Edna Pauline Janisch (Plumstead)

The Occurrence of Phosphates in Pegmatite Bodies in the Zoutpansberg District of the Northern Transvaal.

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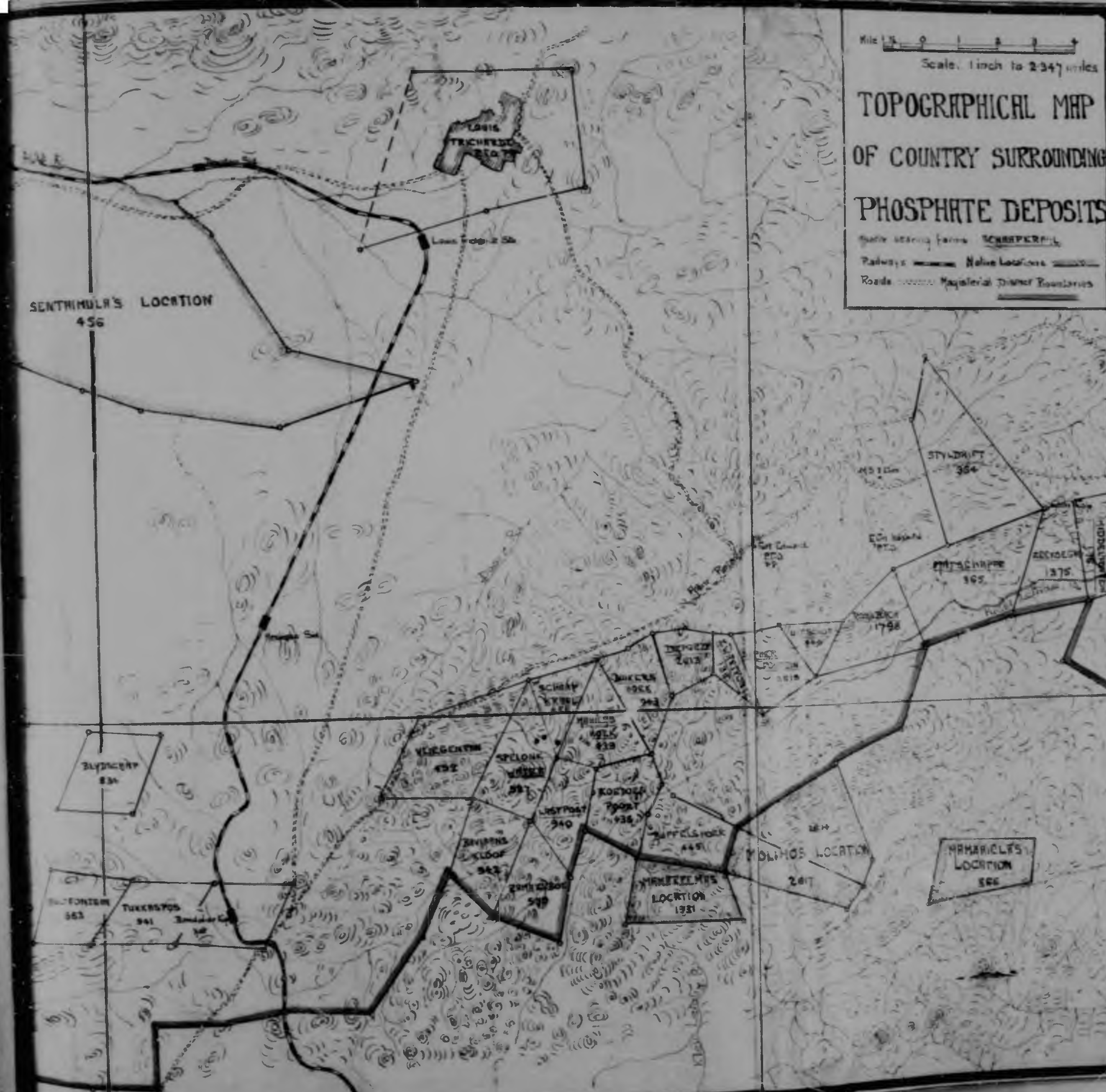
Scale: 1 inch to 2·347 miles
TOPOGRAPHICAL MAP
OF COUNTRY SURROUNDING
PHOSPHATE DEPOSITS
SENTHUMULA'S LOCATION
456
STYLDRIFT
354
SPELONK
LAST POST
940
MOLIHOS LOCATION
2417
HAMARELAS LOCATION
MAMABELAS LOCATION
1331
BLYDSCHAP
834
TURKSTOS
941
SEEKOEGAT
1375
ZAMENKOMS
509
RAFFELSHOEK
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VERGENOEG
432

THE OCCURRENCE OF PHOSPHATES IN PEGMATITE BODIES IN THE ZOUTPANSBERG DISTRICT OF THE NORTHERN TRANSVAAL.

General Summary of the nature & Distribution of phosphate occurrences throughout the world.

The main sources of phosphate in the mineral world are Apatite and Phosphorite, the former a chlorine and flourine bearing orthophosphate of lime, and the latter a massive or earthy variety of phosphate of lime of variable composition and with many impurities. Phosphorite bears the same relation to Apatite as limestone does to Calcite.

Apatite is a very common constituent of all igneous rocks in which it occurs in tiny well-formed crystals. It is, normally, an accessory mineral, usually one of the first to crystallise. The small percentage of P_2O_5 in the analyses of most igneous rock is due entirely to apatite.

Occasionally a considerable quantity of the mineral occurs associated with pegmatite bodies. The apatite is probably of primary origin. At Kragerö in Southern Norway, and in the Provinces of Quebec, Ottawa and Ontario in Canada, apatite occurs in this manner. The pegmatite is intrusive in

ancient ...

ancient gneissic rocks. Both the Norwegian and the Canadian resemble the Northern Transvaal deposits in many features and will be described later in this connection.

In India, apatite is abundant in Mica pegmatites near Kodarma in Hazanbagh, also in Bombay and in the Manganese mines of Madras. In all of these it is neglected as a waste product.

In the trachytes of Cabo de Gata, veins and dykes of apatite occur in much brecciated rocks. The surrounding rocks too are impregnated with apatite veins. These are attributed to post-volcanic action.

In Alpine talc and chlorite schists, apatite occurs in well formed transparent crystals filling druses and clefts.

This is due to lateral secretion.

In the volcanic breccia of Monte Somma apatite occurs partly as an original magmatic deposit and partly as a result of secondary pneumatolytic action.

It is commonly associated with metaliferous veins. In the case of pneumatolytic tin deposits, apatite is an almost constant associate of cassiterite, wolframite, mispickel, fluorite, topaz and zinnwaldite. It is found with tin ores in Cornwall.

In granular, partly metamorphosed, limestones

in ...

in the neighbourhood of magnetite and other iron ores it occurs in small veins and pockets, sometimes in giant crystals e.g. Norway, Finnland, Canada, New York, New Jersey, etc.

Most metamorphosed limestones contain a certain percentage of apatite crystals, e.g. Lulu Kop in Northern Transvaal where the crystals form in places as much as 10% of the rock.

__Phosphorite__. The more heterogeneous phosphorite is of much greater importance commercially than actual Apatite, because it occurs in much greater quantities and is more easily mined. To be of any commercial value, phosphorite should contain 40% tribasic Calcium Phosphate. But so much high grade rock is available, that the standard demanded by manufacturers and consumers is very high.

Lower Grade 50 - 60% Tribasic calcium phosphate
Higher " 60 - 80% " " "

Apatite dissolves with difficulty in water, and is usually converted into superphosphate by treatment with weak sulphuric acid, before being sold.

$$Ca_3(PO_4)_2 + 2\,H_2SO_4 = \underbrace{(Ca\,H_4(PO_4)_2 + 2\,Ca\,SO_4)}_{\text{Superphosphate of Commerce}}$$

$CaCO_3$, Fe_2O_3 and Al_2O_3 are common impurities. The last two are especially detrimental to manufacturing processes. Phosphates are therefore usually sold under a guarantee of not more than 4% of these impurities.

Phosphorite ...

Phosphorite occurs in diverse geological formations, in schists, sandstones, limestones, marls, dolomites and chalks. Metosomatic deposits, concretions and spring or marine deposits are common. The rock may be of organic or inorganic origin.

The principal deposits are in the United States, North Africa and certain Pacific Islands.

1. The most important type forms extensive beds replacing limestone in sedimentary deposits, e.g. The United States (Florida Tennessee, and Western States), the North African (Algeria, Tunis, Morocco and Egypt, the Palestine deposits) and several minor ones.

The United States produces 2/5 of the world's supply, but most of it is used in the country. In Florida the deposits are of two kinds, (a) hard rock phosphate of Oligocene age in huge irregular masses embedded in a matrix of sand and clay. The whole is underlaid by a bed of limestone. The phosphorite is guaranteed to be 77% tribasic calcium phosphate. (b) land pebble phosphate of Pliocene age. This is a collection of phosphatic pebbles embedded in the same matrix as (a) and probably derived from it by denudation and re-distribution. The Florida deposits are believed to be due to secondary enrichment.

In Tennessee, brown and blue bedded deposits occur in phosphatic limestone of Ordovician and Devonian age, which are probably due to original sedimentation.

In ...

In the Western States, important deposits occur in Idaho, Utah and Montana, in limestones of Carboniferous and Permian age. The Idaho phosphorite is oolitic and of tremendous extent, thousands of millions of tons being held in reserve.

The North-African deposits are next in importance. These occur in a belt running from the Atlantic to Asia Minor. The Morrocan, Algerian and Tunisian deposits lie chiefly on the Northern slopes of the Atlas Mountains, and they are continued Eastwards in Cyrenaica in some low grade beds which lie nearer than any of the others, to the sea; These are followed by the Egyptian, and finally the Palestinian deposits.

In several parts of this belt the difficulty of transport has made mining impossible.

In Algeria the deposits are in Upper Cretaceous marls and Eocene limestones. The chief workings are near Tebessa, where phosphorite occurs in basin shaped deposits composed of five separate beds of which three are workable. The thickness of the beds varies from 1½' - 9'. Vast resources exist.

In Tunis, which produces, after Florida, the greatest amount of phosphate in the world (more than two million tons in 1913), the deposits resemble closely the Algerian. The phosphorite occurs as extensive lenses up to 10' thick in middle Eocene rocks.

At ...

At Gassa, the chief mining centre, the phosphorite rock averages 60% tribasic calcium phosphate.

In Egypt the chief occurrence is in the Safaga district near the coast of the Red Sea. The Beds form part of the infilling of a basin-shaped depression in older rocks, the deposits themselves being of Upper Cretaceous age. They are interlaminated with grey clays and chert beds. There are several other fairly extensive beds in the Nile Valley.

In Palestine, very extensive deposits are found in the neighbourhood of Es Salt, east of the Jordan Valley. Here two types are found

(a) Plateau deposits extensive and thick, as much as 10 metres, averaging 4% tribasic calcium phosphate;

(b) Rock deposits averaging 66% but carrying up to 83%.

Minor occurrences of bedded type are found in New Zealand in the Milton district, and in Germany near Nuremburg. This latter is the only source of phosphorite in Germany, although that country was, before the war, the biggest manufacturer and consumer of superphosphate.

The second important type is connected with Guano deposits. In regions of heavy rainfall, phosphatic matter is washed out of the Guano into the

underlying ...

underlying rocks. Where these are of coral limestone, they are almost entirely metasomatised into phosphorite. The main occurrences are:-

Ocean Island, one of the Gilbert Islands where the rock is of very high quality. On the central table-land the phosphatic deposit is 50' deep and averages 85% tribasic calcium phosphate.

Nauru Island. Phosphorite occurs in surface deposits, scattered over the whole interior of the island. The underlying rock, hard coral limestone, has been in places much denuded. It remains standing in high pinnacles between which lies a deep layer of phosphorite averaging 85-86%. This deposit holds 80-100 million tons in reserve. These vast supplies have only to be quarried and transported in lighters to ships.

Assumption Island, in the Seychelles, and Christmas Island, 190 miles south west of Java in the Indian Ocean, have similar deposits, averaging 80%.

The third type, beds bearing phosphatic nodules, at one time furnished great supplies, but now is of little importance. These were chiefly European occurrences. In the United Kingdom, in the Upper Greensand at Cambridge, there is a bed, 8-12" thick, of dark brown nodules of calcium phosphate. In Suffolk a similar bed 12-18" thick was mined for some time. In Belgium phosphatic nodules occur in clay, and as phosphatic chalk in Cretaceous and Tertiary rocks.

In ...

In France, similar low grade phosphate is found, but now is only used loc[illegible] as the French practically control the North African deposits.

In Canada, in Quebec and Nova Scotia, coprolitic beds are worked, and in Manitoba and Alberta, low grade hard black phosphate occurs.

In India near Pondicherry, a bed of black phosphatic nodules is worked in Cretaceous rock; at Trichinopoly in the United Provinces, nodules of phosphate and phosphatic rock occur in a band of shale at the base of a chert bed. The latter occurrence is of higher grade than is usual in this type of deposit, carrying as much as 75% tribasic Calcium Phosphate.

Small quantities of high grade phosphate are obtained from caves and some oceanic islands in the form of guano, but do not effect world supplies.

Occasionally Greensands containing much glauconite, a hydrated silicate of iron and potash with a certain amount of phosphatic water, are used as a source of phosphate.

Massive aluminium phosphate occurs in appreciable quantities on the Island of Redonda in the West Indies, and at Saldanha Bay, Cape Province.

South Africa has very few phosphate resources. Vast tracts of the land are of use only for agricultural purposes and the deficiency of phosphate

is ...

is therefore a serious problem.

The Saldanha Bay deposits are the most important. They occur on parts of the Peninsula which were at one time islands inhabited by sea birds. Both phosphorite and aluminous phosphate are found here. The phosphorite occurs on the southern side of the Peninsula and is the result of the phosphatization of boulder bearing shell breccia by solutions from guano accumulations. The average percentage of tribasic calcium phosphate is about 77%. The deposit is not very large and is attended by great mining difficulties; for these reasons it is not used.

The aluminous phosphate deposits occur in two places, (a) on Hoedjes Bay peninsula, and (b) on Oude Post, on the Southern Peninsula. The former is due to the phosphatization of granite debris, and in part granite itself, from which the Alumina is derived. It is dark brown in colour and is fairly extensive. It will probably be found to be continuous along the whole raised beach area. The highest P_2O_5 content hitherto discovered has been 28.37%. (b) This deposit is much larger than (a). It is harder and contains more quartz, but has a higher P_2O_5 content - 32.63%. The origin is essentially the same. Phosphatic deposits have been

reported ...

reported from various parts of this coast, and may prove of value.

Other deposits occur in the neighbourhood of Weenen, where small quantities of phosphate occur in impure limestones interstratified with Karroo shales. The P_2O_5 constitutes only about .5% of the rock so that it is ofno value except locally.

At Lulu Kop in the Northern Transvaal, a small percentage of apatite crystals occurs in metamorphosed limestone.

Phosphate deposits are known to occur also in South West Africa at Cape Cross, North of Swakopmund, in the Kuruman and Kenhardt Districts and in Bird Island, Algoa Bay.

None of these is important.

PLATE II

Fig 1 View looking due north from Matulas Kop towards Zoutpansberg

Fig 2 View looking due south from Matulas Kop over the valley of the Thousand hills

Fig 3 Valley of the Thousand Hills. Phosphate workings are to the right in middle distance

Fig 4 View looking South East from Matulas Kop towards Low Country

THE PHOSPHATE DEPOSITS NEAR BANDOLIER KOP.

The largest deposit of apatite known in South Africa is the property of the S.A.Phosphate Exploration Syndicate, Ltd. They own 15 farms in a belt of country running E-W, east of Bandolier Kop, on the Pietersburg-Messina Railway. See Map. The farms are:-

Vliegen Pan	2623,
Diepgezet	2613,
Matschappe	865
Kruisfontein	510
Spelonk Water	927,
Zwartfontein	135,
Zekoegat	1375,
Schaapkraal	2622,
Sypherfontein	2619,
Middlefontein	176,
Mahilashoek	2546,
Uiteschut	2616,
Driefontein	16,
Duikershoek	1631,
Rossbach	1798,
Grootfontein	17.

Apatite has been reported from all of these but only three have been actively exploited.

PHYSICAL FEATURES.

The 3 farms referred to adjoin one another and are Spelonkwater (927); Schaapkraal (451); and Mahilashoek (439). Spelonkwater is about 7 miles from Bandolierkop Station in an E.N.E. direction on the Main Road from Bandolier Kop to Elim, which passes the North boundary of all 3 farms. (see map).

The most prominent feature in the district is Mahilas Kop, on the top of which the beacon marking the junction of Schaapkraal and Mahilashoek is placed. From this Kopje a very extensive view of the country for many miles in all directions is obtained.

Looking northwards from this kopje the country stretches flat and bare. A few small but prominent kopjes

are ...

are the only relieving features. These are probably gneissic, like Mahilaskop itself.

This flat stretch is ends about 15 miles to the north where the Zoutpansberg form a prominent range running E-W. This range is the escarpment of the hard Waterberg quartzites. The town of Louis Trichardt lies almost due north at the foot of these mountains. See Plate II fig.1.

Towards the West the plateau stretches unbroken but there are more kopjes of which Bandolier Kop is one.

In the S.W. the country begins to break up and becomes more and more irregular towards the S.E. The hills and valleys fold into one another as far as the eye can see. This feature is so pronounced that it is known as the Valley of the Thousand Hills. The Klein Letaba river runs from W-E through the region, and its tributaries are responsible for dissecting the country to this extent, for on either side, furrows have been cut from the hills down to the Letaba (See Map and figs 2, 3 and 4 on Plate II).

As might be expected there natural drainage has determined the topography, the trend of the geological structure has been masked, but a certain parallelism of chains of hills ~~in~~ from W.S.W. to E.N.E. indicates that the gneissic bands run in that direction. Judging from their similarity in outline to Mahilaskop the loose boulders which cap several of the highest points are gneiss.

Eastwards from ~~Matules~~ Mahilas Kop although only hilly country is visible, the altitude decreases rapidly towards the low country. Generally the valley is enveloped in mist in the morning and evening so that even the highest among the thousand hills is invisible. It is part of the mist belt, the high rainfall of which is responsible for the varied relief.

The ....

The phosphate deposits lie S.S.W. from Mahila's Kop in this transition zone between the plateau andlow countries. This zone is increasing in size. At present a line drawn E-W through Mahila's Kop is roughly the watershed although it does not form a conspicuous ridge. The streams however which flow to the south are far more numerous and the gradient steeper so that they are beginning, by head erosion, to capture those which now wend their way in shallow depressions across the almost flat plain towards the north.

The vegetation is determined by the amount of water. The thorn tree is conspicuous everywhere but along therivers courses a more luxuriant type flourishes. Scattered euphorbia trees, large flowering trees and numerous creepers introduce thetvariation in scenery which is so lacking in the Bushveld farther south.

GENERAL GEOLOGY.

Unlike the occurrences of sedimentary phosphate which furnish so large a percentage of the world's supply of phosphate and which occur in comparatively young rocks, the N.Transvaal apatite occurs associated with the oldest rocks of S.Africa. The distribution of the rocks and the direction of schistosity and banding in them indicate that the structural trend of this part of the country is from E.N.E.- W.S.W.

South of theZoutpansberg, which is the escarpment of Waterberg quartzites closing the area to the North, lies a broad belt of gneissose granite, granite and gneiss. The rocks show different degrees of banding andof weathering. Dr.A.L.Hall, in describing them in his Memoir on Corundum in the N. and E.Transvaal, suggests the possibility of a

difference ...

