allanite described by Hutton (1951[a]) contains 0.69 per cent MgO and has an optic axial angle of 57°. The optic axial angle of this Vrede allanite (positive) is about 40° while that of Colorado is 30°. Unfortunately Geijer did not mention the optic axial angle of the Östanmasso allanite. Normal allanite has an optic axial angle of 60° or more.

It is possible, therefore, that some kind of relationship may exist between a high percentage of Mg, a positive axial figure and a relatively small axial angle in allanites.

4. Radiometric Assay

Chip sampling was done of all the deposits. The samples were crushed and radiometrically assayed against a standard uranium-thorium sample. In Table 5 the values obtained for samples from Vrede are compared with those for samples of pegmatitic origin.

Table 5. - Radiometric Assays of
Allanite bearing ore

Locality	U_3O_8 per cent.	ThO_2 per cent.
Vrede - main deposit eastern occurrences (chip sampled)	0.038	0.008
Vrede - western occurrence (chip sampled)	0.14	-
Vrede - allanite from pegmatite deposit, north of eastern occurrences	0.11	0.42
Klein Mottles River, Kenhardt	0.93	0.358
Steynputs, Kenhardt	0.67	0.295

Analyst: J.J.J. van Rensburg; Geological Unit, Atomic Energy Board.

The average values obtained for samples from Vrede are 0.096 per cent. U_3O_8 and 0.142 per cent. ThO_2. For the purpose of the Atomic Energy Act (Act 35, 1948) the allanite is, therefore, a prescribed material. It is unlikely, however, that uranium or thorium will ever be recovered economically from the ore, which represents essentially a source of the cerium group of rare earth metals.

IV. GENESIS

Different authors on the subject of ore genesis (e.g. Brown, 1948, p. 104; Lindgren, 1939, p. 116) have pointed out that ore-bearing solutions continually change in composition, as well as in character through a pegmatitic, pneumatolytic and finally a hydrothermal stage.

The allanite-bearing lodes under discussion are not pegmatites although their mineral composition points to a genetic relationship with pegmatitic fluids. The formation of the lodes was clearly controlled by the dip and strike of the foliation of the metamorphic wall-rocks. Mineralising vapours and solutions apparently circulated along the foliation-planes and partially replaced the wall-rock. There is no indication whatsoever of any shear- or fault-zone in the immediate vicinity of the deposits that could have acted as a channelway for mineralising solutions.

From their mutual relationships it is concluded that the sequence of crystallisation of the ore-minerals probably was:- zircon, monazite, tourmaline, apatite, allanite, magnetite and quartz. The volatile nature of the constituents (phosphorus, fluorine and boron) of some of the ore-minerals indicates the presence of a gas phase during the formation of the lodes.

The solutions that brought in the allanite and apatite were capable of dissolving the quartz and feldspar of the wall-rock; this is shown by its extensive replacement by the minerals of the lode. At this stage the solutions contained varying amounts of boron, water, silica, zirconium, iron, calcium, lanthanum, neodymium, dysprosium, holmium and yttrium. Such liquids would have been alkaline in nature and would have reacted with the minerals in the adjacent wall-rock to give rise to minerals such as tourmaline and apatite (Von Backström, 1950, p. 48). Following the allanite deposition, the solution again changed in chemical character so that quartz was no longer attacked, but resorption of the allanite took place, followed by the deposition of magnetite.

The emplacement and deposition of the ores therefore probably depended primarily on the relief of pressure, and were thereafter determined by the temperature gradient.

In the beginning, impregnation must have been delayed where the foliation planes were closed, and the replacement would have been limited to narrow openings of capillary size. As a result the mineralising fluids would become highly charged with volatiles and this would cause an increase in the vapour pressure and lower the temperature of crystallisation (Von Backström, 1950, pp. 48-49). Minerals of higher vapour pressure would be deposited first. This would explain the early deposition of tourmaline by the reaction of highly volatile boron vapours with the feldspar in the adjoining wall-rock. On release of pressure, volatiles and mineralising solutions would escape into open fissures and replace the wall-rock extensively in places.

Hypogene mineralising solutions then entered and the deposition of apatite, allanite and magnetite followed in that order. Quartz crystallised last and not only filled all the available spaces, but also replaced part of the wall-rock and some of the early lode-minerals.