PLATE III

Fig I Sketch Map of Phosphate Farms

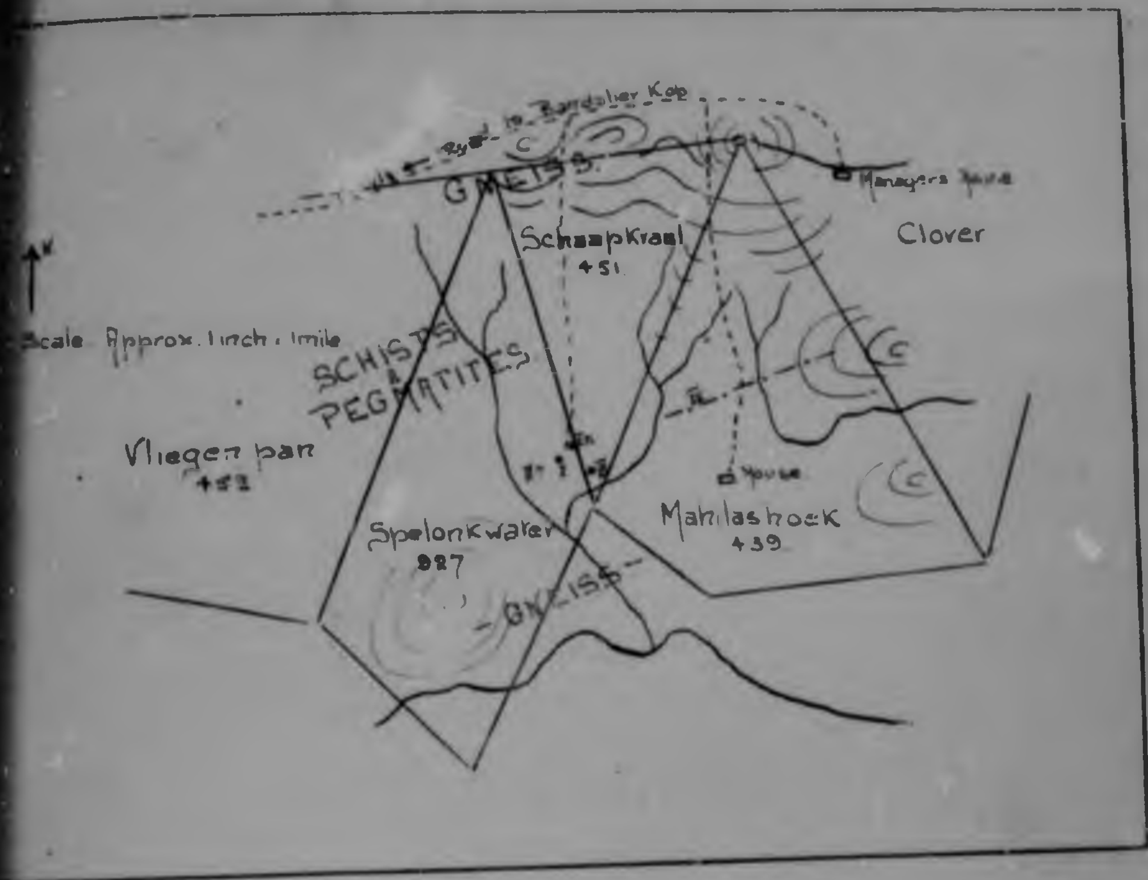


Fig 2 Diabase Dyke cutting across older formation (see page)

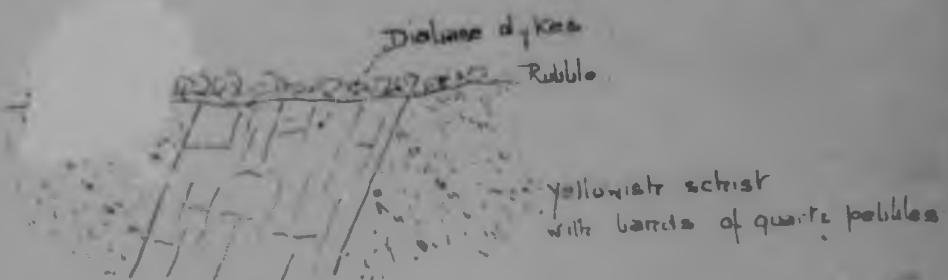


Fig 3 Granite Kopje between Pietersburg & Bandolier Kop

difference in age, and that the massive granite is intrusive into, and consequently younger than, the banded greissose rocks. All these granitic rocks however, are at present classified as "Older Granite" formation. Both the massive granite and the gneiss in places, form Kopjes.
the massive granite and the gneiss in places, form Kopjes.
Mahilaskop and the other smaller Kopjes in the neighbourhood of the phosphate mine are composed of gneiss of very dark, coarse nature. This will be described later in detail. Large lichen-covered boulders, quite fresh inside, cap the Kopjes. On Plate III. fig.3 a photograph is given of a granite kopje a few miles south of Bandolier Kop. In appearance it differs vastly from the gneissic kopjes.

South of this belt which ends in the neighbourhood of Mahila's Kop, lies a zone of basic schists, interleaved with coarse pegmatitic veins and occasional bands of hard gneiss. The strike of these rocks follows the structural direction, i.e. E.N.E. - W.S.W. as does the banding in the individual layers. The dip is towards the North at varying angles. It is in this complex belt that the phosphate occurs, associated with pegmatite veins. The belt is from 2-3 miles wide, and is flanked to the South by gneissic formation. Numerous diabase dykes have been intruded into the rocks already mentioned and run in various directions, E-W, NE-SW and SE-NW. These are very uniform in character, being fresh, fine grained, bluish-grey rocks with very marked jointing, which gives them a slatey appearance. In the bed of the stream, south of the main phosphate occurrences, this dyke rock is well exposed, for the stream crosses a large dyke several times. In a shallow trench in No.I working a small dyke cuts across the banding of the other formations (See Plate III fig.2.).

These ...

These dykes as a rule, form straight ridges, but in Mahilas Kop vicinity none of those noticed were more than a few feet above the general level of the country. According to Dr.A.L.Hall they are probably of Post Transvaal age.

The Schists were unfortunately only studied in the phosphate workings. No other exposures were seen. In these localities they must have been effected by the pegmatite intrusion.

Pegmatite. The pegmatite veins, although very much fresher than the older granite, in all probability represent the last phase of that intrusion. Their distance from the Palabora Plutonic Complex with which the very coarse mica-corundum bearing pegmatite is associated, is too great for a connection with it to be probable.

Apatite occurs chiefly in pegmatite as bands of massive apatite or as perfect hexagonal crystals embedded in a white very porous rock which proved to be chiefly barium sulphate and which itself occurs as lenses and veins in the pegmatite. Another important source of phosphate is the zone of mixed rock, made up of more or less equal proportions of felspar, apatite and schist which usually lies between the apatite-bearing pegmatite and green schistose rock.

It is necessary to give a general sketch of the rocks which characterise these deposits, though a detailed description will be reserved until later. They fall into 4 groups:-

A. Pegmatite:	(i)	Normal graphic,
	(ii)	Phosphatic.
B. Porous Rock.		
C. Schist:	(i)	Hornblende,
	(ii)	Mica.
D. Phosphatic Rock.	(i)	Mixed Rock
	(ii)	Massive Apatite.

A. PEGMATITE.

(i) Normal Pegmatite is usually a graphic intergrowth of pink and white feldspar with quartz. Apart from cloudiness in the feldspar the rock is fairly fresh. It is never seen in direct contact with phosphate.

(ii) Phosphatic Pegmatite: This, as a rule, is not graphic but is a coarse-grained aggregate of dark grey-blue quartz and feldspar, which shows alteration in several respects. This is evident chiefly in the colour which instead of pink or white, is buff or mauve, sometimes deep purple, or bright green on cleavage faces. This pegmatite is always found near phosphate. It is still a compact rock, despite the alteration. On analysis the presence of phosphate is always found, though not in large quantities, was usually 3%.

B. POROUS ROCK.

This is an extraordinary rock. It has the appearance of being an aggregate of skeleton feldspar crystals which had been kaolinised. It is very white but iron oxide has been deposited in the hollows causing the red and white granular rock to bear a marked resemblance to bauxite. The rock is, as might be expected, very friable and crumbly. It carries large, well-formed, hexagonal crystals of Apatite. On analysis the rock was found to be chiefly barium sulphate with some calcium sulphate.

C. SCHISTS.

(i) A soft, greenish-yellow, friable schist, composed chiefly of hornblende, occurs in large bodies near phosphate.

(ii) A Mica Schist composed mainly of flakes of biotite and altering hornblende often carries a large percentage of decomposing feldspar and quartz grains, in definite layers. It adjoins normal pegmatite and

represents ...

represents an absorption of pegmatitic constituents by schist. (i) and (ii) are probably different manifestations of metamorphism of the same rock.

D. PHOSPHATIC ROCK.

(i) Mixed Rock. This is a mixture of pegmatite, apatite and schist in varying proportions. It is found in endless varieties of texture colour hardness etc. Sometimes the porous rock contributes to the aggregate.

(ii) Massive Apatite.

DESCRIPTION OF THE WORKINGS:

The chief occurrences are on the 3 farms, Spelonkwater (927); Schaapkraal (451); and Mahilashoek (439), which were the only ones examined. (See Plate III fig.1.)

The largest working is on the farm Spelonkwater. It is called No.I and is on the E slope of a kopje. This is a small open working about 10'0" deep, with several trenches radiating from it. On the E wall of which a body of massive apatite is exposed with pegmatite foot wall and schist hanging wall. It is several feet thick and dips steeply to the North. A vertical shaft 33' deep has been sunk in this open quarry, and at its base an irregular 50'0" drive has been cut towards the North and a smaller one to the South. See Plate IV fig.1. The walls of the shaft are composed entirely of decomposing normal pegmatite, except at the base where the southern drive cuts through a body of schist. The latter shows perfect spheroidal weathering, due to metamorphism by the surrounding pegmatite (See Plate IV figs 2 and 3).

The 50' Northern drive is cut chiefly through schist with bands of pegmatite and low grade mixed phosphate rock. Stringers of fairly pure apatite occur also in the hornblende schist. Barium sulphate rock occurs in isolated small patches in the pegmatite but always near to a body of apatite. It is not found in big zones here as in No.III working.

At the end of the drive a thick body of massive apatite, about 5', is intersected and another shaft 15'0"

deep ...

PLATE IV

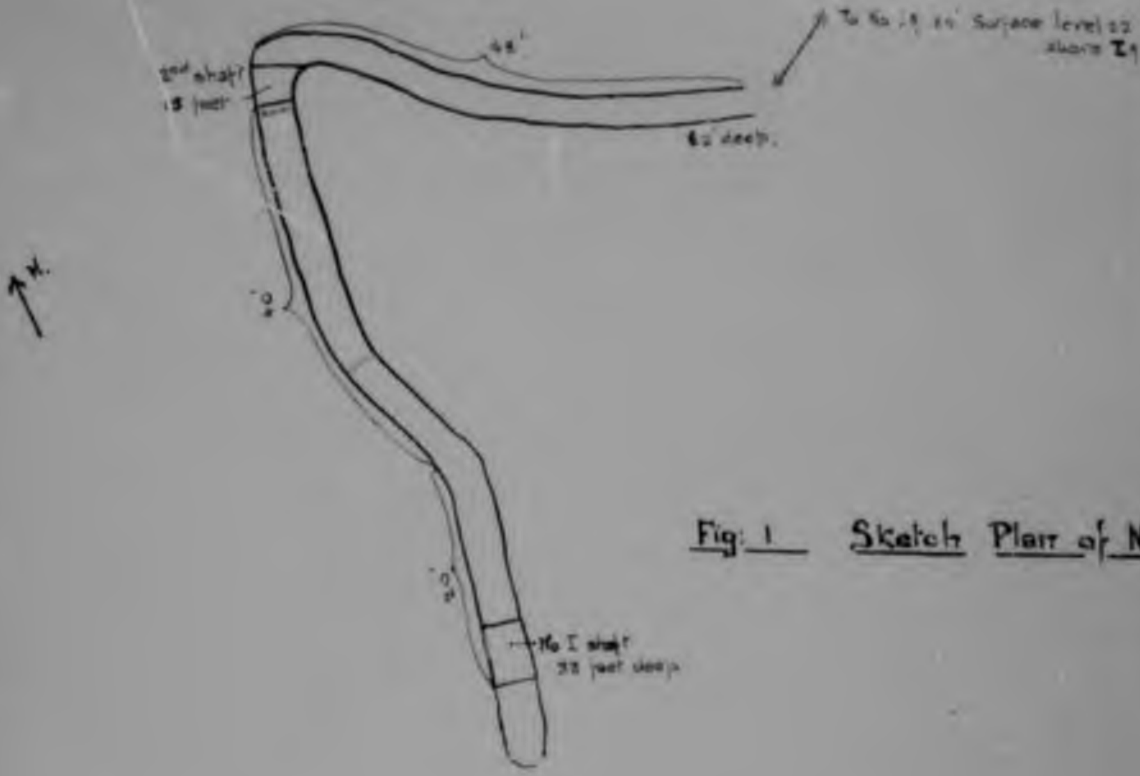
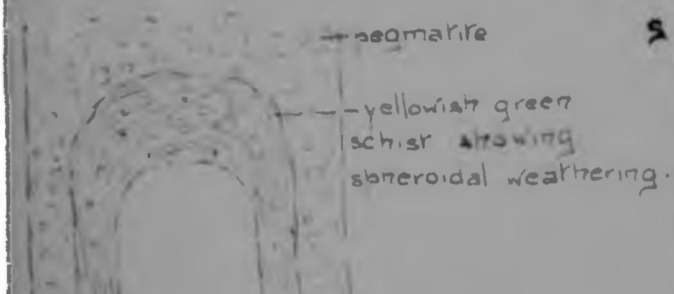


Fig: 1 Sketch Plan of No I



Face of Southern drive
base of No I shaft Body
schist included in pegmatite

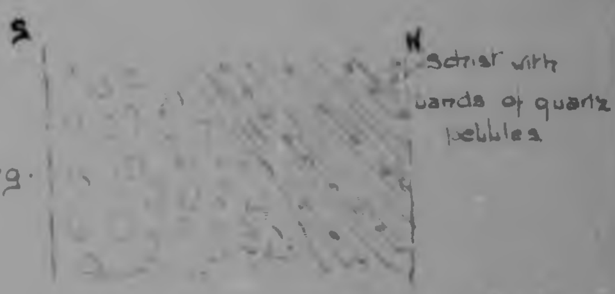
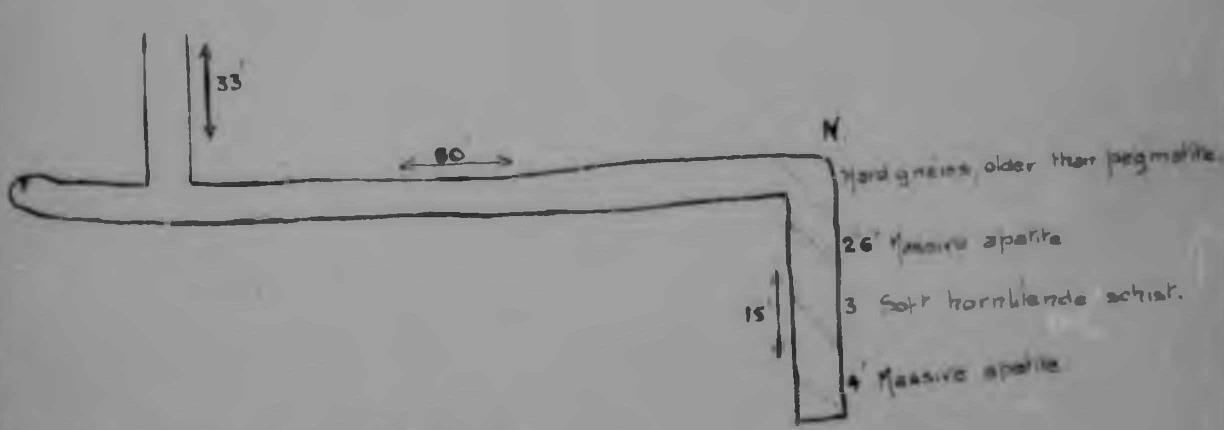


Fig 3 Section of same body
Note parallel arrangement of quartz pebbles



4 Rough Section of No I working

deep has been made in order to follow it at a lower level. From the base of this second shaft a drive, approximately 48' 0" along the strike, has been cut. A sketch of the second shaft is given to show the occurrence of massive apatite (Plate IV fig.4) -- The gneiss at the top of the 2nd shaft is identical with that which forms the summit of the Kopje on the slope of which the working is situated, and is similar also to the gneiss of Mahilas Kop. It is slightly coarser grained and with a much higher percentage of biotite than the other. (A description of these will be given later) -- This phosphate body is probably that which is exposed in the quarry above. Although it is farther North than would be expected from the dip shown at the surface, This variation in the dip is very characteristic of all the phosphate bands, in most of them it ~~the dip of which~~ increases and decreases most irregularly. This, however, is to be expected in deposits whose distribution is determined by pegmatite bodies which are always uncertain. These branch thin out or change their direction frequently. In the workings under discussion however the pegmatite bands maintain in general a Northerly dip.

About 130'0" to the North-east of No.I, another vertical shaft called IA is being sunk, At a depth of 112 feet it cuts what is probably the main apatite bed. The rocks immediately above the phosphate are the characteristic accompaniments of apatite, namely - 15" phosphatic pegmatite, then 2" mica schist, composed of small flakes of very dark brown biotite, then a thin band of mixed rock (schist pegmatite and apatite) followed by pink and green massive apatite with small inclusions of schist.

Another shaft (No.II), has been sunk 150' West of No.I, but this was not examined. It is reported that in this

working ...

PLATE V

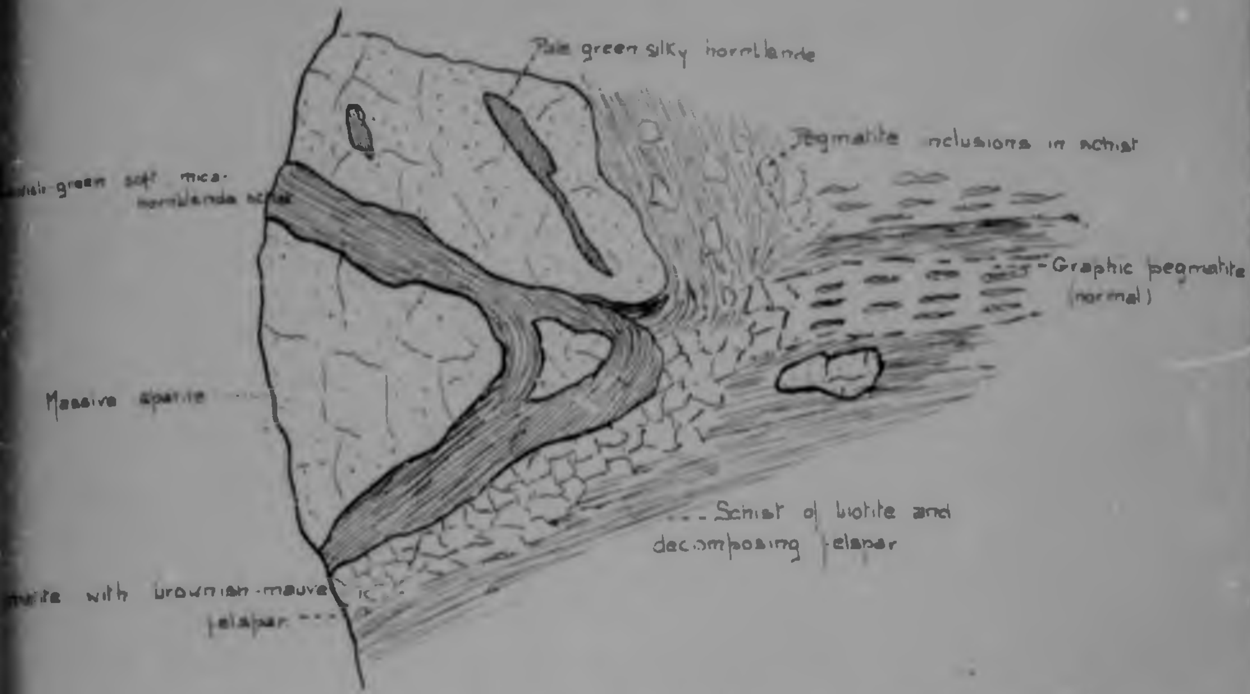


Fig 1. Diagramatic sketch of jutting wall of small quarry at the top of No I shaft showing the relationship of apatite to schist and pegmatite.

working two bodies of phosphate rock about 8' thick are out. The material from all these workings forms several large dumps. Some very interesting specimens of various rock types were found on these.

The relationship of massive apatite to the other rocks is well shown in the open working above No.I Shaft (See Plate V fig.1). Here large bodies of massive phosphorite are surrounded by a hornblende schist carrying a little mica, in which the schistosity followed the outline of the phosphate body. Immediately below this yellowish green schist is a band of phosphatic pegmatite which passes into normal graphic pegmatite a short distance from the phosphate inclusion. The pegmatite in turn is underlain by schist composed chiefly of very dark coloured biotite with a large percentage of decomposing feldspar.

Where pieces of schist have been included in the phosphate they have been converted into large, pale-green, silky hornblende crystals; the same alteration to hornblende occurs in several inclusions of schist in phosphatic pegmatite. Some such pieces were 6" square and formed apparently one crystal; there is no parallel arrangement of these large hornblende crystals. It is significant, however, that where schist is embodied in ordinary pegmatite or borders pegmatite zones, biotite becomes very prominent. At the margins of pegmatite bodies the process of alteration from hornblende to biotite is often noticeable. The effect of metamorphism is not so complete where the inclusions are large. In such cases the alteration is similar but limited to the margins. The pale green hornblende weathers to bright yellowish green.

In one of the trenches leading out of the quarry, bands of fibrous barium sulphate rock underlie a mixture of schist,

with ...

with fresh feldspar and small pieces of the sulphate rock. This vein is only a few feet above a massive apatite band. The presence of barium sulphate rock is always indicative of the proximity of apatite, and in many cases it encloses apatite crystals. In No.I, this rock is not as important as in No.III, a working further south, where it occurs in large bodies and carries the best apatite crystals.

A feature of the graphic pegmatite in the main excavation is the E-W direction of the layers of quartz and felspar; following the bedding planes.

No.III.Working. Perhaps the most interesting occurrence is on the Southern slope of a hill South of the main workings at Nos. I, Ia, and II. This is known as No.III. (See Sketch Map on Plate III). Its chief feature is a tunnel driven 240'0" into the hill-side. It is 7'0" high and 5'0" wide, and curves quite considerably, so that day-light is cut off almost immediately. The occurrence here of apatite, differs from those already described in several minor features. More time was spent in the examination of this working than on any other, as its length made possible a more extensive study of the features characteristically accompanying both crystal and massive apatite.

Immediately above the tunnel a trench has been dug, and from the walls of this it was at once evident that the pegmatite and the associated phosphate rocks behaved erratically in this area. The beds undulate, vary in thickness, and are in every sense more irregular than at No.I.

At the head of this trench, i.e. at North Wall, a pocket of barium sulphate rock carrying good apatite crystals, is exposed. Unfortunately, the photographs of this and of the undulating pegmatite in the same trench, are failures, and

A ...

PLATE VI

No III Working

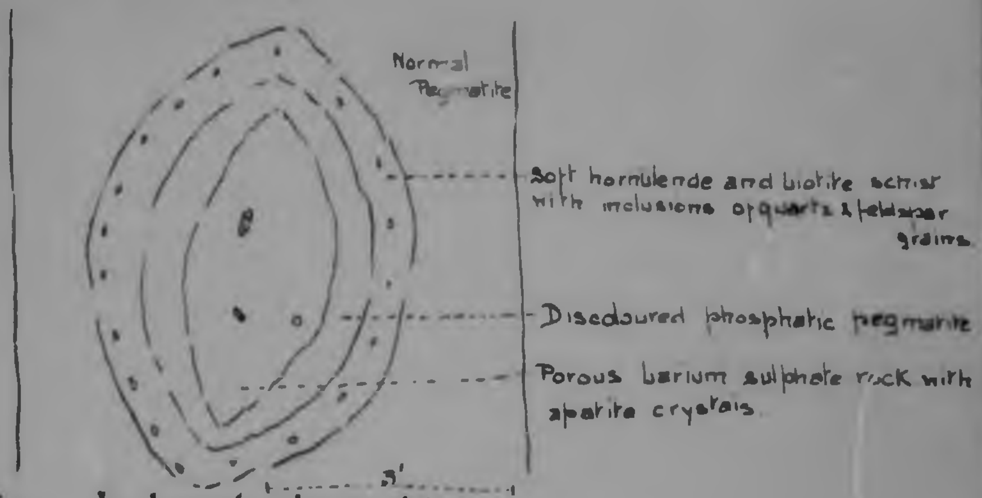


Fig 1. In trench above drive

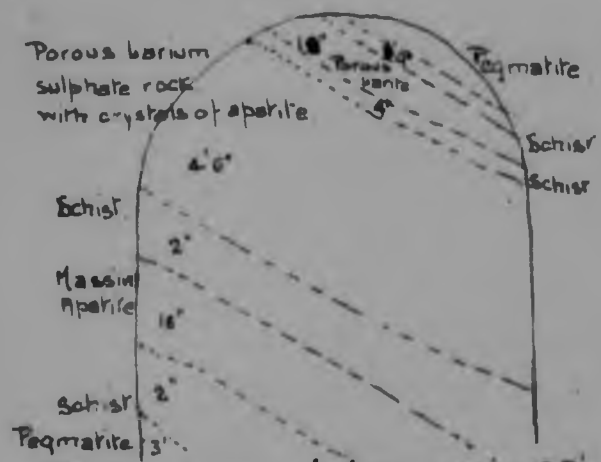


Fig 2 Section between 94 & 128'

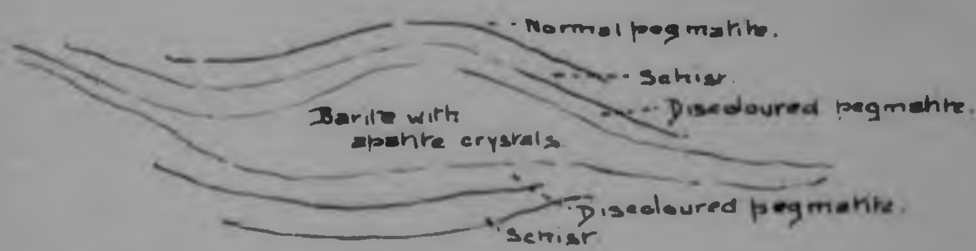


Fig 3. East wall 170 - 209'

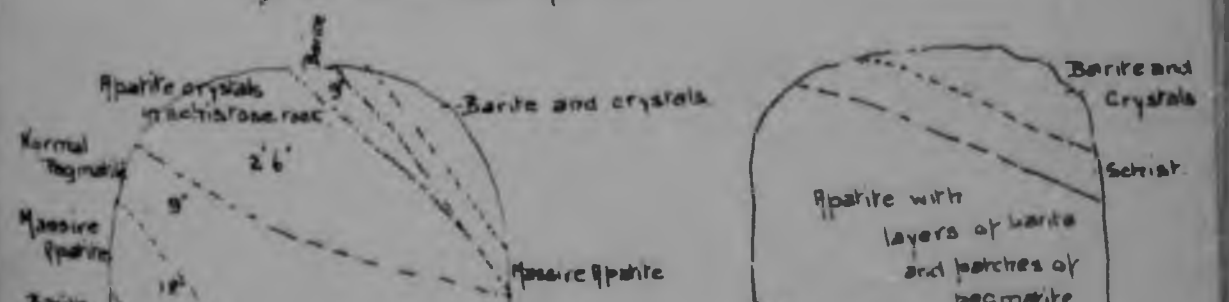


Fig 4. 'a'. 225' 'b'. Section at 230'

a rough diagram made to annotate thephotograph, is therefore the only record.

The order of the contact rocks is that which is believed to be constant in all deposits, so it is reproduced in Plate VI fig.1. In the drive itself an attempt was made to follow the order of rocks from the mouth to the end, noting their dimensions, with a view to determining to what extent the relations of associated rocks are constant. At various places cross sections were measured, and sketched, and notes made on the longitudinal distribution of the rocks. These are given below. The notes on the latter would have been of more use had a constant direction been maintained in cutting the drive. Where not otherwise stated, the same conditions, though naturally with different dimensions, prevailed on both walls of the drive. The measurements are not claimed to be absolutely accurate, because the light was too poor to distinguish actual margins but the existence of type rock is definite. 0'-94' West Wall Isolated boulders of oxidised pegmatite in soft yellowish green schist which dip N at very shallow angles 0'-94' East Wall. Ordinary pegmatite with a few lenses of barium sulphate rock in which no apatite crystals were seen. 94' - 128'. See Plate VI fig 2 ~~(See Fig. XIII)~~. In the sulphate rock very large apatite crystals (Hexagonal prisms terminated by pyramids), occur. The thickest one seen was 6" in diameter, and the longest one followed was 2'6" and still continued into the wall. Owing to the easy basal parting it was impossible to get more than a few inches of the crystal without breaking it. There is no doubt that crystals of a much larger dimensions will be found if they are sought. The 2'6" crystal was seen in the East wall at 127'. It was only 1½" in diameter.

140'. ...

140'. Here sulphate rock carrying apatite crystals, occurs in lenses up to 18" wide and up to 4' long. It lies between bands of schist.

170'-209'. A very large lens of barium sulphate rock is visible on theEast Wall. It is probably a vein which has not been followed directly, and so appears tothin out on the foot-wall at 170' and in roof at 209'. (See Plate VI fig.3)

225' (See Plate VI fig.4). This section is typical of the conditions which prevail from 211' to 230' where a thick phosphate band is visible in the footwall 3'6" and on the hanging wall 4'6". At first these were thought to be identical. A closer examination however revealed thinner outcrops of similar rock on either wall so that a more normal explanation seems to be that the west wall and footwall outcrops represent one vein and the hanging and east wall another. The position of these four outcrops is not always constant for at times two of them merge into one another (cf. Plate VI fig.4 ~~and Plate VII fig.1.~~) The phosphatic band is solid apatite in places and barium sulphate rock bearing apatite crystals at others. Quite frequently veins of the crystal bearing rock traverse the massive apatite.

230' - 237'. A cross cut has been made which extends for several yards on either side of themain drive but does not cut thephosphate veins. See Plate VII fig.2.

237' - 240' Discoloured pegmatite passes into normal graphic pink and white pegmatite. The drive tends eastwards and so loses the phosphate vein which continues in the west wall (See Plate VII fig.1.)

The strike of this phosphate vein is apparently S-N and the dip sometimes vertical and sometimes steeply eastwards.

The other sections drawn all seem to bear out this steep eastward tilt of the phosphate veins in thelatter

portion ...

portion of drive, and the only explanation possible is that in No.III working the phosphate, instead of being in thick beds following the pseudo-stratification, due to pressure lines, of the country rocks, is in a vein running irregularly across the schistosity, maintaining no consistency of thickness or of direction save in a general way N.

They are therefore of a different type from the thick beds at No.I working and will probably be found to be most erratic in their manner of occurrence and in the thickness and quality maintained. Veins of this nature in Canada and Norway often die out suddenly.

Just north of No.III, a few trenches have been cut from E-W, and in these the same conditions prevailed. The phosphate bands were not followed out along the strike as might have been expected from an E-W strike, but were cut across and seen to be dipping E. The Monazite bearing vein just W of No.III, which will be referred to later, was followed Northwards for several yards along the strike. In several respects, however, the phosphate occurrences of these two hills differ, and this difference in the manner of injection at No.I and No.III may possibly account for them.

TRENCHES WEST OF NO.III.

In the vicinity of No.III drive there are quite a number of shallow surface workings; all were examined but only three deserve special mention (see Plate VII). The first is a small circular hollow about 6' deep and 10' to 12' in diameter, which has been excavated where a pocket of barium sulphate rock outcropped. In this loose material numerous apatite crystals are embedded. (See Plate XIII fig.3). The crystals are very varied in size, colour - red, green and white being found - and even in shape. Although all are hexagonal prisms, they have been subjected to

pressure ...

pressure which has effected them in different ways. A feature of all the apatite crystals is the inclusion of numerous long, thin, yellowish needles which were identified as monazite. The crystals will be described in detail later. There is no arrangement of these long apatite crystals in any particular direction for they lay h rizontally, obliquely or vertically in a most irregular way. It is curious that the apatite prisms should all exhibit signsof pressure, some twinned, others twisted, many broken and then rejoined, whilst the rock in which they lie is so soft and porous. It is obvious that the porosity must have been subsequent to the solidification of the crystals.

The second working, to which special attention was paid, is a trench of varying depths which has been dug in an S.W-N.E direction just N.W. of No.III, and offers a good cross section for comparison (See Plate VII).

1-10' is normal pegmatite dipping E at 45°.

10-15' is soft greenish schist.

15-25' is the same schist with several quartz stringers, about 2" wide lying parallel to the junction of pegmatite and schist.

25-30'. Here an abnormal lense of massive apatite lies horizontally between bands of pegmatite. The pegmatite above and below grades into the phosphatic pegmatite which surrounds the lense of apatite. The latter is traversed by small stringers or bands of schist and phosphatic pegmatite.

30-40' is soft schist which, near the junction with the phosphatic rock includes several bodies of massive apatite. The schist is far more micaceous than that in the west of the trench. It contains much dark biotite and includes several bands of phosphatic pegmatite.

40'-45' is mixed rock, (schist, apatite and feldspar)

underlain ...

PLATE VII

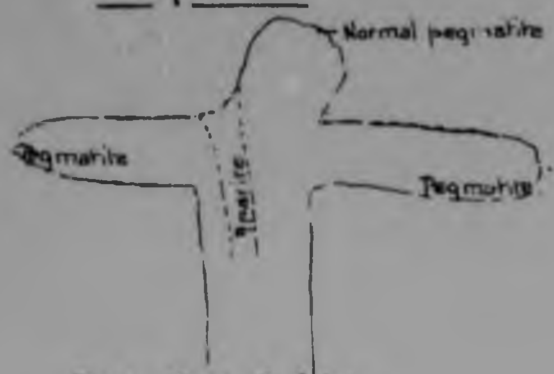


Fig 1. Head of drive.

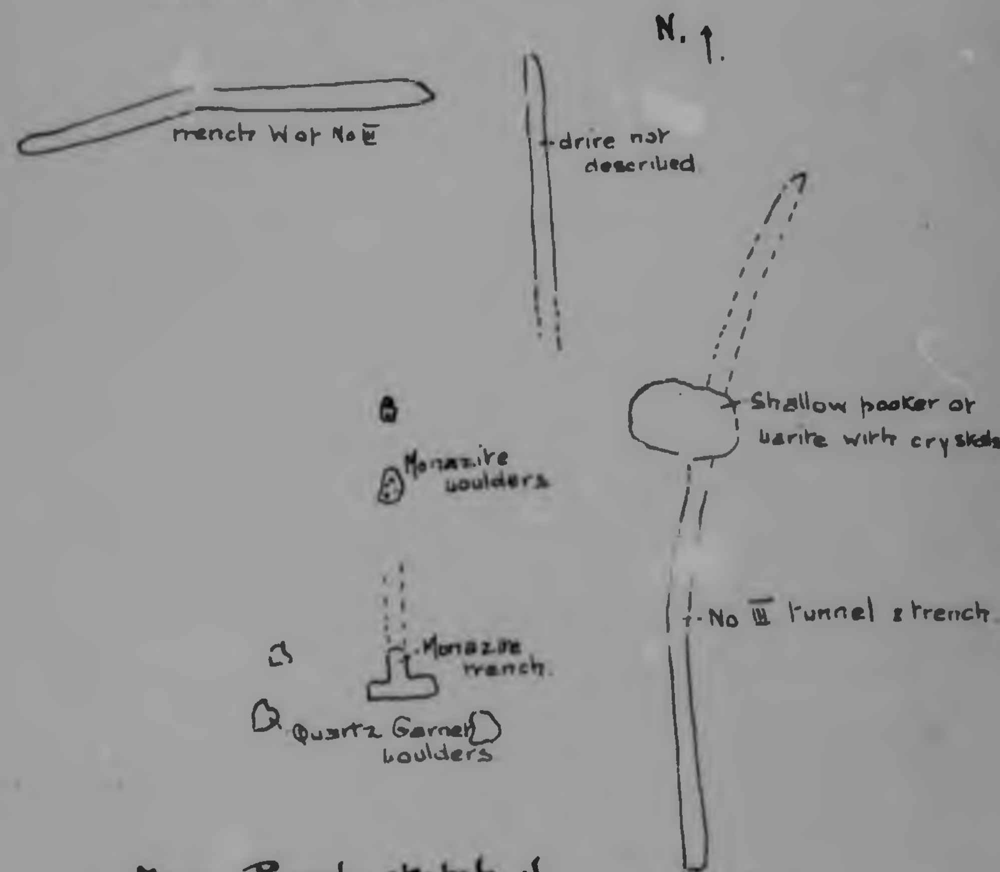


Fig 2. Rough sketch of position of workings near No III on the southern slope of a hill south of No I main mine.

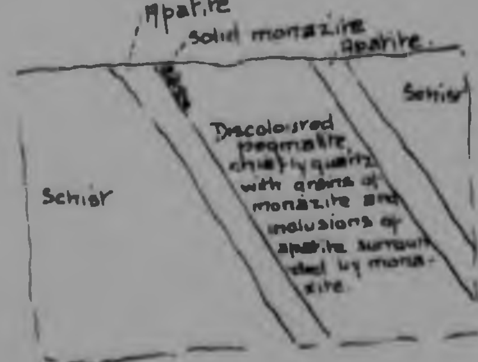


Fig 3. Sketch of monazite trench.

underlain by a wedge of pinkish apatite.

45'-50' is schist with inclusions of phosphatic pegmatite.

50'- 53'. Here bands of pegmatite and schist dip westwards. Stringers of massive apatite run into the schist at the contact. This synclinal structure may be due to original undulation or to the surface collapse of the schist body which now lies between the two apatite arms.

53'-58' Schist with interbedded bands of pegmatite still dipping W.

58'-63' Here a small body of massive apatite is embedded in phosphatic pegmatite which gradually gives place to graphic pegmatite

63'-85' is soft schist. ~~It will be seen that~~ The bedding here is very irregular.

The 3rd workingis much smaller but of specialinterest. In a small excavation about 3' deep, 30 yards west of No.III, a narrow pegmatite dyke about 2' wide is exposed (See Plate VII fig. 5). It cuts through greenish schist and is bordered by a thin layer of massive apatite. Throughout this pegmatite body, grains of dark brownish red monazite are scattered, sometimes irregularly, sometimes in bands. The latter are associated with apatite and several pieces were noticed where an irregular fragment of apatite was surrounded by a dense aggregate of monazite grains (See Plate XVI). At the one side of the pegmatite, at its junction with phosphate, was a thin zone 1" wide of apparently almost solid monazite. The association of monazite and apatite seemed constant. This dyke was dipping E at a fairly high angle, and if continuous would have passed below the tunnel of No.III. On the surface, the only indications of the strike of the band was in a N.E. direction. The directionis based on the occurrence of loose monazite bearing boulders and is not absolutely reliable.

The ...

The monazite grains vary in size from pieces 5 mms in diameter to much less than a pinhead. The grains show cleavage but no outward crystalline form can be distinguished. It seems a peculiarity of monazite to occur in this form for E.S.Dana refers to occurrences in several places as in "masses or rolled grains". In enclosed pieces of apatite which show no crystal form, small scattered grains of monazite occurred as well as the long needles which abound in crystals elsewhere. There is very little feldspar in the pegmatite in which monazite occurs. Most of what there is, is stained green like that at No.I, a characteristic of weathered phosphatic pegmatites. The quartz is a very dark greyish-blue.

One other occurrence was noted. This is in the bed of a small stream, south east of the other workings, on the farm Mahilas Hoek. It is exposed in a short tunnel out northwards for 30'. At its mouth impure phosphate associated with a number of secondary minerals, especially a coating of epidote, occurs. The alteration and decomposition are accelerated probably by the proximity of the deposit to the river; A small stream trickles along the floor of the drive. Further in, good massive phosphate in the form of sugar apatite is found. This consists of a number of tiny glassy green apatite crystals forming a granular aggregate. It occurs commonly in Norwegian and Canadian deposits.

On the opposite bank of the river is a trench in which some of the best examples of mixed rock were found. Soft, green, hornblende schist, apatite, and pegmatite in uniform particles make up a very fine grained ~~mixed rock~~ aggregate. Massive apatite and ordinary pegmatite are also exposed in this trench. The phosphatic pegmatite body dips West and is immediately overlain by hard, fresh looking gneiss similar

to ...

to [illegible] which occurred at the top of the 2nd shaft in No.I working. About three yards to the East in the bed of the stream, a large joint block shews the actual intrusive contact of pegmatite with gneiss. Here pegmatite containing irregular pieces of apatite appears to be enclosed in gneiss. These are probably just sections of tongues of pegmatite. The trench and tunnel have therefore both been made along a narrow dyke - 3 yards wide, - of apatite bearing pegmatite intruded in a general Northerly direction and with a Westerly dip into hard gneiss. For its width the pegmatite was extraordinarily rich in phosphate, possible becuase the latter is only found in the vicinity of basic rock.

In this occurrence there are none of the thick bands of soft greenish schist which invariably accompany apatite in the other workings. The mixed rocks however abound with this constituent though only in small particles. The only source of this hornblende lies in the gneiss which flanks the pegmatite and it is suggested that what has been described hitherto as soft greenish schist is the result of the metamorphism produced in gneiss by the intrusion of a body of peg[illegible]tite. Where the pegmatite vein is narrow the alteration is naturally not so extensive.

Anoth[illegible] river boulder at the mouth of the tunnel has, at the junctio[illegible] f gneiss and pegmatite, a zone about 2' wide composed of alternate bands of the two rocks. Some distance down stream, just below No.III, the rocky bed of the stream shows a similar intrusive contact.

The injection of such numerous and long apophyses into the country rock indicates great liquidity or a high power of fusion on the part of the pegmatite magma.

The other workings on Mahilashoek were not examined, but were reported to be just shallow trenches exhibiting no new features.

PLATE VIII

Specimens of Graphic Pegmatite

Fig 1 Parallel wavy intergrowth

Fig 2 Fine parallel hooked intergrowth

Fig 3 Radiating Intergrowth

Description of the rocks associated with Apatite.

PEGMATITE.

The normal pegmatite generally exhibits two varieties of feldspar, pale pink and white. The former occurs in large irregular masses sometimes as much as 4"-6" square in which quartz and a little muscovite are included. The quartz inclusions become larger and more numerous towards the margins of the feldspar individuals. Between these crystals of pink feldspar is a graphic intergrowth of white feldspar and quartz. The structure of the intergrowth varies, 3 photographs are given.

Plate VIII fig.1 showing parallel wavy intergrowth.

Fig.2 showing small straight parallel quartz inclusions often with a small hook at one end.

Fig.3 showing radial intergrowth.

Often large masses of pegmatite are composed of rather fine grained granular white feldspar and quartz.

The demarcation between pink and white feldspar is sometimes very distinct but at other times the pink appears to shade off into white; where the demarcation is distinct the pink is of earlier crystallisation.

What has been called phosphatic pegmatite, more from its association with apatite bodies than from the percentage of phosphate contained, is far more impure than the normal pegmatite and is characterised chiefly by the discolouration of feldspar. The pegmatite is usually both coarse and even grained.

The quartz is always very dark bluish grey and the feldspar any shade of purple brown or green but always showing signs of decomposition. The cleavage lines usually show up as white cracks. This pegmatite is not a different type from the normal but merely an alteration of the latter

for ...

for in many hand specimens the change from fresh pink and white feldspar to the dark discoloured variety is evident. Sometimes in quite fresh looking feldspar small stained zones occur.

One pegmatite specimen is a mass of quartz with a much smaller percentage of mauvish feldspar and with occasional small glassy mauve crystals of spinel jutting out from the surface. It has several rosettes of hornblende crystals which are probably fragments of included schist.

In several pieces of phosphatic pegmatite picked up from the dump, the feldspar crystals were olive green in colour. These specimens were always full of foreign matter, pieces of apatite, crystals of hornblende, micaceous schist inclusions, a great deal of epidote both on the faces of hand specimens and in the cleavage cracks, a few spinel, etc. This green feldspar was not seen in the workings though the brownish mauve colouring was plentiful there. The green colouration is probably only found in these pieces of phosphatic pegmatite which have been exposed to the weather for some time.