The only known intrusive rock in the immediate vicinity from which the mineralising solutions could have been derived is the grey gneiss which outcrops about 15 miles to the southeast. Poldervaart and Von Backström (1949, p. 492) have related the pegmatites of the surrounding area to a granitic instrusion younger than the grey gneiss, probably the acid granite intruded into parts of Bushmanland to the south of the area. The author believes that a crystallising pegmatite furnished the immediate source of the mineralising solutions and vapours. This belief is based upon the presence of an allanite-bearing pegmatite occurring a short distance to the north of the main deposit and the fact that pegmatite is the typical habitat of allanite.

According to Landes (1934, p. 700) later hydrothermal solutions may be given off by deeper-seated portions of crystallising pegmatites. This author continues: "Such hydrothermal solutions of pegmatitic origin do not necessarily confine themselves to the pegmatite, but may travel out into the adjacent country rock". Beryl, for instance, is sometimes found in deposits other than pegmatites. Examples are the emerald occurrences in schist in the Murchison area, Transvaal (Van Eeden et al., 1939, p. 94), and the beryl-containing wolframite-quartz veins in Burma, Tasmania and New South Wales (Landes, 1934, p. 700). Investigators in all these cases ascribe the origin of beryl and associated minerals to deposition by pegmatitic solutions.

The allanite-bearing pegmatites at Bokseputs lie about 10 miles to the west of the Vrede deposits and probably belong to the same period of mineralisation. Apparently rare earths were present in unusual proportions in the original granitic magma (Bushmanland granite - Poldervaart and Von Backström, 1949, p. 492) and became concentrated in the resulting pegmatite differentiate.

Niggli (1929, pp. 19, 39) relegated the formation of the rare earth minerals in general to the pneumatolytic-pegmatitic stage of magmatic ore formation. The Vrede deposits, however, also show evidence of hydrothermal action and can therefore be described as hydatopneumatolytic.

V. ECONOMIC ASPECTS

A. ORE RESERVES

The depth to which the lodes may be expected to extend cannot be predicted from the present study. Seeing that they are not continuous along strike, they are probably also not continuous in depth. If, however, the ore was introduced by solutions from which volatiles were continually released as vapours, it is possible that it may continue intermittently down to considerable depths.

To obtain a clearer view of the size and persistence of the ore bodies a systematic drilling programme will be necessary. The vertical dip of the lodes will require the drilling of inclined boreholes.

To date no extension of the allanite deposits along strike has been discovered. However, the study has shown them to be related to the regional structure, and further occurrences may therefore be expected.

On the whole the proposition is economically not impressive. Only the main deposit may perhaps be workable; if the allanite bands there extend to a depth of 200 feet, the ore reserve will be of the order of 1500 tons of allanite, assuming that the ore contains roughly 10 per cent. allanite.

B. EXPLOITATION OF DEPOSITS

The nearest railhead to the deposit is Lutzputs, about 23 miles from Vrede. Kakamas is the nearest business centre. A secondary road connects Lutzputs with Kakamas, and a farm track from Vrede joins this road at Biesiespoort, about 12 miles from Lutzputs.

All the deposits of the eastern occurrences are easily accessible, being near the road from Vrede to Lutzputs. The deposits of the western occurrence are situated in very broken country and are not so easily reached.

The ore may be recovered by standard mining methods. A difficulty may be that it is unlikely that local supplies of underground water will be sufficient to support mining operations.

Several wells have been dug in the bed of the Molopo

River. The seepage water, however, is too brackish for domestic use. Bore-holes on the banks of the river yield water of a somewhat better quality, but the yield seldom exceeds 1500 g.p.h. Successful bore-holes have been drilled next to amphibolite bodies, and in shear-zones and faults in the pink gneiss, yielding water which is quite suitable for domestic use. The yield ranges from 1500-2000 g.p.h.

The O'okiep Copper Company inspected and sampled the occurrences in 1958. Beneficiation tests and assays were carried out, but the Company was influenced by the narrow width and erratic distribution of the stringers of ore, its low cerium content and the uncertainty of the market for rare earths, and it was felt that the deposits did not warrant further investigation. No further interest has been taken in the prospect by the O'okiep or any other company.

C. DEMAND FOR RARE EARTHS*

Minor quantities of the rare earths, especially those of the cerium group, have long been used in the manufacture of flints, searchlights, cinema arcs and optical glass. However, in the United States of America so many applications are being found for the rare-earth metals that manufacturers are encouraging a rapid development of fabrication technology. Amongst such recent developments may be mentioned the spectacular improvement in the heat-resisting properties of steel through the addition of yttrium, which may hold the key to special alloys required for space flight and nuclear reactors.

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*Based on information supplied by The Officer-in-Charge, Mineral Development, Office of the Government Mining Engineer, Johannesburg.