Another pegmatite specimen is a large piece of almost solid, pearly, pink and white feldspar. The colours shade into one another for there is no evidence of separate crystals. Small inclusions of quartz occur throughout the feldspar and round about each of them and in connecting stringers between them are deposits of epidote. There are several specimens like this, one or two with quite a thick coating of epidote. In several of the feldspar masses ~~patches of~~ brownish purple patches occur. They shade off gradually into the pearly white variety. Small flakey inclusions of hornblende altering to biotite also occur.

Minerals of the Pegmatites.

The feldspars. Four types of feldspar have been mentioned in which the chief difference is colour.

(1) A pink feldspar from normal pegmatite.

(2) A white feldspar from normal pegmatite.

(3) Discoloured feldspar from phosphatic pegmatite (purple, brown and green).

(4) Large bodies of pearly feldspar.

In discussing the colour of feldspar in his book On Rock Minerals, J.P.Iddings says that colour is always due to inclusions, frequently indistinguishable microscopically, which act as pigments. It is well known that opacity is due to numerous inclusions. "White feldspars may be of any composition but the more frequent ones are albite. Yellowish pinkish and red tints come from iron oxides in most cases. Pink feldspars are very frequently potash feldspars but may be albite. Green colours in some cases arise from inclusions of ferrous silicates such as chlorite, in other cases their source is not definitely known. Dark grey colours are produced by innumerable inclusions of dark coloured minerals in minute particles. These are especially common in more calcic feldspars but also occur in some highly alkaline varieties such as the soda microcline of Fredricksvärn."

The optical examination of the various types of feldspar was practically useless for all of them were so crowded with inclusions that they were opaque even in thin thin sections. Of the few fairly transparent grains which were found in the powder of all four types not one showed twinning lamellae. The powder was immersed in liquid with R.I. of 1.5217 which according to the table given by Iddings on page 218 is higher than the α value of most potash

feldspars.

feldspars. In each case however 1.5217 was an intermediate value for most of the grains. This would be the case in any orthoclase with numerous inclusions.

In ordinary light the pink colouration of (1) is quite evident whilst the thicker grains appear pink under crossed nicols. The kaolinisation, if such it is, is apparently too far advanced to allow the transmission of light. The white variety (a) is very cloudy and grey or brownish in colour.

The discoloured feldspar (3) although the grains are cloudy is not as opaque as the first two, which is not in accordance with the outward appearance.

(4) is too decomposed to examine microscopically.

Both in the workings and in hand specimens the proximity of discoloured feldspar to apatite is very marked so that it seemed natural to attribute the differences between normal and discoloured feldspars to the effect, either primarily or secondarily, of the phosphatic minerals. To corroborate this Mr. Weall was asked to make analyses of (a) as pure as possible a piece of pink feldspar from normal pegmatite and (b) about 10 grains of discoloured pieces of feldspar, obtained by selection from the rough crushing of a piece of phosphatic pegmatite. The results prove that the changes are not due directly to any admixture of phosphate but otherwise are most indecisive. They are however given below with a few analyses of feldspar which is used commercially in various parts of the world.

(a) Theoretical comp. of pure orthoclase.

(b) Pink orthoclase from Bandolier Kop, analyst Mr. Weall.

(c) Discoloured feldspar from Bandolier Kop, analyst Mr. Weall.

(d) Analysis of a picked sample of dark red microcline

from ...

from Frontenac County Ontario.

(e) Albite from Villeneuve Mine, Villeneuve Township, Ottawa, County Quebec.

(f) Orthoclase from O'Brien Mine, West Portland Township, Ottawa County Quebec.

(d) (e) and (f) were analysed by F.L.Turner of the Mines Branch of the Department of Mines in 1914 and published by Hugh S.de Schmid M.E. in his memoir on Feldspar in Canada.

	a	b	c	d	e	f
$Si\ O_2$	64.7	63.8	60.8	64.44	65.65	65.07
Al_2O_3	18.4	19.7	23.6	17.63	21.65	18.20
Fe_2O_3		.8	.8	0.74	0.46	0.08
Fe O				0.03	0.03	0.06
Mg O		.4	.3	0.02	0.18	0.02
Ca O		.9	4.6	0.40	1.20	0.72
$Na_2\ O$		4.65	5.75	3.31	9.87	2.83
$K_2\ O$	16.9	8.95	1.7	13.39	1.08	13.46
$H_2\ O$		.25	.45	0.12	0.08	0.10
$Ti\ O_2$		.05	.1		trace	trace
Mn O					trade	trace
Sn O						
BaO				0.02	trace	trace
CO_2					nil	nil
$P_2\ O_5$	.1	.1	.1			
Loss on ignition		.6	1.2			
Total	100.00	100.20	99.7	100.10	100.20	100.54

The composition of (b) is not abnormal. The numbers of impurities are evident and the $K_2\ O$ % low whilst the

Na_2O is correspondingly high. (c)4 however is much nearer in composition to oligoclase andesine than orthoclase having low silica, high Al_2O_3, high CaO and Na_2O, and low K_2O contents.

The other minerals of the pegmatites are:-

Quartz. A characteristic of the quartz is the inclusion of minute black needles only visible with the highest power. These are probably rutile. Quartz is generally granular near the junction with other minerals. This is probably due to pressure. Hornblende, Biotite and Chlorite are commonly included where pegmatite is near to schist. Muscovite is not often noticed. Iron oxides both red and black are fairly common.

Spinel. Small crystals of a mauve variety are occasionally seen.

Epidote. The relatively large quantities, in which this mineral occurs is a feature of interest. It is attributed to the decomposition of a lime bearing feldspar.

PLATE IX

Fig 1 Porous Barite with red iron oxide filling in cracks x ¾ ([illegible])

Slide x 19·3

Filled in material and many of the dark specks are Red iron oxide

Remainder of dark material is Barite

Light spaces are holes

Fig 2 Thin section of rock above
By transmitted light – barite is opaque

Slide x 19·3

Filled in material is Red Iron Oxide

Light material is Barite

Dark spaces are holes.

Fig 3 Same section by reflected light

PLATE IX

Fig. 1 Porous Barite with red iron oxide filling in cracks x ⅓
(See page)

Fig. 2 Thin section of rock above
By transmitted light – barite is [illegible]

Fig. 3 Same section by reflected light.

POROUS BARIUM SULPHATE ROCK.

This rock is in every way abnormal and constitutes one of the most interesting features of the deposit. It occurs in large quantities in veins, pockets or lenses always associated closely with apatite. It consists of an aggregate of white crystals which are now more or less skeletons and are represented by small plates intersecting at right angles.

Red Iron Oxide has been impregnated throughout the rock in the interstices of the crystals and in the fretwork itself. See Plate IX fig.1. When a large block of this rock is broken the inside is sometimes of a cream colour and is more compact and veined with tiny quartz stringers.

As has already been mentioned the most perfect, and in fact the only well formed crystals, occur scattered through pockets and lenses of this porous rock. On Plate VIII fig.3, a photograph is given of 2 apatite crystals embedded in barite. The irregular fracture of the crystals masks their hexagonal outlines. The inclusions although usually in crystals are sometimes quite irregular fragments.

The rock is very soft and was thought at first to be a kaolinised aggregate of feldspar crystals in which the cleavage cracks had been filled with some foreign matter and then the bulk of the crystals dissolved or decomposed

to ...

to soft powdery kaolin. Quartz however forms a very small percentage of the rock and an aggregate of small feldspar crystals, not intergrown with quartz, is unknown on the deposits. This and the fact that apatite occurs nowhere else without a certain amount of ferro magnesian mineral, contradict the theory of alteration of pegmatite. A specimen of the rock was sent therefore to the Government laboratories to be analysed with the result that its identity was established as barite or at least 93.2% $Ba\,SO_4$. The following was the analysis:

Loss on ignition	1.65
$Ba\,SO_4$	93.2
$Ca\,SO_4$	2.7
$Ca\,PO_4$	1.3
SiO_2, Fe_2O_3, and Al_2O_3	Traces
	98.85.

The porosity of the rock makes it much lighter than solid barite would be. The quantities in which it occurs and its accessibility may render it a valuable addition to the phosphate mining.

On Plate IX figs. 2 and 3, microphotographs of a thin section of this barite are given. The rock was boiled in Canada balsam for some time to render it stable enough to cut but even with this precaution many of the small plates were broken. The few remaining however, serve to show the intersection of these plates at right angles.

The substance is quite earthy and opaque and hence appears dark by transmitted light, whilst the spaces between the crystals and the thin plates within the crystals are light. The iron oxide fillingis dark. The second photograph is with reflected light and the barite is its

natural ...

natural colour. The density of the intersecting plates is more evident in this, fig.3, than in fig.2.

A small outcrop of barite was visited a mile or two south of any known phosphate occurrence. The rocks in direct contact with it were not visible owing to the dense vegetation but the neighbouring rocks were of the same types, gneiss and pegmatite as elsewhere. The mineral was more massive and recognizable by its specific gravity. No special attention was paid to it as, at the time, the connection of barite with phosphatic minerals was not suspected.

The origin of this mineral will be discussed in connection with the genesis of the deposits.

S C H I S T.

Under this heading there is only one type of rook which, however, exhibits in different localities various modifications. It is the friable material which has been referred to so often as soft yellowish green schist. It is essentially a fine grained aggregate of hornblende crystals in various stages of decomposition and alteration, and is so soft that it crumbles on slight pressure.

The schistosity is most evident in blocks which have been included in pegmatite. These contain a certain amount of quartz and feldspar which mixed with the schist during the intrusion of the pegmatite, and which occurs in small crystals and grains in bands parallel to the edges of the schist body in which they are included. See Plate III fig.2., Plate IV, figs. 2 and 3, Plate V fig.1, Plate VI fig.1.

Weathering is determined by the same factor, e.g. The spheroidal weathering of the block included in pegmatite at the bottom of the shaft in No.I working.

In addition to the minerals derived from the pegmatite, biotite occurs in varying quantities in the hornblende of which it is an alteration product. In places the percentage of biotite, a dark brown variety, is so high that the rock can more accurately be termed a mica schist. The flakes of dark mica impart a speckled nature to the rock. Stains of black iron oxide occur on the larger hornblende

crystals ...

crystals and add to the mottled effect of the aggregate.

According to the amount of exposure undergone, the colour of the schist is green or yellow, whilst the degree of alteration of hornblende to biotite seems to be determined very largely by the admixture of pegmatite. In some places where schist and pegmatite are adjoining biotite forms an actual casing.

In the neighbourhood of apatite however, biotite is rare. The small inclusions of schist and the schist bordering so often associated with phosphate bodies are invariably hornblende only. The change may be attributed to the addition of silica.

In the open working No.I a most striking modification of the ordinary schist occurs. It is really a porphyritic hornblende pegmatite. See Plate X figs 1 and 2, which consists of very large phenocrysts of dark, greenish-black hornblende in a soft yellowish green matrix The matrix is similar to the soft schist described above, but owes its speckled nature more to the presence of specks of dark hornblende like the phenocrysts, than to biotite. Quartz and feldspar inclusions are common.

The hornblende phenocrysts are sometimes 2" in diameter and 7" long. They have no parallel arrangement but lie in all directions. Many are

intergrown ...

PLATE X

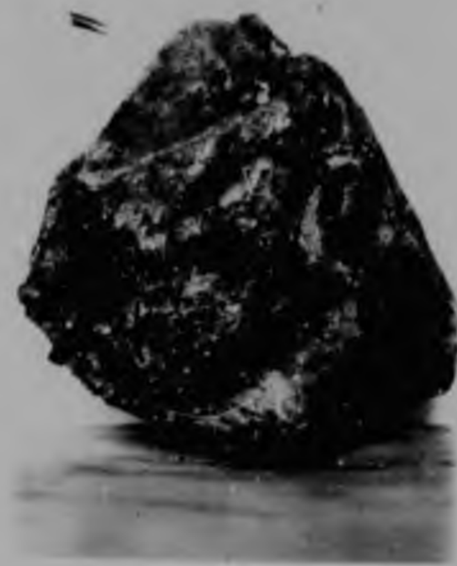


Fig __ Hornblende Pegmatite

Fig 2 Large lustrous black hornblende crystals in a matrix of yellowish green chlorite and biotite

intergrown or branching. Several of the crystals showed, along cleavage planes and fractures the beginning of alteration to biotite.

Apart from their prismatic habit no crystal outlines are visible and fracture is determined more by their fibrous nature than by cleavage planes.

The mineral was examined in powder form under the microscope. Thick pieces are brownish-green, thinner pieces bluish-green and the thinnest sections markedly pleochroic from yellowish to dark green. Cleavage planes intersecting at 120° are very distinct. In prismatic sections the extinction angles are small varying from 12° - 17°. The axial angle too is small.

In several cases the inclusions of schist in apatite are large crystals of hornblende, which are pale green in colour and have a silky lustre. In the schist too, these large pale green silky crystals occurred sometimes instead of the dark variety, and as has already been stated the bulk of the soft schist is composed of grains of pale green hornblende. The cleavage planes are far more prominent than in the dark hornblende, so that the mineral splits on pressure into smooth faced prisms.

Microscopically thin pieces are fibrous, almost opaque and very much decomposed so that the interference colours are flecked. Optical tests

could ...

could not be made because of the opacity, in fact if only microscopic pieces had been available, the character of the mineral would have been most uncertain.

There is little doubt that the presence or absence of excess silica has been the controlling factor in altering these hornblende phenocrysts to biotite, in one instance, and to a pale green decomposition product in the other.

A strange modification of the ordinary hornblende pegmatite occurs in a hand specimen but was not seen in the workings. In this the hornblende phenocrysts are embedded in what is essentially a biotite schist. The presence of a large quantity of pegmatite inclusions in the rock explains the alteration of the hornblende of the matrix to biotite but not the condition of the phenocrysts. It is just possible however that an optical examination might show that a similar change is in progress along cleavage planes.

Another variation is exhibited by two specimens. Each of these has on one side a coarse intergrowth of small ½" flat tabular dark hornblende crystals with the ordinary paler matrix. Out of this the large phenocrysts have apparently grown upwards.

The large crystals of hornblende included in apatite must have recrystallised from irregular inclusions of schist, and it is considered probable

that ...

that all the hornblende phenocrysts are contemporaneous with the intrusion of pegmatite and are the result of the contact metamorphism produced by the latter. The alteration to biotite is probably of the same age though a small percentage of it may be due to normal weathering.

MIXED ROCKS.

These may be mixtures of all three types, pegmatite, apatite and schist, or of any two of them in equal or unequal proportions. They may be granular, or intergrown, schistose or massive, in fact they present almost unending variety. More attention will be paid to them than to the other rocks, because they represent, on a small scale, the relationships of the type rocks to one another, and will therefore throw some light on the mechanics of the intrusion and the metamorphism produced thereby.

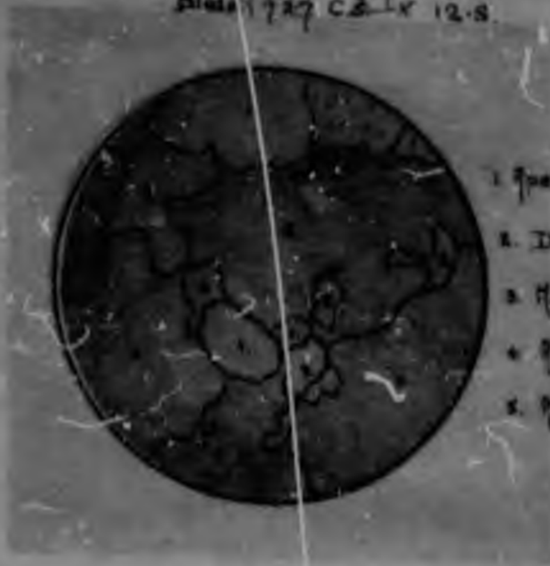
Under "pegmatite" mention has been made of small schist inclusions in otherwise pure pegmatite, and numbers of specimens occur which are either an intimate granular intergrowth of the two constituents, or consist of small bodies of one grading into fairly pure patches of the other.

The specimens numbered C.5. belong to Dr.A.Hall who was kind enough to lend me a few microscopic slides which he had had cut. The numbers are those used in his classification.

Specimen 730 C5 (of phosphate rock of low grade from No.II shaft), has no visible apatite in the hand specimen. This must be because the general green colour makes the green apatite inconspicuous. The rock appears to be nearly all hornblende; both dark bluish green and pale milky green in fibres. Some softer decomposition product,

probably ...

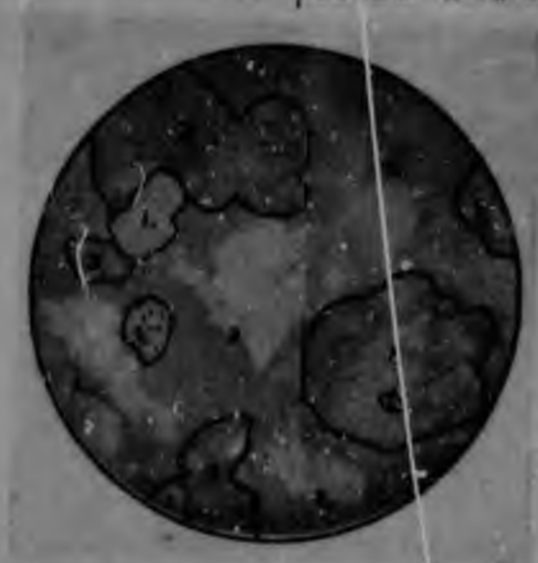
Slide 729 C8 x 12·5



1. Apatite with monazite needles in one section
2. Decomposing feldspar.
3. Monazite
4. Augite showing prismatic cleavage
5. Augite showing intersecting cleavage. Dark patches due to chloritisation.

Fig. 1 Mixed Rock (see page)

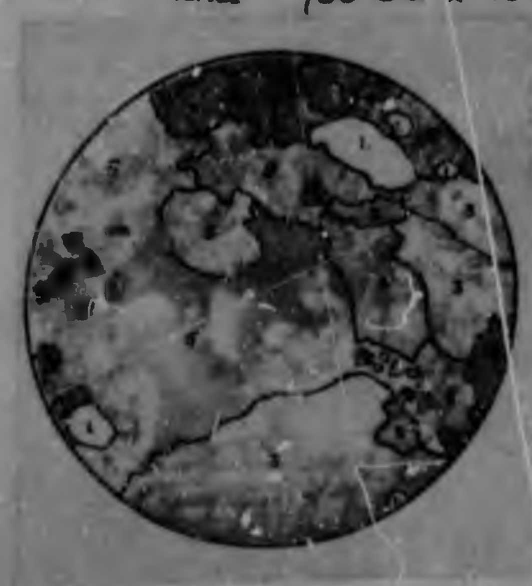
Slide 726 C8 x 12·5



1. Apatite with monazite needles
2. Decomposing orthoclase with some clear patches.
3. Pale yellowish green Augite.

Fig. 2 Mixed Rock (see page)

Slide 730 C8 x 12·5



1. Apatite
2. Decomposing feldspar
3. Hornblende in yellow pleochroic position, showing both prismatic and basal sections.
4. Hornblende in green pleochroic position.
5. Hornblende in various stages of alteration to chlorite

Fig. 3 Showing Chloritization of Hornblende

PLATE XI

Fig. 1 Mixed Rock (see page)

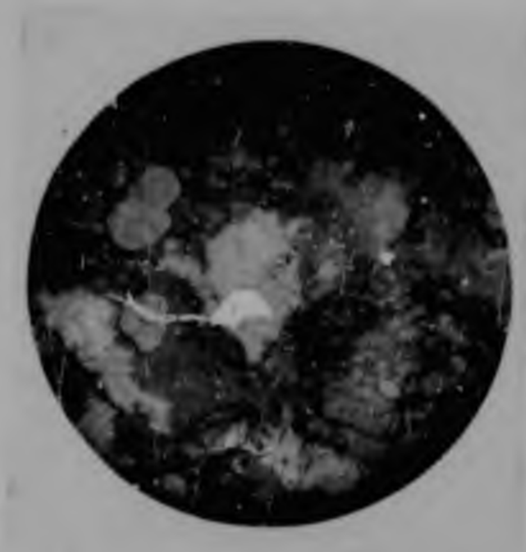


Fig. 2 Mixed Rock (see page)

Fig. 3 Showing Chloritization of Hornblende.

probably chlorite, is mixed with the other mineral. Microscopically most of the slide is chlorite. The hornblende grades into its flaky decomposition product in most cases through fibrous stages. Small patches of serpentine also occur. There is much hornblende with distinct 120° cleavage, pleochroic from pale yellowish brown to dark brownish green. The extinction angle is small, averaging about 10°. In the particular section examined only one variety of hornblende is visible. Cloudy patches of opaque grey feldspar are scattered throughout.

Despite the degree of decomposition which they exhibit, they stand out well and do not merge at the edges into the green ground mass. Numerous grains of apatite of various sizes occur. The larger pieces have irregular cracks running through them, and show in places along these, slight cloudiness. On the whole, however, apatite is very fresh by comparison with the other constituents of the rock. Besides the larger feldspar bodies mentioned, numerous grains of orthoclase occur, especially in the interstices of hornblende crystals. A few frayed out patches of what appear to have been biotite are also present. See Plate XI fig.3.

Specimen 726 C5 is another in which the apatite is not noticeable to the naked eye but on examination in thin section it proved to be a mixture of three minerals, augite and feldspar in about equal quantities with less apatite. The feldspar is not as

decomposed ...

decomposed as in other slides, some of the larger bodies having quite large central areas of fresh orthoclase.

The apatite stands out well, and the bigger pieces have monazite inclusions. The augite has very marked relief, and is colourless or very faint greenish yellow. It is non-pleochroic. Extinction angles are very consistently 30° to 34°, It has a biaxial positive interference figure. See Plate XI fig.2.