Furthermore, the addition of rare-earth metals to non-ferrous alloys has great possibilities if pilot experiments can be applied commercially.

The United States Bureau of Mines is at present conducting an active metallurgical research programme on the rare-earth elements. A simple and efficient commercial procedure for extracting rare-earth compounds from bastnaesite (fluo-carbonate of the cerium metals) has already been developed. New uses for the heavy subgroup elements (i.e. yttrium, scandium, europium, terbium, etc.) have been intimated by research groups, and this may increase the demand for ores like euxenite and xenotime. Monazite, bastnaesite and euxenite are at present the principal rare-earth ore minerals of commerce in the United States of America. In 1958 the consumption of concentrates in that country was about 3,800 tons of contained rare-earth oxides.

At this consumption rate the United States of America could be easily self-sufficient in the rare earths because the world's largest reserve of cerium (light subgroup) metals is in a bastnaesite deposit in California. Several other placer and disseminated deposits contain large reserves of the heavy subgroup minerals.

These are the reasons, together with the fact that in the United Kingdom and the Continent research in this particular field is apparently being undertaken on only a modest scale, why there is practically no demand in these countries for rare-earth minerals like allanite, euxenite and gadolinite from South Africa at present (1960). Only an important new use could bring about a large increase in consumption.

"The outlook for the rare-earth industry is for continued expansion. The rate of expansion will follow the technologic and scientific developments in atomic energy, electronics, and engineering materials. Research has already indicated new uses, which may increase future consumption, and improved technology is showing the way to cheaper and better rare-earth production. World and domestic reserves of the rare-earth elements are adequate to supply many times the present demand for many years" (Baroch, 1960, p. 688).

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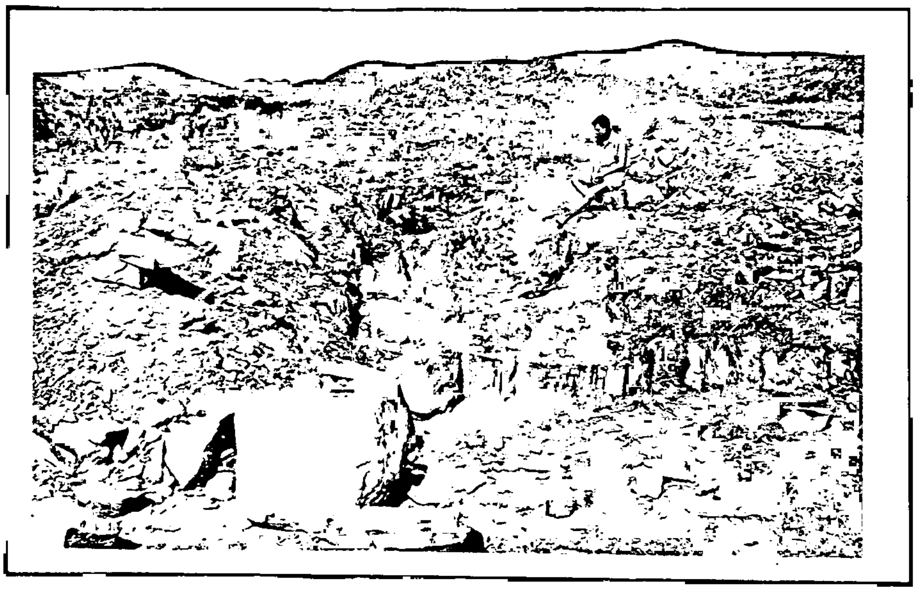

PLATE I.- One of the prospecting trenches at the main deposit on the western bank of the Molopo River showing the vertical disposition of the narrow, dark coloured bands of allanite ore in lighter coloured red granulite.