A specimen showing pinkish feldspar spotted with green schist, most of the pieces about ¼" in diameter, is seen on Plate XIV fig.2. The hornblende is speckled black, showing that weathering is not quite complete.

Another specimen in which the proportions of schist and pegmatite are reversed consists of hornblende mainly speckled with quartz. The hornblende in this is far less altered, and shows the fibrous arrangement characteristic of this dark type. (See Fig.1 Plate XIV.) In some pieces of mixed pegmatite the schist is represented by crystals of varying dimensions, of the pale green hornblende, accompanied by practically no granular material.

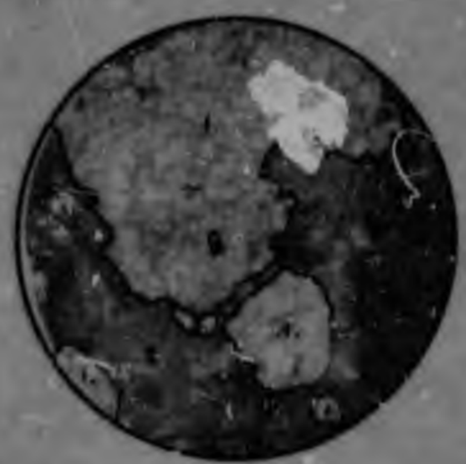
Schist and apatite are never found without a certain amount of pegmatitic matter, the latter, however, may be very much in the minority. In one hand specimen a large crystal of apatite was seen embedded in schist with a small admixture of fine grained pegmatite and apatite. Another large lump

of ...

PLATE XII

Fig 1. Mixed Phosphatic Rock showing pegmatite with irregular intergrowths of greenish apatite ([illegible]) ([illegible])

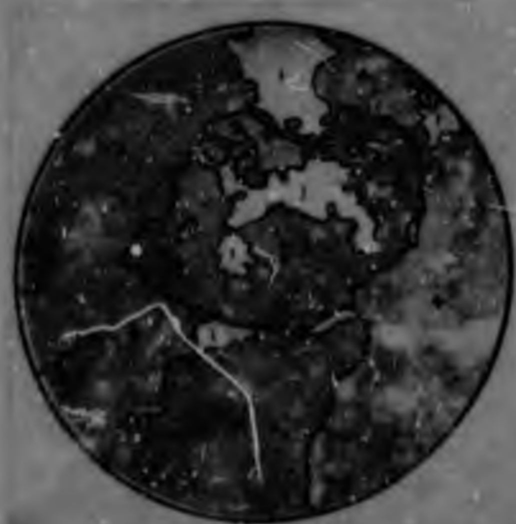
Slide x 19



1. Apatite
2. Decomposing pink feldspar
3. Quartz

Fig 2. Portion of rock above microscopically ([illegible])

Slide x 19·5



1. Quartz
2. Apatite (cloudy)
3. Hornblende decomposing. The piece at the bottom shows the fibrous stage well
4. Pink feldspar very cloudy with dark grey patches

Fig. Mixed Rock showing fibrous hornblende ([illegible])

PLATE XII

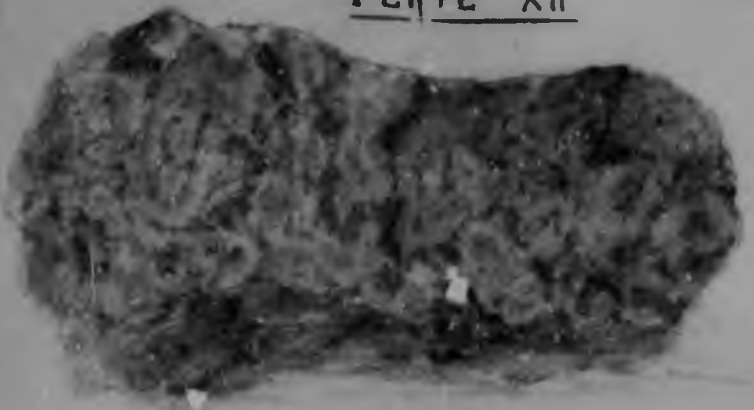


Fig. 1 Mixed Phosphate Rock showing pegmatite with irregular intergrowths of greenish apatite (Nat. size)
(Specimen page)

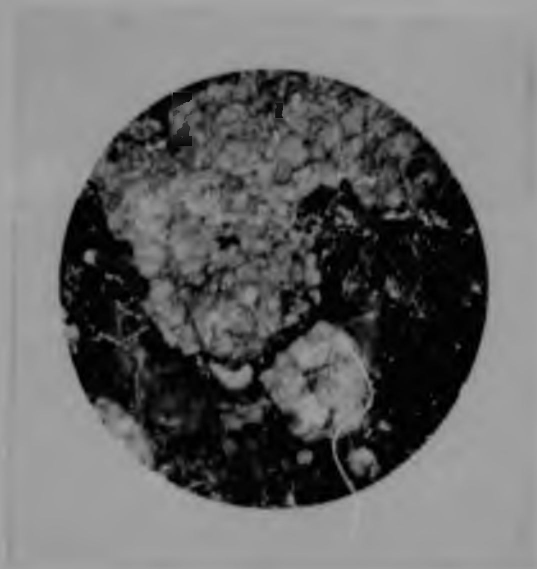


Fig. 2 Portion of rock above microscopically
(Specimen page)

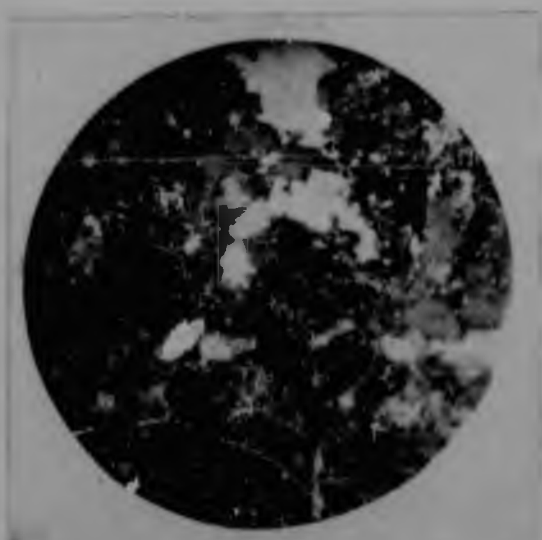


Fig. 3 Mixed Rock showing fibrous hornblende
(Specimen page)

of apatite had interpenetrating hornblende crystals 1" or more in length, the only indication of pegmatite was that one or two grains of felspar were embedded in the hornblende. In several granular mixed rock, the pink or white feldspar element was almost absent, the rocks being a mixture of green apatite and green schist.

Pegmatite and Apatite are of course the commonest combination, of which the inclusions of apatite surrounded by monazite in pegmatite are a phase of Plate XVI figs. 1 and 2.

Not quite so pure a mixture is seen in a coarse intergrowth of pegmatite and apatite, (see Plate XII fig.1). There are small inclusions of schist but these are subsidiary. In almost every instance there is a thin zone of quartz around each apatite inclusion, and the pink feldspar adjoining it becomes a dark brownish red which marks the contact very well. The yellowish soft material speckled through the central inclusion of green apatite is due to the inclusion of small quantities of schist. The polished face of this rock is quite ornamental. Two slides were made, (a) of the intergrowth of apatite and pegmatite, (b) of the portion of apatite including schist.

(a) This is an intimate mixture of feldspar, apatite and quartz. The quartz occurs in large bodies, and in small isolated grains, it is very fresh. Orthoclase and apatite, in large and small pieces, occupy the rest of the slide. The feldspar

is ...

is pink and is almost entirely decomposed, a few clear patches only remain. The apatite is very much cracked. Most of it is in large pieces, but a small percentage is scattered in grains throughout the orthoclase. The only other minerals are a few flakes of red iron oxide, and around some of the apatite crystals a thin margin of ferromagnesian mineral, too small to be determined, but probably hornblende. (See Plate XII fig.2.)

(b) is composed of an aggregate of apatite grains of different orientation, as indicated by the direction of the minute monazite needles as well as by the extinction.(cf Plate XVIII fig.1, and the description of it given under slide, 723 C5.) In addition to these tiny needles, most of which under low power have no thickness, there are several larger pieces of yellow monazite (about ¼" in diameter under 26 magnification). Apart from monazite inclusions, the apatite is cloudy along all fractures and has not the freshness so characteristic of it elsewhere. The centre of the slide is occupied by an aggregate of greenish grey,mostly opaque ferromagnesian mineral, fibrous, and containing some very finely powdered red oxide. This mineral extends along some of the cracks in the apatite. It is regarded as being included schist very much altered. At one end of the slide is a large piece of quartz of obviously later crystallisation than the apatite.

Finally ...

PLATE XIII

Fig: 1 Mixed rock showing an intergrowth of bluish green apatite pink feldspar and fibrous hornblende (Nat. size)

(Specimen see page)

1. Apatite
2. Schist
3. Pegmatite dyke.

Fig 2. Showing a narrow dyke of pegmatite intruded into apatite and schist.

1. Apatite crystals
2. Barite.

Fig 3 Apatite crystals embedded in barite

PLATE XIII

Fig: 1 Mixed rock showing an intergrowth of bluish-green apatite, pink feldspar and fibrous hornblende (Nat. size)

(Specimen see page)

Fig 2 Showing a narrow dyke of pegmatite intruded into apatite and schist

Fig 3 Apatite crystals embedded in barite

Finally there are the proper "mixed rocks" in which all 3 constituents are apparent at a glance. Fig.1 on Plate XIII shows one of these. The specimen was not polished, as the soft hornblende crystals probably would have been destroyed. The drawing was made from a fairly level fracture. It shows pink feldspar, a little quartz and green apatite and schist. The last named enters to a far greater extent in this specimen than in those hitherto described. The apatite has numerous inclusions of hornblende and a little biotite. The most striking feature, however, is the presence of large silky hornblende crystals at the contact of feldspar and apatite, the two such crystals shown in the drawing have banding in different directions, showing that the crystals have no radial arrangement with reference to the apatite.

Specimen 723 C5 in the hand specimen appears to be an irregular mixture of green apatite, a few fairly large augite crystals, and a fine-grained greenish substance, scattered inclusions and tiny veins of pegmatite - pink feldspar and quartz occur.

Microscopically it is a coarse intergrowth of apatite with ferro-magnesian minerals. In the slide apatite occupies more than ½" square. It is not one single crystal, but an intergrowth of smaller pieces with no crystal outlines. Each piece includes numerous needles of monazite arranged in definite order. Some fragments show long parallel needles, others just the emergence of the tops of needles;

these ...

...blende inclusions in quartz ( )

Fig. 2. Small inclusions of hornblende in felspar ( )

PLATE XIV

these latter sections are either basal or approximate very closely to basal (See Plate XVIII fig.1.) The arrangement is therefore the same as that in the large and perfect apatite crystals where the long axes of monazite inclusions are parallel to prism faces (see Plate XVIII fig.2.)

The Ferro-magnesian mineral is almost colourless, non-pleochroic Augite. Extinction angles vary from 40-50°, the cleavage is parallel in prismatic pieces and shows 90° intersection in cross sections. Alteration to chlorite along cleavage cracks is noticeable with a high power objective.

Much decomposed pinkish feldspar occurs throughout the augite and at the margin, but not actually in apatite.

Small patches of epidote and grains of magnetite are seen occasionally. No quartz occurs in the section.

<u>725 C5</u> in the hand specimen is very like 723 C5. In a thin section the whole slide is a very pale greenish grey, almost colourless. It consists of a large amount of very slightly pleochroic augite with parallel cleavage cracks. Extinction is oblique. The angles diverge very little from 34°. The mineral gives a biaxial positive interference figure. Large portions of it extinguish at the same time, as a result, probably, of poikilitic intergrowth. All the grains show a certain amount of decomposition, but not along any definite planes. A few irregular clear apatite fragments with high relief occur. There is much ...

much feldspar which is grey and opaque, and in isolated pieces. Small patches of yellowish epidote and specks of iron oxide occur.

Slide 727 C5 showed the same essential characters namely, apatite with a few very small inclusions of monazite, decomposing feldspar, augite with chloritised cleavage planes, grains of magnetite, etc. (See Plate XI fig.1.)

Another specimen microscopically is a fine grained aggregate of bright pink feldspar, quartz and hornblende.

The latter shows alteration from a dark bluish green to the pale yellowish decomposition product. In one part there is a thin coating of epidote.

Slide. This specimen differs from those already described in having quantities of quartz which occurs both in large pieces and in a fine granular aggregate around many of the other minerals, and in irregular interstices.

The quartz with large masses of quite opaque, intensely decomposed feldspar makes up the bulk of the slide.

The feldspar which appears so pink in the hand specimen only shows pink in patches, most of which adjoin hornblende bodies. This may, however, be accidental.

Next in abundance is a dark green hornblende unlike that in the other rocks. It is pleochroic from yellowish green to bluish green, and much of it is fibrous. There is a greenish black, opaque

substance ...

substance with speckled circumference in the middle of which fibres of the fresher green hornblende sometimes occur. It is just possible that this is augite, in the process of altering to hornblende. Or it may be an older generation of hornblende. There is little doubt that the fresh green hornblende is secondary.

Apatite occurs in small fragments, but is quite subsidiary. Decomposing biotite, grains of epidote, and specks of magnetite are additional minerals.

Several specimens appear to be porous mixtures of hornblende schist, granular and crystal apatite, and the ~~calcium~~ barium sulphate rock. The last occurs sometimes in rosettes of radiating fibres, which are often rose coloured and resemble natrolite. At other times it has the more typical structure, suggestive of its replacement of feldspar. In one of these specimens a large body of quartz was embedded, a thing of rare occurrence.

Specimen 722 C5 is an abnormal one.

A vein of pegmatite about 1" wide is intruded, into a mixture of large pieces of apatite with hornblende schist. ~~(See Plate XIII fig.2.)~~

The pegmatite has numerous cavities (See Plate XIII fig.2.). This intrusive vein is an evidence that the pegmatitic magma continued to intrude after the formation of the phosphatic bodies."

This is the only specimen in which the crystallisation of the normal pegmatite constituents is obviously later than that of apatite. In all probability this last injection was a small one and of short duration

Mr.Weall of theGovernment Chemical Laboratories made analyses of 2 specimens of mixed rocks, those described as 726 C5 and 727 C5. These are given below as they indicate the proportions of pegmatite, schist and apatite present.

ANALYSES OF MIXED ROCKS.

	726 C.5.	727 C.5.
Moisture ...	0.4	0.5.
Loss on ignition	1.0	.85
$S.O._2$ ...	49.4	33.8
Titania ...	0.1	0.1
Alumina ...	10.95	1.25
Ferrous Oxide	3.15	3.15
Ferric "	.45	.95
MnO_2 ...	trace	trace
Lime ...	16.7	32.[illegible]
Magnesia ...	6.[illegible]	7.35
Sodium Oxide ..	3.25	1.35
Potassium Oxide	2.3	0.4
P_2O_5 ...	5.6	17.0
$C\ O_2$ ...	0.1	0.05
Fl. ...	0.3.	0.7
Cl. ...	trace	.1
Total.	100·25	100·16

QUARTZ GARNET ROCK.

At the top of the trench in which the monazite rock was exposed, and scattered over the surface in its vicinity, were loose boulders of a garnet quartz rock. They varied in size from 2 feet in diameter to much smaller. These rocks had not been found anywhere in place. The rock, however, deserves more than mere mention since it occurred so close to the monazite, and was not seen elsewhere, and because it may shed some light on the changes to which the pegmatite was subject.

In a hand specimen the rock bears a close resemblance to the quartz monazite rock. It consists of a ground mass of the same dark bluish grey quartz which characterized the monazite rock with small granular crystals of garnet of a brownish red colour, but of a lighter shade and more glassy than monazite. These are uniformly scattered throughout the rock and not concentrated in dense stringers as the monazite grains are in the neighbourhood of apatite inclusions.

A photograph of a hand specimen is given on Plate XV fig.2.

Another difference lies in the absence of feldspar and apatite inclusions. The S.G. measured in a large piece of rock, so as to minimise the error, was 2.877. If the minerals, other than quartz and garnet are disregarded, which can be done without great inaccuracy, for their percentage is obviously very

small ...

small, the proportion of quartz to garnet can be roughly estimated. This was done by crushing some of the rock finely; the powdered material weighed 11.385 grms. This was shaken in a mixture of Bromoform and turpentine, S.G. 2.675, to effect a rough separation. That which sank weighed 2.67 grms. and the floating material 8.7 grms. Therefore Garnet : Quartz :: 1:3.25 by weight or, roughly, ¼ of the rock is garnet. The S.G. of the garnet was then determined by means of a weighing bottle and found to be 4.1 which would mean that it was Almandine 3.9 - 4.2 or Spessartite 4.0 - 4.3. It was not found possible to make a full quantitative analysis of the mineral, but a qualitative test revealed it to be a silicate of aluminium, ferric iron, a little magnesium, and a trace of calcium, but no manganese. It is therefore nearer to almandine than any other variety, which was to have been expected from its occurrence in so highly siliceous a rock. The presence of only a trace of Calcium is significant as it obviates the possibility of the absorption by the Magma of any quantity of limestone. Prof.Shand in discussing the syenites of Sekukuniland considers the presence of melanite, Ca.rich garnet, as one of the strongest proofs of his theory that the alkalinity of the syenites is due to the absorption by the igneous rock of a large block of Dolomite during its intrusion.

On ...

On the other hand, H.S.Spence in his memoir on Phosphate in Canada, says that almandite and hessonite have been found associated with apatite in Quebec. Both the varieties are common in the gneisses of the district and are occasionally met with in crystalline limestone near intrusive contacts of pegmatite. Spessartite occurs plentifully in the feldspar and mica of Villeneuve Mine and uwarowite in Wakefield associated with Apatite, tourmaline and pyroxene.

Only one slide was made, as the rock showed in a hand specimen such uniformity. A photograph of this is attached. Plate XV fig.1.

QUARTZ GARNET ROCK (MICROSCOPICALLY.)

The Quartz is fairly fresh, but with serpentine filling a few irregular cracks. It occurs in large pieces, except at its contact with garnets where it is almost invariably granular.

The Garnets show no crystalline outlines, but are more or less circular.

Scattered through the quartz are irregular bodies of garnet, hornblende and plagioclase. The garnet usually occupies the centre of such bodies, but even there it is fragmental. Hornblende forms, in most cases, a marginal rim and patches of it occur in the middle. All the hornblende in any particular unit is in optical continuity. The

remainder ...

remainder of the space is plagioclase, all more or less decomposed.

The garnet is quite normal in appearance, having very high relief and traversed by numerous irregular cracks. It is quite isotropic. (Brogger states that garnets formed directly from an igneous magma, as well as those produced by the slow processes of regional metamorphism are "isotropic", while those produced by hot solutions or by contact metamorphism often show an apparent anisotropic character. In a table he gives Almandite and Pyrope as the only ones, invariably isotropic, garnets are known to alter to felspar and hornblende, but this is apparently rare. Inclusions of pyrite, in varying sizes are common in the garnet and its decomposition products. Most of them show alteration to magnetite and flakes of haematite. Crystals of very high R.I, probably epidote, occur. They are colourless or with a very faint pinkish tinge and are biaxial and negative in character. The garnets contain smaller crystals of the same mineral. The Hornblende is the same as that in the gneiss, pleochroic from pale yellowish green -- reddish brown, with no distinct cleavage and a not very distinct biaxial negative interference figure.

I can find no reference in any of the descriptions of garnet rocks from this vicinity to one which resembles this specimen. Most of them are garnet gneiss rocks with much felspar and not a

predominating ...

predominating percentage of quartz. The ferro-magnesian mineral too, constitutes a large proportion of the rocks which are dark coloured in consequence.

In discussing the pegmatite Dr.Hall says that the garnet in this formation is rare, but notwithstanding this, this particular quartz garnet rock appears to be rather a phase of pegmatite than of gneiss.

Other specimens of quartz gneissose garnet rocks were found later with a much higher percentage of ferromagnesian mineral, but with quartz still predominating. It is believed that the intrusive pegmatite embodied some of the garnet gneiss rock, and that the garnets being most resistant, were scattered unaltered throughout the siliceous magma.

If Dr.Brogger's theory is accepted as correct, the isotropic almandine could not have been produced by contact metamorphism and therefore its transference unaltered, from the gneiss must be inferred.

Unfortunately Dr.Hall in referring to the garnet gneiss rock makes no mention of the variety of garnet.

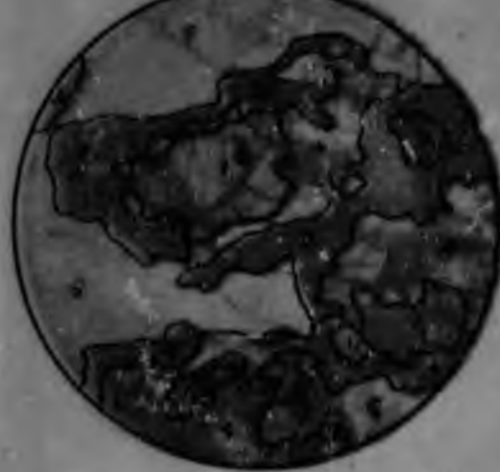
The zone of hornblende around them may be a remnant of that in the original gneiss, but its optical continuity suggests that it is an alteration product of the garnet. The large quartz garnet boulders belong therefore to both types, the

garnets ...

garnets and their associated minerals being of greater age. The temperature of the pegmatite containing the many mineralisers, would not have been nearly as high as that generally associated with molten magma.