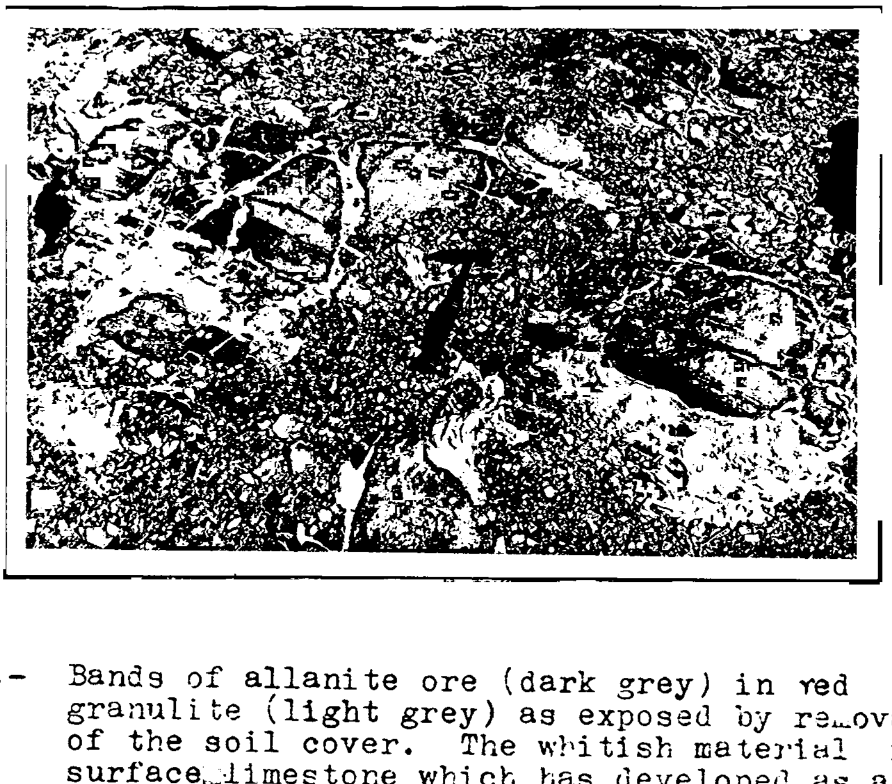

PLATE II.- Bands of allanite ore (dark grey) in red granulite (light grey) as exposed by removal of the soil cover. The whitish material is surface limestone which has developed as a product of weathering (eastern occurrences).

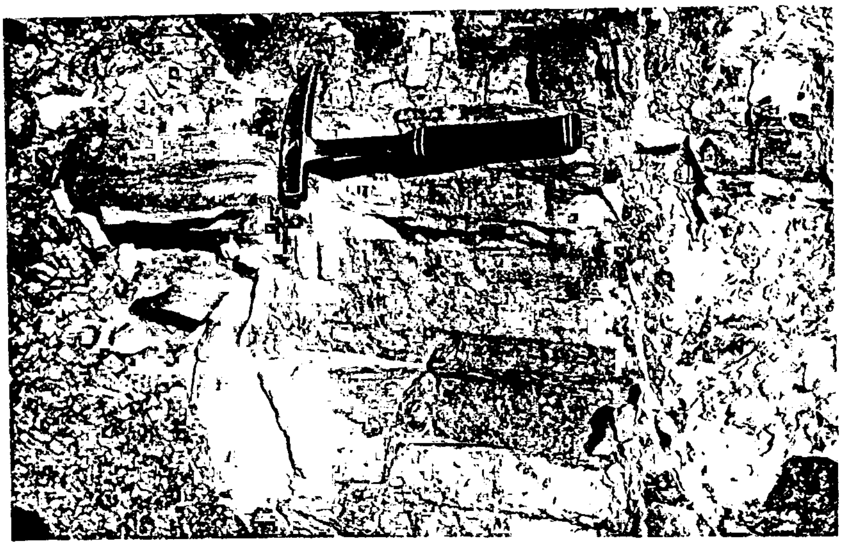

PLATE III.- Bands of allanite ore (dark grey) in red granulite (light grey) from which the weathered surface has been removed (eastern occurrences).

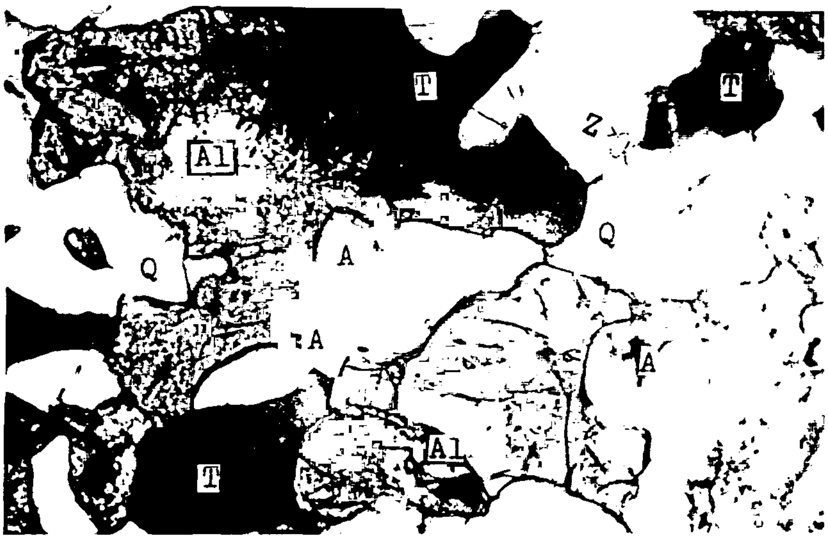

PLATE IV.- Photomicropraph showing the mineral assemblage of the allanite ore (eastern occurrences). Al = allanite, A = apatite, Q = quartz, Z = zircon and T = tourmaline