PLATE XV

Slide x 19



1. Garnet
2. Pyrite [illegible] black [illegible] [illegible] [illegible]ed [illegible] [illegible]ack.
3. Hornblende [illegible] [illegible]es.
4. All light [illegible] [illegible] [illegible] ones [illegible] [illegible]oclase.
5. Quar[illegible]

Fig. 1 Quartz Garnet Rock microphotograph & Fig 2 Handspecimen.

Slide 717 C.S. x 19.5

1. Hornblende, pleochroic from yellow to green, basal & prismatic
2. Plagioclase feldspar granular & twinned.
3. Augite almost colourless.
4. Hypersthene pinkish.

Fig. 3 Gneiss from Mahilas Kop

Slide 718 C.S. x 19.5

1. Ferromagnesian mineral.
2. Biotite, showing extreme pleochroism. All the fine needles in 3 are biotite.
3. A granular & decomposed mixture of felspar & quartz.
4. All the black spots are Chromite.

Fig 4 Gneiss from No I

PLATE XV

Fig. 1 Quartz Garnet Rock microphotograph & Fig. 2 Handspecimen.

Fig. 3 Gneiss from Mahilas Kop

Fig 4 Gneiss from No I

G N E I S S.

The gneissic rocks which make up so large a percentage of the country rocks, and which flank the pegmatite schist belt, both to the north and south, occur also in the belt itself. Two specimens of this rock were specially noticed (a) a piece of the rock which builds Mahilas Kop, and (b) Gneiss which adjoins pegmatite at the top of the second shaft in No. I. (See Fig.4, plate iv).

These rocks are both remarkably fresh in both hand specimens and in thin sections, which is surprising considering their enormous age and the exposure to which they have been subjected. Large, lichen-covered boulders which cap the hills and which must have braved the agents of weathering for ages, reveal quite fresh interiors when a flake is struck off by a hammer. The difference exhibited by the two specimens is probably due to the metamorphism produced by the intrusion of siliceous pegmatite into (b). Both rocks, however, are more basic in character than acid, by far the greater bulk of them being ferromagnesian.

(a) In a hand specimen it is a more or less even grained granular rock. The crystals are much smaller than those of (b). It is predominantly dark coloured, but contains an appreciable percentage of light material. Gneissose banding is not apparent.

In a microscopic slide the light mineral is only slightly decomposed, and is apparently all plagioclase,

for ...

for, with the exception of one of two small pieces it all shows twinning under crossed nicols. In most instances this is according to both the Albite and Pericline laws and the lamellae therefore intersect. The lamellae generally are fine, in a few pieces they are broader. The occasional pieces which showed no twinning are probably quartz, but the percentage must be very small. The plagioclase makes up about 1/3 of the slide. Another third is occupied by fresh, green hornblende pleochroic from yellowish-green to yellow. The extinction angles are small and vary, e.g. 8°, 12°, 11°, 13°, 19°.

Ferromagnesian Minerals. Occasional pieces show cleavage planes intersecting at angles of 120°. There is much almost colourless augite with fairly high relief, with intersecting cleavages at 90°, high extinction angles and bright interference colours.

There is also a slightly pinkish mineral with higher relief and irregular cracks running across it. This has grey interference colours, and where cleavage is visible, extinction is straight. It is slightly pleochroic and gives biaxial negative interference figures. This is almost certainly hypersthene.

Occasional pieces, with the same pinkish tinge and with high relief, have bright blue or yellow interference colours and may be olivine. No conclusive interference figures can be found.

In places, flakes of chlorite appear, but on

the ...

the whole the ferromagnesian minerals are very fresh, though hypersthene is brownish along cracks.

Grains of black iron oxide are fairly abundant. A photograph of part of this slide is given in Fig.3. plate XV, showing all four minerals described. The higher relief of the pinkish mineral is evident.

(b) The most prominent feature is a mineral in large pieces, which is intensely pleochroic from dark reddish brown to pale yellowish green, or from either to sap-green. The cleavage for the most part is an irregular network, but usually one series of cracks predominates and to these extinction is parallel. The interference figures are very indeterminate, but some of those from which results were obtained were negative. It may be hypersthene or else is an intermediate pyroxene. Most of it has high interference colours.

There is a great deal of fresh very pleochroic biotite. Most of the flakes are bent and many show wavy extinction. Black chromite occurs in quantities, sometimes in almost graphic intergrowth with hypersthene. Quite a number of black grains shade off into a bright green on thin edges. This is probably the green chrome ochre halo referred to in some text books, though it exhibits no marked pleochroism. It is not metallic by reflected light.

Every here and there an almost circular zone of speckled quartz, plagioclase, biotite and iron

oxide ...

oxide occurs. In several pieces of plagioclase there were chloritized zones; these do not appear in the ferromagnesian mineral. In the biotite, small colourless grains of a mineral with high relief and very bright interference colours occur, these are probably zircons, the customary dark halo is only occasionally present.

Small pieces of a bright blue mineral occur. They are pleochroic to a paler blue and anisotropic; probably corundum.

A photograph of this slide is appended (Fig. 4 plate XV) but the minerals are too dark for any marked contrast to show.

Dr.Hall gives numerous descriptions of gneiss in his memoir on "Corundum in the Northern and Eastern Transvaal" and the pyroxenes and amphiboles are tremendously varied. He makes several references to enstatite but not to hypersthene or to any very pleochroic pyroxene. The exact character of these minerals could probably only be determined chemically. There is a further possibility to be considered.

Dr.Hall describes a series of massive ultrabasic rocks pyroxenites, hornblendites etc. into which the granite gneiss group is intrusive but which occur only in isolated patches and do not form prominent outcrops as the rock just described, does at Mahida's Kop. Apart from this, these

specimens ...

specimens resemble the massive basic rocks more closely than the gneiss. This conclusion was come to after the examination of 3 slides and 3 hand specimens for not much attention was paid to the mineralogical composition of the gneiss during the very limited time spent in the area. It may therefore be too precipitate. Dr.Hall suggests that the so-called granite-gneiss group may represent two intrusions and that the granite in turn is intrusive in gneiss. The relationships however must be investigated more closely before any definite conclusion can be reached. The gneiss in many places contains a high percentage of ferro-magnesian minerals though quartz is always fairly common (unlike ~~Matula's~~ Mahiela's Kop).

Dr.Hall suggests that this high ferromagnesian content and the intimate association between gneiss and the basic rocks may be accounted for by the assimilation of some of the basic rock by gneiss at the time of the latter's intrusion. Whether the rock from ~~Matula's~~ Mahiela's Kop and neighbourhood is primarily basic, or gneiss impregnated with a high percentage of basic material, its basic tendencies are undeniable.

A P A T I T E.

In the Zoutpansberg District apatite occurs in three forms:- Massive; Crystalline: and Granular.

The Massive Apatite is usually green and glassy. It has small inclusions of feldspar and schist and numerous monazite needles, but on the whole is remarkably pure. It is simply apatite which has formed a thin bed instead of crystallising into prisms and pyramids.

Microscopically it is identical with the irregular inclusions of apatite which occur in the 'mixed rocks' and which were described in that connection. On Plate XVIII fig.1 is a typical section. The rock is a coarse grained aggregate of idiomorphic apatite crystals. Even in these the distribution of monazite follows the same laws as in the large and perfect crystals, i.e. with the elongation of the needles parallel to the vertical axis of the apatite crystal. All sections which under crossed nicols have relatively high interference colours, have long monazite needle inclusions. In those with lower interference colours, which have been cut obliquely with reference to the vertical axis, the inclusions are correspondingly shorter, whilst basal sections show only the points of emerging needles. In addition to these needles, monazite occurs filling spaces between apatite grains

and ...

and sometimes in granular pieces. Some of the latter show indistinct crystal outlines but others are quite irregular. Small inclusions of feldspar, quartz and hornblende are common. They are in all respects similar to those described under 'mixed rocks'.

The apatite crystals are hexagonal prisms terminated by pyramids. None were seen with pyramids at both ends and it is probable that they rarely exist in this form. In Canada the same peculiarity is found for a complete crystal is very unusual. All of the crystals show very marked parting, parallel to the basal pinacoid, and most of the crystals are terminated by one of these planes. In size they vary greatly, both in length and in diameter. The greatest length seen was 2'6". This crystal occurred in No.III (see page 11), and was followed into the wall for this distance without reaching the end.

The diameter of those seen varied between 1" and 6". Both these dimensions would undoubtedly be found to increase greatly if special notice were taken of all the crystals mined. It is only possible to estimate the length of a crystal in situ, however, because, as a result of the parting planes the crystals either break off when moved or exist in their parent rock in a fractured condition, and on the removal of the surrounding rock they

break ...

APATITE CRYSTALS (See page)

PLATE XVI

1 Well developed crystal

Fig: 2 Pivotal junction of two crystals or two portions of a crystal

3 Crystal faulted and recemented

Fig 4 Twisted Crystal

Fig: 5 Actual tracings of crystals a & b flattened in different directions

Apatite Crystals (See page)

PLATE XVI.

1 Well developed crystal

Fig: 2 Pivotal junction of two crystals or two portions of a crystal

Fig 4 Twisted Crystal

3 Crystal faulted and recemented

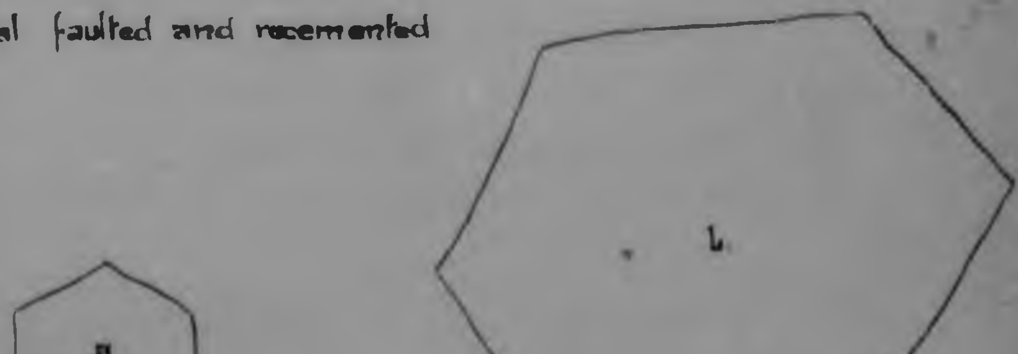


Fig: 5 Actual tracings of crystals a & b flattened in different directions break into pieces a few inches long. None of the crystals show perfect symmetry, but all exhibit signs of mechanical strain. On Plate XVII fig.5'a'&'b' tracings of the cross sections of two typical crystals are given. These were taken at right angles to the vertical as nearly as possible. Quite a number of the crystals show flattening, sometimes so that the longest horizontal axis passes from edge to edge (see fig.5'b') sometimes from face to face (See Fig.5'a'.)

One of the most symmetrical looking of the crystals has 2 angles of $117\frac{1}{2}^{\circ}$ and 4 of $120\frac{1}{4}^{\circ}$ and another 2 angles of 125° and 4 of 120°. (The errors in the perimeters are due to the unevenness of the surfaces which make measurement very difficult)

The pyramid faces are invariably asymetrical and the edges are always rounded to a certain extent, sometimes so greatly that the faces just merge into one another, and make measurement almost impossible. The measureable angles in the specimens available are very few, but lacking better material these are given.

(a) The angle between prism and pyramid faces 50°, 45°, 50°, 50°, 50°, 45°, 51°, 47°, i.e. average 50° and (b) interpyramidal angles 35° - 40°.

No other forms than prism and pyramid were seen in any crystal.

Several of the crystals are twinned parallel to a prism face. This in some cases is not

definite ...

definite twinning but just an interpenetration, or parallel growth, which occasionally is not parallel to the vertical axis but slightly pivotal (see Plate XVII Fig.2.)

Several of the crystals have been broken and then recemented after a slight movement had taken place. See Fig.3. Others are twisted (see Fig.4). Quite a number have yielded to the pressure in more than one way. Some of the crystals just taper off to an end without any pyramidal point. All show varying degrees of corrosion of the crystal faces which are roughened and pitted and occasionally quite concave.

Many of the crystals have a coating, especially on pyramidal faces of small, green, glassy, apatite grains, some of which appear to be hexagonal, but the majority are irregular. This may be a form of corrosion but, more probably, represents an additional growth.

A certain amount of the surrounding rock adheres to the crystals, particularly the barium sulphate rock which, as has already been stated, is by far the most common habitat and is really the only rock in which good crystals occur.

The <u>granular apatite</u> - or sugar apatite as it is called in Canada and Norway where it forms an appreciable percentage of the deposits - occurs only as a coating of large crystals or occasionally in a loosely bound mixture with schist. No massive specimens of pure sugar apatite were seen, and even

if ...

if further development exposes such, it is not likely to form an important representative of apatite types in the Northern Transvaal.

The physical properties of all the types are similar.

The cleavage is imperfect and fracture usually conforms partly to a cleavage plane and then becomes irregular. The parting planes, as already stated, constitute a far more general mode of division.

As regards solubility, apatite is known to give different etching figures with different solvents, but no satisfactory results were obtained from experiments in this direction.

The Specific Gravity varies. According to Doelter a range of 3.09 - 3.39 has been recorded in different varieties. It usually lies however between 3.14 and 3.22.

P. Pusirewsky, after experimenting with various Russian apatite specimens, maintained that the Specific gravity decreased with the increase of Chlorine. This is not found to be the case always, so is probably inaccurate. In the Transvaal apatite the specific gravity of the green apatite was found to be 3.136 and 3.151; that of a dark red variety 3.165, and that of white variety 3.091. (The first and last figures were determined by Mr. Weall of the Government Laboratories. In each case only one sample was taken, but it is highly probably that there would be a discrepancy in

the ...

the S.G. of any two specimens, even of the same colour, as that factor is affected very largely by the amount of included monazite which naturally varies. Allowing for this constituent, the S.G. of the Apatite itself would probably be found to be below the average.

The colour of apatite is very variable. Green, blue and yellow are the commonest. According to Doelter, red varieties are rare. The latter however are reported from Norway and Canada, and occur also in the Transvaal; the commonest colour in the Zoutpansberg district is green, but quite a number of reddish brown crystals occur and also a greenish white type. The last is possibly bleached green apatite.

The massive variety is found in shades of green, whilst the granular type is the colour of the crystal to which it adheres. The colour is, as a rule, lost on heating. Zimanyi found that in those specimens with which he experimented, decolourisation to transparency tookplace at 320°. The colour has been attributed by various writers to different elements, e.g. manganese and organic compounds in small amounts, . 02 Carbon, or .011 Hydrogen, but nothing has been definitely established.

The Refractive Index in sodium light is 1.6330 - 1.6482. Variability in this has been attributed to Chemical Composition. K.Walter maintains that the refractive index, double refraction and dispersion,

all ...

all increase with the Mn content, but the R.I. most of all. A connection between optical properties and Chlorine content has also been the subject of experiments with conflicting results. As in the case of Colour, no certain conclusion has been arrived at.

The mean R.I. of powdered green apatite from the Zoutpansberg district is 1.6382. E.S.Larsen gives the values as ϵ = 1.631 and ω = 1.634. He adds however that ω increases with the Chlorine content. The percentage of this element however is very small. in Transvaal apatite so that if it alone is responsible for the rise in the R.I. it must be very active. The R.I. of Norwegian chlor apatite is not known so that I could not estimate whether or not the increase is proportional.

Chemical Composition.

Apatite is an orthophosphate of CaO with varying amounts of Ca F_2 or Ca Cl_2. The Fluorine and Chlorine can replace each other and may, themselves, be replaced by OH to a certain extent. There is really an isomorphous series from Fluor-apatite - Chlorapatite, between which many intermediate stages exist which contain both fluorine and chlorine. The halogens may be replaced of O_2.

A.F.Rogers has proposed the name Voelckerite for Apatite without either Fluorine or chlorine. He explains the isomorphism of Voelkerite with Fluor and Chlor-Apatite by mass action isomorphism in which 1 atom ...

atom of oxygen is replaced by 2 atoms of Fluorine. He distinguishes between four isomorphous compounds.

Fluorapatite	3 Ca_3	$(PO_4)_2$	Ca F_2
Chlorapatite	3 Ca_3	$(PO_4)_2$	Ca Cl_2
Dahlite	3 Ca_3	$(PO_4)_2$	Ca CO_3
Voelckerite	3 Ca_3	$(PO_4)_2$	Ca O.

As these minerals are indistinguishable physically, and all have the general formula 3 Ca_3 $(PO_4)_2$ Ca (F_2 Cl_2, CO_3, O), the term Apatite is used to embrace them all. The CaO in Apatite is usually replaced to a small extent by Mn O_2, Fe_2O_3 and Mg.

The Transvaal Apatite is intermediate between the first 2 being a fluor-chlor apatite with a very low chlorine content. The rare earths are often associated with apatite apart from the inclusion of Monazite which characterizes both the Norwegian and Transvaal types. The Ce percent found by Scheerer in S.Norwegian augite was confirmed by Brogger. He investigated the fresh transparent wine-yellow crystals microscopically and found that the Ce was independent of cryptolite (monazite needles) inclusions.

F.Zambonini found in apatite crystals of Biella by spectroscopic methods, the presence of praesodimium, and confirms the opinion of Cossa that all apatite contains cerium metals in traces. When these are present in sufficient quantity, monazite

crystals ...

crystals form.

The analyses of two Zoutpansberg specimens are given below, with several from other localities for comparison.

(a) Fluor-apatite - Renfrew County, Ontario.
Analyst. - P.Jannasch. Ber.DTsch. Chem. Ges. 1910.

(b) Fluorchlor-Apatite. Reddish brown prisms from Renfrew, County Ontario, Canada. Analyst M.A.Carnot, Ann. Mines. Ser. 1896.

(c) Fluorchlor-Apatite. Green apatite from Zoutpansberg Dist.Northern Transvaal. Analyst. - Weall, 1925.

(d) Fluorchlor-Apatite. Whitish crystal from Zoutpansberg Dist.Northern Transvaal. Analyst. - Weall, 1925.

(e) Chlorapatite, from Atendal, Norway. Analyst. J.A. Voelcker. Ausz. Ber. DTsch. Chem. Ges. 1883.

(f) Apatite with rare earths from Suarum, Norway. Analyst R.Weber, Pofg. Ann. 1851.

TABLE ...

TABLE OF ANALYSES.

	a.	b.	c.	d.	e.	f.
Na_2O	0.92					
K_2O	0.50					
Mg O	1.34					
Ca O.	54.67	50.84	53.9	53.6	51.97	53.16
Mn O.						
Fe_2O_3	0.49	4.59	}	}	0.24	
Al_2O_3			} 0.8	} 0.7	0.91	
Fe O			}	}		
P_2O_5	39.68	41.00	41.45	41.9	40.48	41.82
F	3.75	2.24	1.6	1.55		
Cl		0.28	0.25	0.15	5.06	2.66
Moisture	0.12		0.1	0.1		
Loss on Ignition			0.4	0.35	0.14	
Silica		0.55	0.59	0.68		
Thoria			0.04	0.045		}
Ceria			0.66	0.77		} 1.76
Oxide of Yt, Na, Pr, Er.			0.59	0.69		} Incl. Fe_2O_3
Deduct Oxygen Equivalent of F and Cl			0.75	0.7		
CO_2		1.50				
SO_3					0.18	
Insoluble					1.77	
TOTAL	100.33	101.00	101.13	101.235	100.75	99.40

In the green apatite (c), there was 2.4% of material insoluble in nitric acid and 2.8% in the white (d). This would include free quartz and monazite. Apart from these there are no impurities such as alkalis, Mg or Mn in the apatite. By comparison with analyses of 80 different specimens of apatite from different parts of the world (given by C.Doelter in his Handbuch der Mineral-Chemie), the lime content of (c) and (d) is a good average. The Fe_2O_3, and Al_2O_3, vary more, as these are effected by external agencies but on the whole in these too (c) and (d) are average.

The P_2O_5 though it appears high in theTable above, is not by any means abnormal when compared with the wider range

The highest P_2O_5 content given by Doelter was 44.6 (Apatite from Tyrol), and the lowest 36.42 (This is a very incomplete analysis, the lowest otherwise being 38.14). There are only 8 out of 80 with P_2O_5 above 43%, and 3 below 39%, the majority being 40% and 41%.

The fluorine and chlorine percentages, however, are distinctly on the low side. Very few of the analyses had a combined halogen content of less than 2%, and those were chiefly chlor-apatite, some of which had only a trace of Cl and no Fl. As regards rare earths, only 4 analyses are given of apatite containing any. One from Greenland has 4.88, and 3 from Suarum, Norway, 1.86, 1.76 and 1.74.

There remains only the question of the

inclusions ...

MONAZITE

inclusions to be discussed. These are obvious even to a casual observer, particularly in the white apatite in which the yellow and brown monazite needles show up well. They seem also to be more numerous in the red variety than in the green. The analyses and specific gravities of the varieties seem to support this theory, as well as the fact that in Norway where green and red apatite occur, the monazite needles, called cryptolite, are acknowledged to be more abundant in the red. In every instance, the long axes of the needles are arranged parallel to the vertical axis of apatite crystals. The needles should more correctly be termed flattened prisms. The length varies, several more than [illegible] cms long were found, but the average is 1 cm. It is sometimes difficult to tell whether one needle is running into another. The breadth is usually about 2 mms (with the naked eye). The third dimension is too small to measure. On closer examination it is apparent that the flat sides of the needles are parallel always to a pair of apatite prism faces. A diagram of the arrangement is given ~~in~~ On Plate XVIII fig 2.