X 40

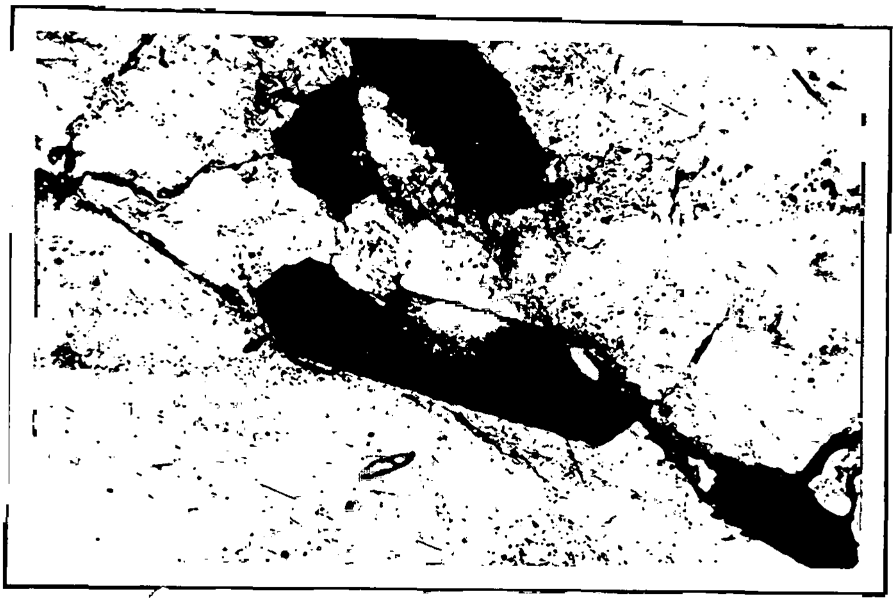

PLATE V.- A small euhedral crystal of allanite in the quartzose ore body, western occurrences. Needle-like inclusions in the quartz can be clearly seen.

X 75

PLATE VI.- Allanite (A) showing differences in reflectivity due to slight differences in composition, being replaced by a veinlet consisting of magnetite (M) and ilmenite (I). Note embayment of allanite by ilmenite along fracture planes (eastern occurrences).

X 50

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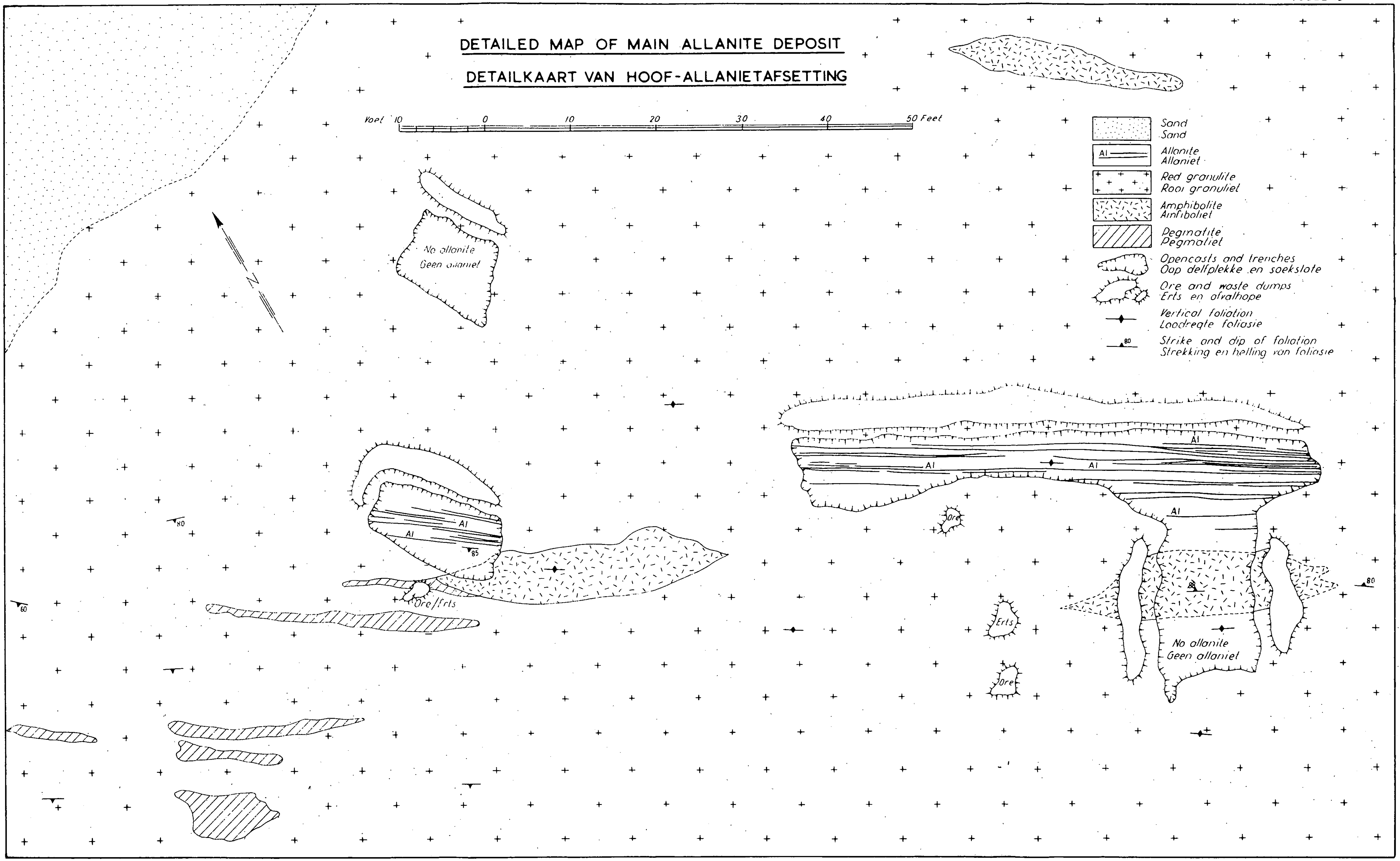
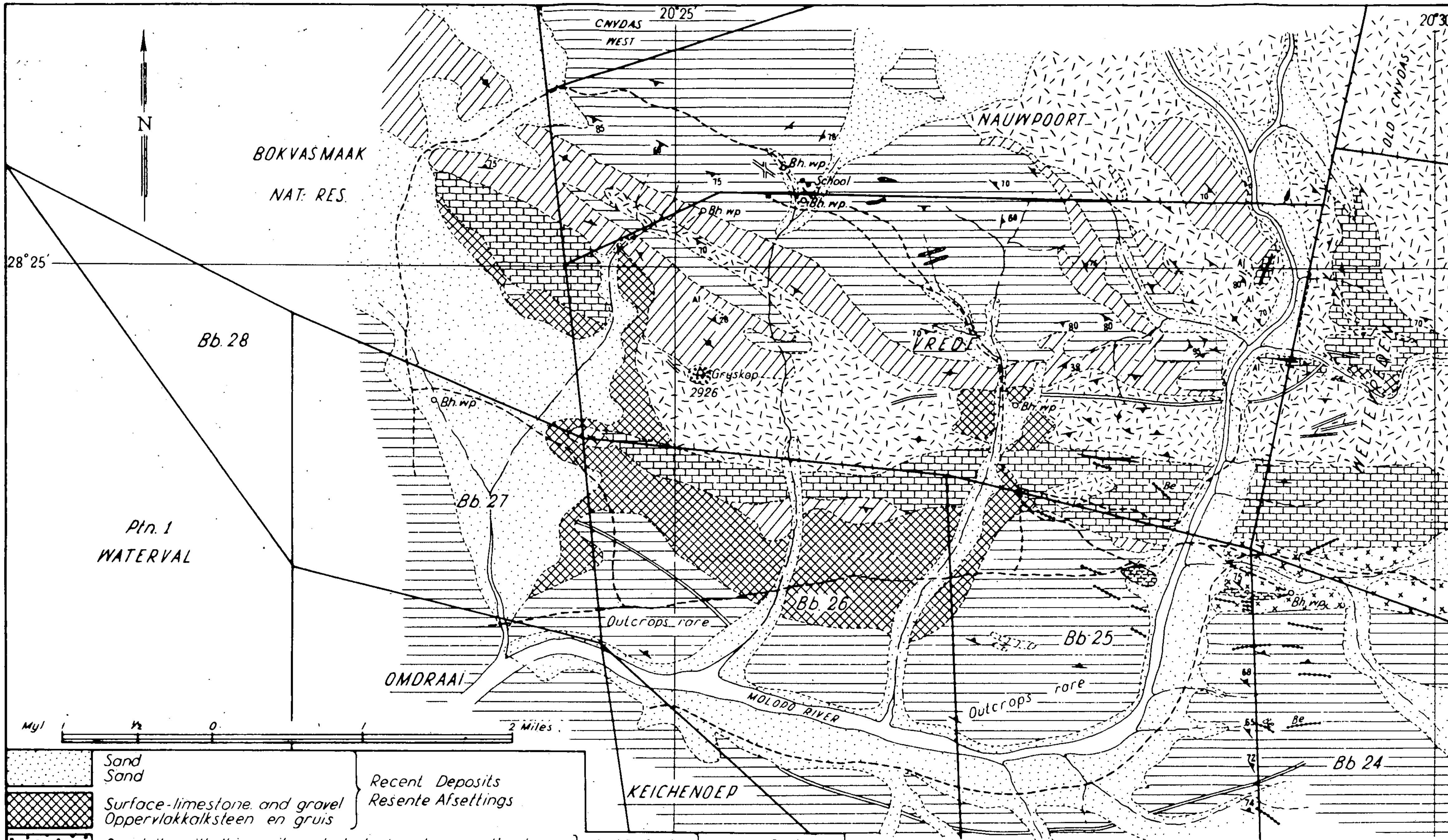