A thin slice of apatite, less than ¼" thick was cut as nearly as possible parallel to the base, and cemented to a glass plate with canada balsam. This was used in a radio-active photographic experiment. Every precaution was taken to exclude light. The result is not very satisfactory because, as it

appeared ...

PLATE XVII

Fig: 1 An aggregate of apatite grains of different orientation as shown by the monazite inclusions. Those marked a' are basal sections. This granular structure is typical of apatite inclusions in mixed rocks. (Specimen 723Cs See page) and massive apatite

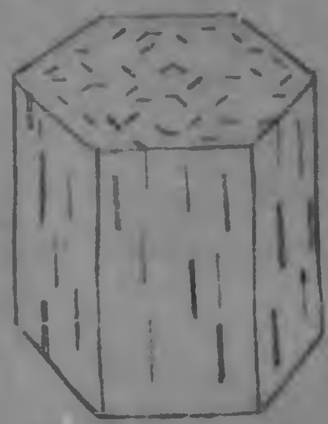


Fig. 2 Diagram of an apatite crystal showing the vertical and prismatic arrangement of monazite needles

Fig: 3 Photograph taken by radioactivity of monazite (see page)

PLATE XVII

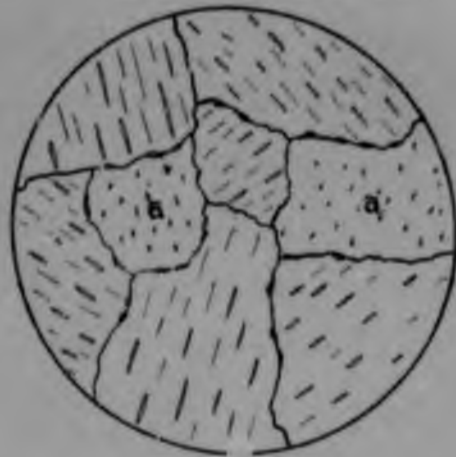


Fig: 1 An aggregate of apatite grains of different orientation as shown by the monazite inclusions. Those marked 'a' are basal sections. This granular structure is typical of apatite inclusions in mixed rocks. (Specimen 723C5. See page) and massive apatite

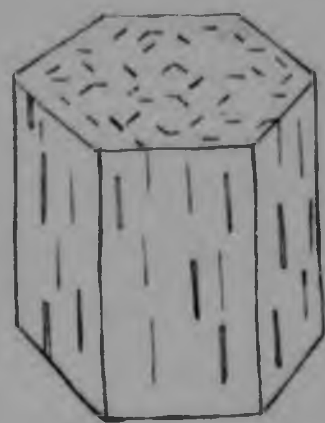


Fig: 2 Diagram of an apatite crystal showing the vertical and prismatic arrangement of monazite needles

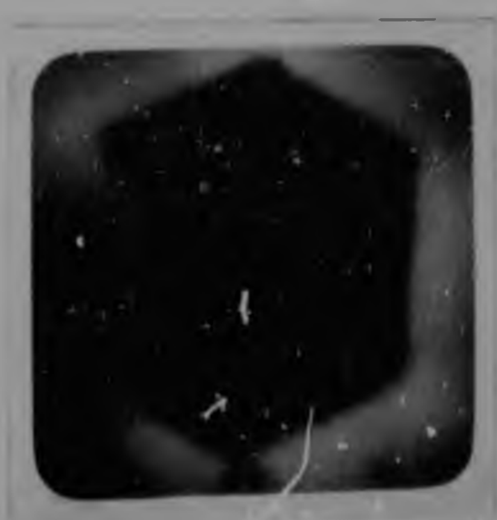


Fig: 3 Photograph taken by radioactivity of monazite (see page)

appeared later, the monazite is only slightly radio-active because of its low thorium content. In a basal section too, the sections of monazite exposed are so small that in any case a striking photograph was not to have been expected.

After six weeks the plate was developed: a very light print is given on Plate XVIII fig.3. In darker prints the arrangement of monazite was not so clear. The imprints of the smaller needles are blurred, but in a few of the larger ones the parallelism to the prism faces of apatite is evident.

Two thin sections of crystal apatite were cut, one basal and one prismatic. The apatite is crowded with inclusions. The monazite is not always in needle form, but sometimes in small irregular patches; the larger bodies are always crystalline.

In the prismatic section the irregular basal parting planes are very evident, some of these are filled with monazite; and one of the cracks is filled with granular quartz. Most of the monazite is distributed in long needles at right angles to the cracks. It is honey-yellow in fairly thin pieces, and brownish in thick sections. Irregular fragments of monazite and minute dark specks are scattered throughout the section.

In addition to the larger yellow monazite prisms, there are myriads of tiny colourless needles with the same orientation, all lying perfectly parallel.

These ...

These are visible even under low power where, however, most of them appear as single lines. When a small piece of apatite is put into Hydro-chloric acid it is attacked and partially dissolved, and from a basal section a forest of these minute colourless needles protrudes. They are, of course, extremely brittle, and fall off in a short while. Many of these are undoubtedly thin monazite needles but others are believed to be quartz. (The chemical analysis of the foreign matter in apatite indicates the presence of free quartz). The difficulty of isolating them and their extreme thinness made a determination difficult.

On fractured prismatic faces of apatite, long glassy green strips appear which look like quartz inclusions, but which are the smooth junction of apatite and monazite after the latter has fallen out.

MONAZITE.

This mineral occurs as already stated, in two distinct forms. In fine yellow needles in the apatite crystals, and in larger, reddish-brown, rolled grains distributed throughout a narrow pegmatite dyke but concentrated around apatite inclusions (See page 26).

A similar phenomenon is found in the granite of Arendal in Norway where wine yellow cryptolite prisms occur in the apatite crystals and are called cryptolite, whilst in the granite itself monazite occurs as reddish "fragments and rolled grains or as large coarse, reddish-brown crystals". It is not known what degree of coarseness is implied by the above statement, but none of the grains from the pegmatite of Schaapkraal showed any definite crystalinity. This is the only apparent point of difference in the two occurrences.

The terms "cryptolite" and "monazite" will be used to distinguish the two types, though they are thought to be identical mineralogically, the difference lying only in colour and mode of occurrence.

The cryptolite was identified first by chemical tests. On treating apatite crystals with concentrated nitric acid, it dissolved, leaving an insoluble residue of thin needles of an obviously foreign mineral. This residue when fused with

Sodium ...

Sodium Carbonate before the blow-pipe, dissolved in nitric acid, and added to a solution of $(NH_4)_2 Mo O_4$ gave the bright yellow precipitate of a phosphate. Monazite is the only fairly common phosphate insoluble in HNO_3. A rare earths test was tried by boiling a small quantity of finely ground powder with from 4-6 drops of concentrated sulphuric acid for some time. When cool it was diluted with 10 ccs of water and then ammonium oxalate added. A heavy white precipitate formed.

This is a preliminary test for monazite or xenotime. In dilute hydrochloric, nitric and sulphuric acids, the mineral bleaches but is not attacked. In c[illegible]trated sulphuric acid, however, after boiling fo[illegible]e time, a thick gelationous precipitate settl[illegible] but the process of solution is extremely slow. [illegible]ilar tests were tried in the case of the dark monazite with the same results. Spectroscopic methods were then tried, as these constitute an infallible proof of the presence of rare earths.

A small heap of cryptolite was placed on a slide on the stage of a Fuess microscope, which is provided with a small adjustable spectroscope. Light was concentrated on the powder by means of a powerful condensing lens which caused it to penetrate some distance into the mineral before being reflected back through the microscope tube. A spectrum resembling that of monazite was obtained. The

instrument ...

instrument was not perfect enough to determine the finer lines, but the distribution and proportions of the main dark bands were sufficiently accurate to prove the mineral to be monazite. An examination of dark monazite gave no spectrum however. This was, without doubt, due to the opacity of the substance which does not allow the passage of light.

The mineral was therefore decolourized by boiling in acid and then re-examined when a spectrum similar to that of cryptolite was obtained.

The radio activity of monazite is indirect proportion to the Thorium content. Some of the powdered monazite and some cryptolite were examined in an electroscope, but the result was disappointing for the gold leaf indicator moved very slowly. For comparison some monazite from Mbabane in Swaziland was examined, and showed a much higher radio activity. This may have been due partly to the fact that the material had been stored for several years in a closed tin.

Commercially, monazite is by far the most important of all the rare earth minerals, and it is almost entirely to the Thorium percentage that it owes its value, for its chief use is as a source of Ceria and Thoria used in the manufacture of incandescent gas mantles. The percentage of thorium, however, varies tremendously, from 1 to 29%, but averages about 5%. This variation has been the cause of much speculation and, more recently, of many experiments. There were

two ...

two possibilities of combination, by mechanical mixture or in solid solution. Penfield found small dark specks in monazite, which he believed to be thorite, (Th Si O_4), and that Th was embodied in this form.

Kress and Metzger, in over 50 analyses from 30 different specimens, came to the conclusion that the Thorium present as phosphate is an essential constituent, but that there is always some admixed silicate, probably feldspar.

Doelter, after considering the results of many investigations, expresses the opinion that monazite is a solid solution of cerium phosphate, and thorium phosphate, and occasionally thorium silicate (Thorite). SiO_2, Ce_2O_3 and ThO_2, may be present in small amounts, but the theory of the mechanical mixture of ThO_2 and ThS $ThSiO_4$ with monazite is not tenable.

The following analyses were made by Mr.Weall of the Government Laboratories, (a) of cryptolite, (b) of monazite from Bandolier Kop. Unfortunately the same means of separating the two types from their country rock, was not employed; the discrepancies are due to this fact.

Analysis (a) is that of the insoluble material after treating an apatite crystal with concentrated H_2SO_4 HNO_3 and would include any free quartz in the sample. As already stated, there are numbers of fine colourless needles which are believed to be quartz and many of the cryptolite needles appear to be surrounded by a thin casing of quartz so that this constituent would

be ...

be present in appreciable quantity. The very high silica percentage and the consequently much lower percentages of other constituents in (a) is explained in this way.

(a) Analysis of insoluble material, after treating an apatite crystal with HNO_3:-

SiO_2	24.4
P_2O_5	22.15
ThO_2	1.6
CeO_2	27.6
Oxides of Yt,La,Nd,Pr,Er.	24.8
	100.9

If this insoluble material had been finely ground and shaken up in methylene iodide, the quartz would have been separated. This procedure was followed in the case of "b". The average silicate percentage of 11 analyses given in Doelter was 1.836. If this is taken as the silica content of Bandolier Kop cryptolite, the precentages will be raised to the figures given below, for (a.) which are nearer to ordinary analyses. This is admittedly inaccurate, because certain analyses do give a fairly high SiO_2 percentage, though never as high as 24.4 The highest found anywhere was 9.65, which was very abnormal. The majority lay between 1-2%.

A table of 6 analyses is given below for comparison. (a) Cryptolite, Bandolier Kop, (b) Monazite from Bandolier Kop, (c) North Carolina, biggest producer of monazite until the opening of Brazil. (Analyst A.Thorpe 1896). (d) Brazilian-

Espirtu ...

Espirtu Santo (Analyst Sidney J.Johnstone 1914).

(e) Transvaal (locality not given. Analyst L.Andersen-Aars, 1905).

TABLE OF ANALYSES.

	a_1.	b.	c.	d.	e.
$Ce\ O_2$	35.79	29.10			
Ce_2O_3	(34.13)	(27.[illegible]5)	25.98	62.12 (Ce₂O₃ + La₂O₃)	34.58
La_2O_3	32.17 (La₂O₃ – Er₂O₃)	33.60 (La₂O₃ + Di₂O₃)	23.62		11.25
Di_2O_3					16.00
Y_2O_3					2.[illegible]4
Er_2O_3					
$Th\ O_2$	2.07	2.40	18.01	6.06	3.6[illegible]
P_2O_5	28.72	27.70	28.43	28.50	27.38
$Ca\ O$		0.40	0.91	0.21	0.31
Fe_2O_3		4.00		0.97	0.44
Al_2O_3		.60		.10	.86
$Si\ O_2$	1.84	1.80		0.75	1.52
$Sn\ O_2$			1.62		0.29
$Mn\ O$			1.33		
Ta_2O_5					0.15
Loss on ignition				0.38	2.21
Total.	100.39	99.60	99.90	99.89	100.64

The most notable features of (a_1) and (b) are the high percentages of oxides of Yt, Er, La and Di, their low ThO_2 content and the very high Fe_2O_3 of b. In 60 analyses of monazite from all parts of the world, only two were found with Fe_2O_3 content anywhere near

this ...

this. One was impure monazite from Norway, 4.63, and one from Northern Nigeria, 3.00. It is probable that most of the Fe_2O_3 is secondary, which conclusion is supported by physical evidences.

The Bandolier Kop Monazite is of no value commercially, even had there been large quantities of it, because of its small Thorium content. This applies also to other South African monazite.

Some very interesting experiments have lately been carried out in thorium bearing rocks in connection with estimating the age of various rock formations by determining the proportion of helium given off by radioactive substances present in them, or by the ratio of lead to uranium or lead to thorium, the rate at which these substances disintegrate being known. Results have been checked by specimens of relatively known age. Lower Devonian rocks have been estimated at 370 million years and Pre-Cambrian at 1000-1640 million years, which is greater than the age estimated by either palaeontologists or physicists. Thorium is important because Helium is almost never found unless Thorium is present. Uranium and Radium compounds containing no Thorium may have no Helium. Means of estimating the helium content are not ordinarily available. If they had been it is possible that where the palaeontological correlation of South African strata with those in other parts of the world has not been feasible, these chemical methods would succeed.

The ...

PLATE XVIII

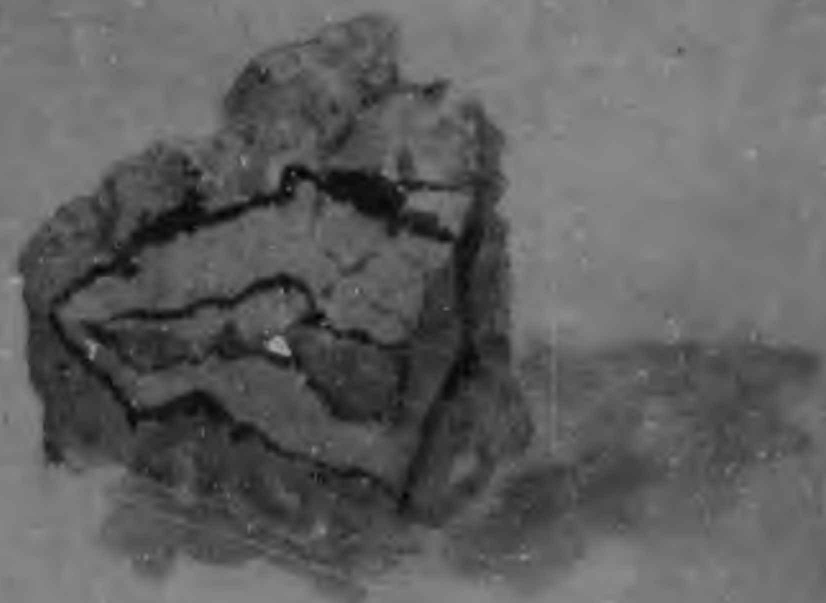


Fig 1. A vein of apatite in pegmatite. Quartz is very dark bluish grey. Feldspar is much discoloured. Apatite is surrounded by a thick zone of monazite and has numerous minute inclusions of the same mineral (specimen [illegible] See page [illegible])

Fig 2 Similar specimens

PLATE XVIII

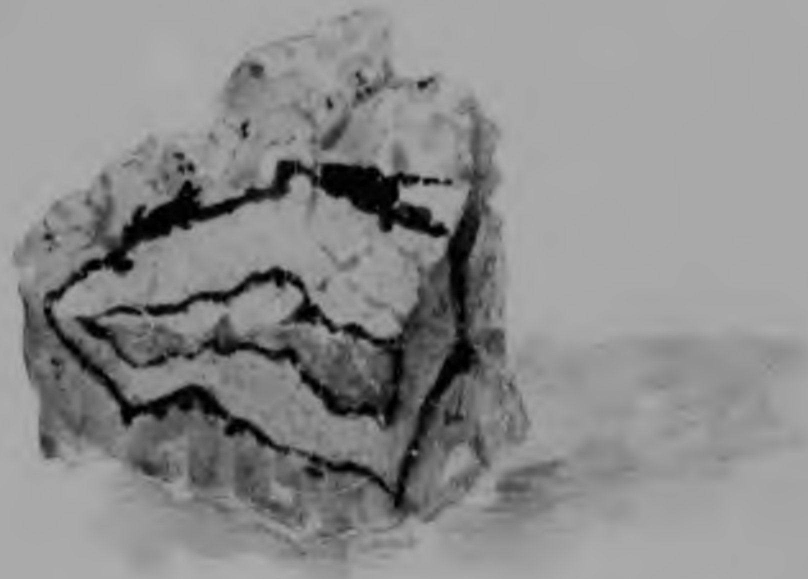


Fig 1 A vein of apatite in pegmatite. Quartz is very dark bluish grey. Feldspar is much discoloured. Apatite is surrounded by a thick zone of monazite and has numerous minute inclusions of the same mineral (Specimen nat size See page 85)

Fig. 2 Similar specimens

The occurrence of red monazite is shown on Plate XVI figs. 1 and 2 and on Plate XIX fig.2. The percentage of monazite in these specimens is obviously very much higher than in the normal apatite bearing pegmatite. The inclusions of monazite in the apatite bodies are very numerous and the latter are surrounded in addition by a bordering of monazite grains. Little veins of the red mineral branch out from this border into the pegmatite and isolated grains and specks are scattered in the vicinity. The figs. on Plate XVIII both show the apatite inclusions but in fig.2 on Plate XIX the flat face of the specimen is cut parallel to the inclusion and the dark bands of monazite are cross sections of veins branching off from the apatite. It would seem therefore that where the rare earths were present in large quantities, monazite separated out first, lining the irregular space available and pushing into any radiating cavities until the temperature or other conditions governing the crystallisation of apatite, allowed that mineral to solidify in conjunction with the small remnant of monazite solution.

A macroscopic slide was made from the face of the specimen shown in fig. 2 plate XIX. A sketch of it is given above. It is evident on casual examination that the red colouration is concentrated in cleavage planes and cracks from which it spreads outwards until occasionally whole grains are stained a brownish red. The colour varies in intensity

being ...

PLATE XIX

Fig: 1 Drawing of slide showing concentration of iron oxide in cleavage cracks of monazite. Light material is quartz, grey is decomposed included schist. 1 piece of magnetite on the right

Fig: 2 Hand specimen from which slide was taken showing monazite & quartz and narrow vein of schist running from left to right being very dense in grains which are traversed by many cracks. Large pieces however, often show no signs of this impregnation and remain the light honey yellow colour of the cryptolite needles. The nature and manner of the red colouring, as well as the high percentage of Fe_2O_3 shown by chemical analysis, leaves no doubt that iron oxide is the colouring agent. It is of secondary origin and probably derived from the iron bearing minerals of included schist. In the slide a piece of magnetite is seen in the middle of a dense red patch and irregular inclusions of greenish grey schist are common. The quartz is impregnated with foreign matter along all cracks. It occurs in fairly large pieces and is granular at the margins. The cleavage is very distinct in the slide. Some fragments show perfect parallel cleavage, others an intersecting rhombic cleavage which however is not so distinct. Others show signs of three cleavage directions but in such the spreading of iron oxides has masked the angles.

According to Levy, common forms in monazite crystals are ortho and clino pinacoids, a (100) & b (010), hemiprisms m (110) and n (120) hemi orthoprisms w (101) & x (101), hemiclinoprism e (011), hemipyramid v (111) etc. basal pinacoid rare. The habit is tabular parallel to 'a'. Crystals may be needle shaped by elongation parallel to 'b' axis or prismatic by a good development of v.

Cleavage parallel to 'c' is perfect; parallel to a distinct and parallel to b difficult. The

plane ...

plane of the optic axes is perpendicular to b and nearly parallel to a. The acute bisectrix is inclined to a at an anle of 1° - 4°. As no distinct crystals were foundin dark monazite the actual form of crystallisation is unknown. Early reports on cryptolite class the mineral as either tetragonal or hexagonal. Both the cryptolite and dark monazite from Bandolier Kop however gave biaxial positive interference figures.

The evidence of interference figures alone is not sufficient to determine the crystalisation of a mineral and even in these iron oxide masked most of the figures in the monazite slide and a thin film of apatite either above or below confused the figures obtained from fine needles of cryptolite.

The few indications obtained however accord with those given by Levy e.g. In the dark monazite the best figures were obtained from pieces which did not show good cleavage. These showed the emergence of both optic axes. In the cryptolite the needles will only lie on one face so that all the figures obtained were of one type, showing a large axial angle, broad ill defined brushes and no coloured rings which is to be expected if elongation isparallel to b. It is highly probable that the crystallisation is the same as that determined by Levy and Dana. No alternative elongation is given in any of the text books to which reference was made but possibly all the authors

have ...

have accepted the original description as correct.

In sections showing only one perfect cleavage the extinction ∠s are small varying from 4° - 12°.

In colour, lustre, hardness etc. the monazite is according to type. The specific gravity determined by a specific gravity bottle is 5.185 (According to Dana, S.G. of monazite is 4.9 - 5.3 but mostly 5.0 - 5.2).

Mineralogically and in its mode of occurrence the Zoutpansberg monazite is similar to that in other parts of the world except that no references can be found anywhere to the fringing of apatite veins and inclusions by solid monazite, so that it is either unique or hitherto unnoticed.