DETAILED MAP OF MAIN ALLANITE DEPOSIT
DETAILKAART VAN HOOF-ALLANIETAFSETTING
Voet 10 0 10 20 30 40 50 Feet
N
Sand
Sand
Allanite
Allaniet
Red granulite
Rooi granuliet
Amphibolite
Amfiboliet
Pegmatite
Pegmatiet
Opencasts and trenches
Oop delfplekke en soekslote
Ore and waste dumps
Erts en afvalhope
Vertical foliation
Loodregte foliasie
Strike and dip of foliation
Strekking en helling van foliasie
No allanite
Geen allaniet
Al
Ore/Erts
Ore
Erts
80
85
60

FOLDER 3

GEOLOGICAL MAP OF THE FARM VREDE, GORDONIA DISTRICT

GEOLOGIESE KAART VAN DIE PLAAS VREDE, DISTRIK GORDONIA



Sand Sand	Recent Deposits Resente Afsettings		
Surface-limestone and gravel Oppervlakkalksteen en gruis			
Quartzite with thin grit and shale bands near the base Kwartsiet met dun grintsteen- en skaliebandjies naby basis	Kuibis Series Serie Kuibis	Nama System Sisteem Nama	
Quartz-sericite schist with intercalated quartz-tourmaline schist Kwarts-serisietskis met kwartstoermalynskis tussengelaag	Kaaien Series Serie Kaiing	Kheis System Sisteem Kheis	
Grey granulite with pelitic intercalations (light weathering) Grys granuliet met pelitiese tussenlae (met ligkleurige verwering)			
Leucocratic granulite (dark weathering) Leukokratiese granuliet (met donker verwering)			
Red granulite Rooi granuliet			
Coarse-grained porphyroblastic gneiss (Pink gneiss) Grofkorrelrige porfiroblastiese gneis (Pienk gneis)			
Ortho-amphibolite (Basic Intrusives) Orto-amfiboliet (Basiese intrusiegesteentes)			
Pegmatite Pegmatiet			

Shear zone
Skuifskeursone

Strike and dip of foliation in crystalline and metamorphic rocks
Strekking en helling van foliase van kristallyne en metamorfe gesteentes

Vertical foliation of crystalline and metamorphic rocks
Loodregte foliasie van kristallyne en metamorfe gesteentes

Allanite deposit
Allanietafsetting

Beryl-bearing pegmatite
Berilhoudende pegmatiet

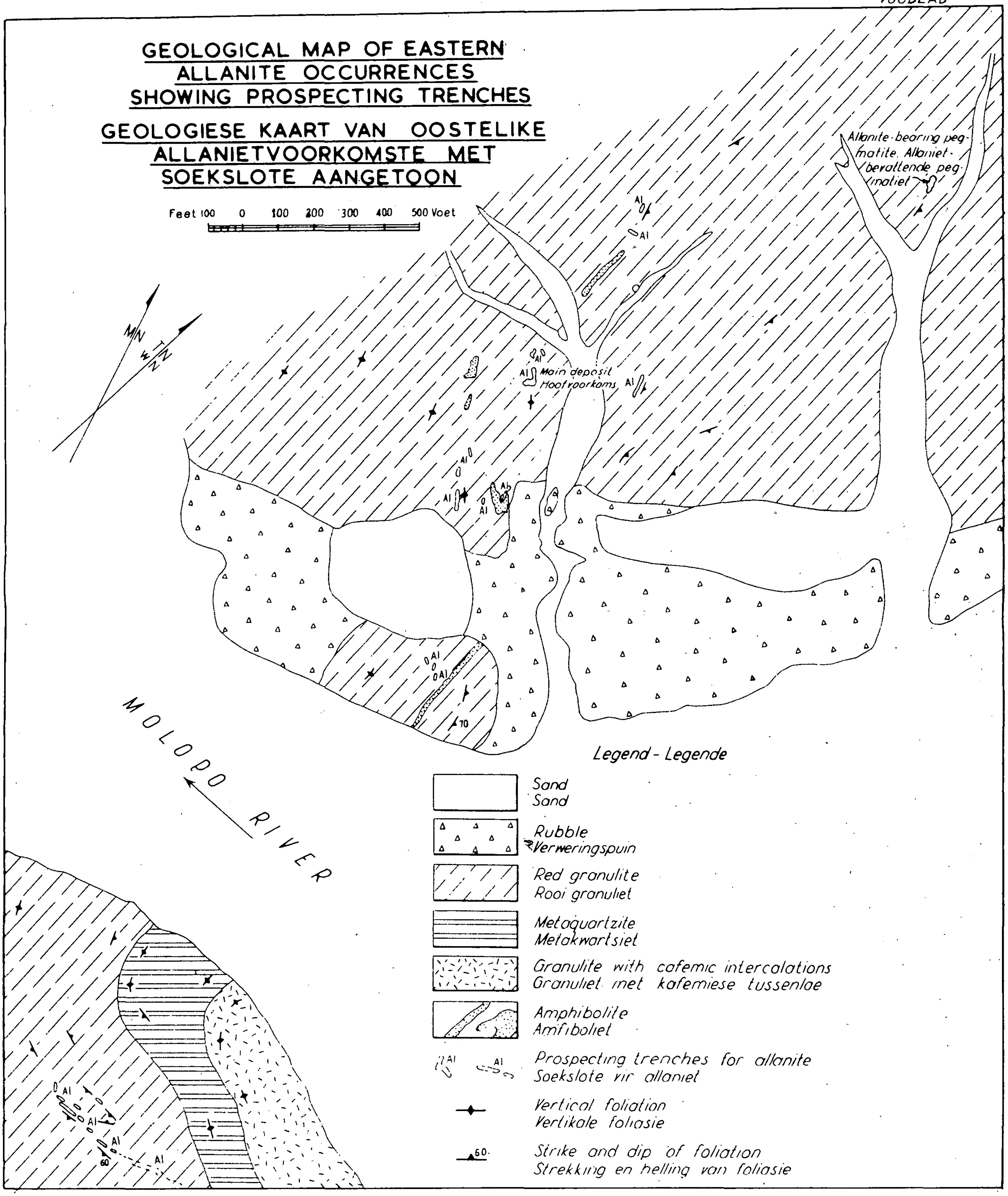
Farm house
Plaashuis

Farm track
Plaaspad

Ephemeral stream
Kortstondige stroom

Borehole, windmill
Boorgat, windpomp

FOLDER 1


GEOLOGICAL MAP OF EASTERN ALLANITE OCCURRENCES SHOWING PROSPECTING TRENCHES
GEOLOGIESE KAART VAN OOSTELIKE ALLANIETVOORKOMSTE MET SOEKSLOTE AANGETOON
Feet 100 0 100 200 300 400 500 Voet
M/N
W/N
Allanite-bearing pegmatite. Allaniet-bevattende pegmatiet
Main deposit
Hoofvoorkoms
Al
70
60
MOLOPO RIVER
Legend - Legende
Sand
Sand
Rubble
Verweringspuin
Red granulite
Rooi granuliet
Metaquartzite
Metakwartsiet
Granulite with cafemic intercalations
Granuliet met kafemiese tussenlae
Amphibolite
Amfiboliet
Prospecting trenches for allanite
Soekslote vir allaniet
Vertical foliation
Vertikale foliasie
Strike and dip of foliation
Strekking en helling van foliasie

FOLDER 2

FOLDER 2