Monazite is an extremely stable mineral. It occurs in situ only in old rocks. According to Levy it will probably never be found in Mesozoic rocks, and yet it is always fairly fresh. The crystalline material is found sometimes in veins, but more often in tiny crystals disseminated throughout the mass.

Lindgren says that monazite is found only in veins developed at high temperature, and not in those nearer the surface or under conditions of lessened temperature and pressure. In Norway the pegmatite dykes containing monazite are granite off-throws. In Carolina and Georgia and in the Aymore's Mountains in Brazil it is both massive and granular and occurs in gneiss. It is quite common in pegmatite veins in granite. In Queensland, on the Walsh and Tinaroo

mineral ...

mineral fields, it is found both massive and granular in veins in granite associated with wolframite molybdenite and cassiterite.

In small quantities it has a wide distribution as an accessory of granitic diorites and gneisses. In South Africa the three known occurrences at Embabane in Swaziland and Bardolier Kop in the Zoutpansberg District where it occurs in Swaziland rocks and at Houtenbek in the Bushveld where it is associated with fluorite, molybdenite, etc.,in veins in Bushveld granite.

By far the most important source of the mineral is not from the parent rock but from the sands derived from it which collect in river courses and beaches. Magnetite, ilmenite, zircon, garnet and quartz occur commonly in Monazite sands. The most extensive deposits are in Brazil in the provinces of Minas Geraes, Bahia, Espirito Santo, and Rio de Janeiro where they form part of the actual beach between tide marks. Here, the large quantities available, the high Th percentage, the even quality of the sand, and the easy transport, have made these deposits the most importantin the world, and since their discovery, the Carolina monazite has scarcely been worked.

Other large deposits are in Ceylon in India in the State of Travancore on the coast. This latter

contains ....

contains 8-10% Th and is of high grade. It is found also in Queensland, Madagascar, in the Urals, in many parts of the Pacific States of North America, etc. Until the sands have been exhausted, which will not be for a very long time, rock deposits are not likely to be of any value except those with a very high Thorium content.

A GENERAL SUMMARY OF THE NATURE OF THE APATITE DEPOSITS.

From the foregoing it is evident that the Apatite occurs intimately connected with pegmatitic intrusions and is subject to the vagaries common to such bodies. The gneiss in which the pegmatite is intruded has every appearance of being of igneous origin and basic composition as evidenced by the overwhelming percentage of ferromagnesian minerals, supplemented by basic plagioclase, garnet and iron oxides. Quartz and orthoclase are not essential minerals.

The structural trend of the gneissic rocks is from W.S.W. - E.N.E. This has influenced the intrusion of the pegmatite bodies so that the main deposit at No.I has an interbedded relation to the gneiss bordering it. The apatite in the pegmatite has followed these lines and occurs in bedded veins with the strike and dip directions of the other rocks. In some places however the pegmatites are found cutting across the general trend of the country rocks and are far more irregular as a result. Consequently the apatite contained may swell out into pockets, branch into small veins or die out. These irregularities complicate mining.

The phosphates are never found at any great distance from basic rocks so that they tend to be concentrated within the pegmatite body along its margins or occurs in small veins and stringers intrusive in the country rock.

Apatite may form an intimate mixture with the gneissose minerals but is always accompanied by a certain amount of its parent pegmatite. The mixed rocks of the transition ...

transition zone therefore contain all three type rocks. The soft green schist which occurs so intimately associated with apatite bearing pegmatite is believed to represent altered gneiss, of which large bodies were included in the pegmatite magna.

The effect of the pegmatite bodies on gneiss is to alter much of the augite to hornblende. No augite was seen anywhere directly connected with apatite. A further stage in the alteration changes hornblende to biotite, so that bordering pegmatite bodies there is invariably a soft zone of biotite, chlorite, feldspar rock which crumbles easily when rubbed. Where the pegmatite veins are thin the metamorphism produced in the adjoining gneiss is not so marked. It [illegible] remain apparently unaltered as in the bed rocks of the stream to the south of the workings and thehard gneiss foundin No.I. The latter apparently marks the end of the pegmatite in that direction and represents the edge of a large body of gneiss. This fact is borne out by the whole hill northwards being covered with boulders of gneiss. Though not altered to soft material its minerals have been effected by their close contact with pegmatite with the result that immense quantities of biotite are found. Quartz becomes an important constituent and the augite is very pleochroic which are factors absent from the gneiss further away e.g. Mahila's Kop.

Monazite of a low thorium content is present in all the apatite in the form of fine needles which follow the crystalline directions of the latter. Where the pegmatite body is very narrow the percentage of phosphate increases and monazite occurs in massive form. It is confined noticeably to the contact of apatite with the other pegmatite minerals.

Masses ...

Masses of barite very irregular in form but following the apatite closely and as a rule enclosing it, occur also in the pegmatite bodies. Barite does not mix to the same extent as apatite with the country rocks though occasionally small pieces of it occur in mixed rocks, and wherever it occurs, apatite is found either massive or crystalline, embedded in it rather than in quartz and feldspar.

The feldspar too is effected by its contact with schist and phosphatic minerals and shows discolouration. It alters commonly to epidote which occurs filling in many of the cracks in pegmatite.

A COMPARISON OF THE BANDOLIER KOP APATITE WITH SIMILAR DEPOSITS IN NORWAY & CANADA.

In both Norway and Canada apatite occurs in pegmatites in the Laurentian Group of archaen rocks. The occurrences are in many respects similar and both resemble the South African deposit. A comparison can more easily be made by dealing with the foreign deposits separately.

The Norwegian. Most of the information regarding these deposits was obtained from O.C.Davies' book on Earthy and other minerals and mining supplemented by brief accounts from various other sources.

The literature on the subject is not abundant and most of it unobtainable in this country. The deposits lie in a strip of land along the east coast of Norway, west of the Skager Rack and extent from Kragero to Arendal. The parent rock is a dark grey, granular, gneissic rock with a high % of hornblende, which determines the colour. Apatite occurs in veins, nests, pockets, in beds (see plate XX figs 1,2,3 & 4) and in large crystals.

The veins are shrinkage cracks filled with apatite and its associated minerals. They run for several hundred yards along the strike and the apatite lies in these veins in pockets and wedge shaped masses averaging 4' by 8', which are connected by strings of apatite and hornblende. A hornblende

casing ...

PLATE XX

Apatite Deposits in Norway (Earthy & other minerals & mining Jones)

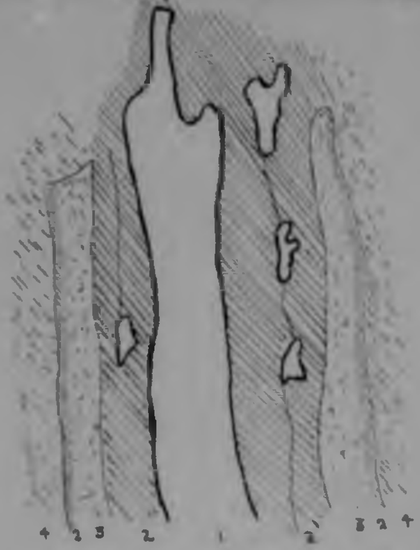


Fig: 1 Apatite Veins Godfield

1 Apatite
2 Hornblende large flakes of mica, & some titanic iron ore
3 White & grey granular } ie gneiss
4. Dark & grey granular } ie gneiss

Fig 2 Apatite vein Tvitrae

1 Apatite vein & stringers
2 Hornblende
3 Quartz stringers
4 Gneiss.

Fig 3 Rich lode near Farsjo Apatite pockets

1 Apatite
2 Hornblende
3 Quartz bands
4 Gneiss.

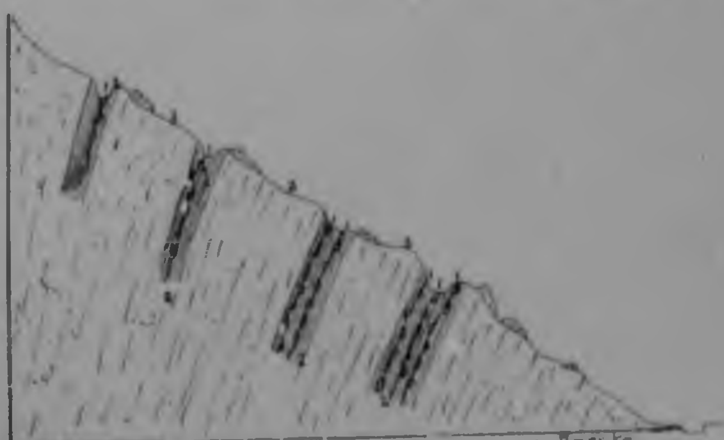


Fig 4 Bedded Apatite Deposits Midbo

1 Apatite
2 Hornblende
3 Gneiss

casing of ½" - 1" thick surrounds all apatite bodies and wherever this continues the miner has hopes of finding another apatite pocket. The restof the vein, about 3/5, is dull quartz. The veins are not always continuous in depth and their worth can only be estimated where a long strike is exposed.

Where apatite occurs in pockets, similar conditions prevail but the apatite is more uncertain. In one case a cluster of nests 30' in length died out at a depth of a few yds. The hornblende crystals always point in length, towards the apatite.

The most valuable deposits occur in beds from 6" to 2' wide interstratified with gneissic rock. They are not regarded by all as true beds but simply veins occupying beddingplanes for though many are traceable for some distance on the surface, others die out at either end in thespace of a few feet. In this type especially good separate crystals of apatite occur. Much rutile is associated with the apatite which ranges in colour from cream white and green to red. The Norwegian apatite is essentially a chlorapatite.

Davies says "the containing gneissic rock is often varied by passing into large masses of pink and red feldspar especially in the immediate vicinity of the apatite pockets. Dykes of the same substance and also of granite not infrequently cross the strata and cut off the veins. He however without any hesitation attributes the apatite to sedimentary

agents ...

agents, and infers from the absence of any organic remains "that they are the original deposits of apatite from phosphatic matter disseminated in the water of those early seas, derived probably from gaseous emanations and eruptions in the interior of the earth and deposited pure and simple without having passed through the structure and substance of living organisms. The gathering of the mineral into separate masses distinct from the rest of the strata, with the crystalline fringe of hornblende and titaniferous iron ore, indicates considerable chemical action, with its resulting crystalline conditions, subsequent to these depositions of the phosphatic matter." This description was published in 1892. The author had spent some time on the workings and his theory of the genesis of the deposit is interesting because it would represent the opinions generally held at the time when the workings were at the height of their development. He does not apparently connect the "masses of pink and red feldspar in the immediate vicinity of the apatite pockets" with their genesis.

In the apatite crystals of these deposits, particularly the red variety, needles of cryptolite occur, in minute 6-sided prisms (according to Davies) this cryptolite has since proved to be monazite and it is probable that the 6 sided description is an error.

The writer was unfortunately unable to procure Brogger's ...

Brogger's treaties on the igneous rocks of this area, including a discussion of the apatite pegmatite which is the standard work on this subject. Later writers however apparently on his authority place the Norwegian deposits in the category of basic pegmatites and do not question their igneous origin.

The Canadian Deposits.

Apatite occurs in vast quantities in the Provinces of Quebec and Ontario. Regarding these there is far more information, the most valuable being contained in a memoir by Hugh S.Spence, M.E. on Phosphate in Canada, published by the Mines Branch of the Canadian Department of Mines. This is a very complete description and discussion of the deposits although more from the economic than scientific standpoint.

Apparently in Canada as in South Africa the problem of correlating archaen strata is very great and the pyroxenites with which apatite is associated may be metamorphic products of pre-existent sediments formed by the agency of injected acid masses, or dykes of later origin than the rocks enclosing them. The latest geological survey 1913-1920 recognises an old sedimentary series of 1. Quartz rock; 2 Sillimanite garnet gneiss, and 3. Cryst limestone. All these were intruded by the pre Cambrian basal complex which ranges from pyroxene granite to peridotite and possesses everywhere a gneissose character. All the former were intruded later by diabase dykes.

This recognises 2 gneisses, 1 sedimentary and 1 igneous. Apatite is associated with the former

and ...

PLATE XXI.

Apatite Deposits in Canada (Phosphate in Canada A S Spend

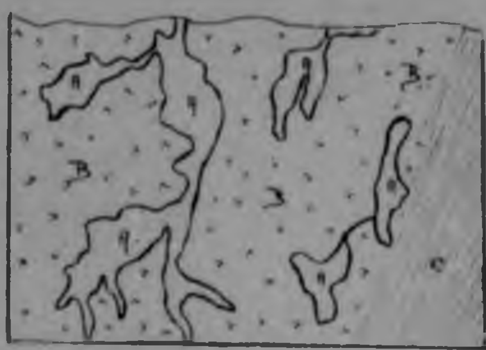


Fig 1 Pockety form commonly assumed

A Apatite leads & pockets
B Pyroxenite
C Country gneiss

Fig 2 Section of working Portland East

A Apatite
B Pyroxenite
C Feldspar
D Country gneiss

Fig 3 Section of working Portland East

A Apatite
B Pyroxenite
C Feldspar
D Mica

and is therefore contemporaneous with the intrusion of the sedimentary series by the basal complex. The intense metamorphism which took place before the intrusion of the diabase dykes has greatly obscured the original relationships.

Apatite bodies occur in a number of forms, generally irregularly shaped pockets joined up by small stringers or veinlets see Plate XXI figs. 1, 2 and 3. Various classifications based on local variations in form, association of constituent minerals and the nature of the enclosing rock, have been attempted, but as the deposits are all of similar age and origin and one type of_ten merges into another, such distinction seems futile. Mr.Spence objects to the term "vein" in connection with apatite for he says the deposits have no defined walls - the bodies usually having the appearance of having segregated in place from the enclosing rock or of being a metasomatic replacement of the latter.

Three phases of the type deposits are recognised which grade into one another. (a) Groups of several narrow and approximately parallel leads, separated by bands of pyroxenite or gneiss. Length along the strike varies from a few hundred feet to much less; width from 25 feet but usually much less. They are generally vertical. There is always a certain amount of calcite. The walls of the deposits are a casing of dark coloured pyroxenite separating it from the gneissic rock.

(b) Instead of a number of leads 1 main body occurs usually 25-50' wide. These carry even more

calcite ...

calcite than (a). Throughout the latter mineral there are numerous scattered small phlogopite and apatite crystals.

(c) In which form all economically important apatite bodies are found, consists of irregular pockets, chimneys or shoots in a rock composed of pyroxene, feldspar and quartz. These are seldom at all regular and may die out suddenly in depth. They may be joined by veinlets or be quite disconnected. Mica and Calcite occur in large amounts but apatite preponderates.

Crystals of pyroxene line the walls. The deepest mine is in the Lievre district where a deposit was worked to a depth of 600' where apatite showed no signs of dying out. The pockets and veins commonly dip between 45° and 90°. As a general rule the veins dip at angles from 60° - 90°. The pockets too are nearer vertical than horizontal. All however widen and narrow considerably.

Apatite occurs in 3 forms massive, sugar and crystalline. Massive apatite forms the bulk of the filling of the large pockets, usually dark green but occurs in red brown, yellowish and blue shades. Sugar Apatite consists of small rounded grains aggregated into coherent masses but which will readily disintegrate on rubbing. The colour is greenish white. As a type it is less common. Crystalline Apatite consists of prisms terminated by pyramids and is especially common in those deposits where mica

and ...

and calcite are abundant. The best crystals are obtained from pockets in pyroxenite where they occur lining the walls closely associated with pyroxene crystals, enclosed in calcite filling. The angles are conspicuously rounded, sharp outlines being very rare and the faces are frequently pitted and exhibit a glazed surface as if they had been subjected to some resorbent action. The Canadian apatite is essentially a fluorapatite (See analysis on page 73)

The pyroxenites are principally monoclinic though orthorhombic varieties occur. In colour they range from dark green to light grey sometimes a large amount of black hornblende is present. The pyroxene frequently alters to soft greenish actinolite when cut by large pegmatite dykes.

The irregular masses of grey-brown feldspar, orthoclase and microcline or feldspar quartz bodies are frequently found in the pyroxenite. They are extremely uniform in character and are regarded as being the last, and pegmatitic, phase of the intrusion of the basic basal complex. They bear therefore only an indirect relationship to apatite and by no means the intimate association shown at Bandolier Kop.

Scapolite is an important mineral in the deposits and is usually regarded as an alteration product of feldspar.

Barite is only found in one spot where masses of small tabular crystals were found encrusting drusy cavities in calcite. The mineral occurs also in small veins in both Ontario and Quebec but is not

associated ...

associated with apatite. It is impure being grey or reddish brown in colour.

Calcite is invariably present.

Chlorite is apparently not very common.

Epidote is occasionally met with. It is greenish yellow and occurs with dark pyroxene.

Garnet is common in the gneisses and limestones but rarely found in apatite bodies.

Hornblende as a pseudomorph of pyroxene is very common and it occurs also as a primary mineral along borders of pyroxenites with limestones. It is quite fresh and black and lustrous. ~~Cietuolite~~ Actinolite in stout green prisms, fibrous mountain leather and asbestos also occur.

Magnetite is not common.

Orthoclase is usually subsidiary to microcline which is the commonest feldspar.

Phlogopite Mica. It is for this mineral that the deposits are now mined, apatite being only a bye product. The crystals are sometimes very large up to 4 feet in diameter which far larger than anything seen at Bandolier Kop.

Quartz is somewhat of a rarity.

The other associated minerals have not been mentioned here because they have no counterpart in the Transvaal and no direct bearing on the nature of the occurrence.

: : : : : : : : : : :

GENESIS OF THE DEPOSITS.

The question of the genesis of the Zoutpansberg phosphate deposits is greatly complicated by the occurrence of 3 minerals, commonly associated with widely different origins, occurring in the same formation. Monazite is a primary igneous mineral; Apatite may be primary or secondary, igneous or sedimentary; whilst Barite in any quantity is invariably a secondary mineral.

The two greatest apatite deposits in the world, which have just been described, presented great difficulties to the mining engineers and geologists who studied them. The uncertainty embraced the associated basic rocks as well as the apatite. The opinions hitherto expressed have been divided between sedimentary apatite, deposits subsequently metamorphosed and in some instances redistributed in veins by aqueous solution, and thirdly, apatite connected with the intrusion of basic igneous rocks. There is rarely a suggestion in any literature of the association of

apatite ...

probably ...

apatite with acid igneous rocks. The theory of sedimentary origin by original deposition at the same time as the deposition of gneisses and limestones as sediments is no longer considered feasible. The metamorphic and igneous theories claim about equal numbers of followers. F.Adams and A.Barlow in discussing the pyroxenites of the Haliburton and Bancroft area believe them to be altered limestones and that both apatite and mica were formed during the metamorphic process. E.Coste advanced the idea that the apatite was wholly of igneous origin and that it has been brought in by magmatic material injected into the Archaean series. The phosphatic mineral tends to segregate in masses along the contacts. This theory of pneumatolytic action as a result of igneous intrusion is more or less accepted today but the nature of the igneous rock is still disputed. Most geologists regard the igneous pyroxenites as the source of the phosphatic material. In both Norway and Canada granite is quite subsidiary to basic rocks in the vicinity of apatite deposits and in nearly all text books in which reference is made to the deposits they are dismissed casually as being connected with basic pegmatites.

H.S.Spence however although making full acknowledgments of the merits of these claims summarises in a paragraph which might easily have been written of the S.African deposits.

"The pyroxenites represent metamorphosed limestones which have been invaded, disrupted and engulfed by immense batholithic masses of granite to which latter rock a gneissic character has been imparted by subsequent dynamic movements."

"The origin of the mica-apatite-calcite bodies is

probably ...

probably to be attributed to the agency of late pegmatitic phases of this granite and of the aqueous solutions accompanying the pegmatites. These solutions were charged wit phosphoric acid and the apatite is therefore to be considered of igneous origin, rather than to have been derived from the original limestones. The calcite probably represents calcium carbonate dissolved from the limestones by heated waters and redeposited in cavities in the pyroxenites, while the mica is of contact metamorphic origin."

The connection of theTransvaal apatite with granite pegmatite is far more marked than, judging from the description, it is in Canada. Whilst in the Transvaal the igneous origin is endorsed by the presence of monazite. The absence of sedimentary limestones in the vicinity removes the possibility of the bedded massive apatite being altered limestone, but it removes also a possible source of barite which is the South African substitute for the Canadian calcite, unless the basic rocks like those of Canada are altered calcareous rock.

Although the apatite is accepted by this theory as being directly connected with granite pegmatite it must be more than a mere coincidence that in every deposit of this nature throughout the world, ferromagnesian rocks, whether of acknowledged igneous origin or the product of metamorphism, are intimately associated with the phosphates.

In 'The Natural History of Igneous Rocks", Harker discusses pegmatites fully and devides them into Basic, intermediate and acid types. He classes apatite as basic saying "In the gabbro family the most important type of pneumatolytic action is that which has given rise to the valuable apatite veins of Norway and Canada." He regards chlorides as playing the chief part as solvents, in circulating the solution.

J.Lindgren ...

J.Lindgren too, in his book on "Mineral Deposits" with reference to acidic pegmatites gives boron and fluorine as the chief mineralisers with a little phosphorus and sulphur. Orthoclase, albite and quartz are always present and usually microcline and muscovite. Accessory minerals are magnetite, tourmaline, fluorite, cassiterite, apatite, monazite and many others. He states further that basic pegmatites are less common. In these boron and fluorine are not usually present but phosphorus and chlorine and probably also sulphur play important parts. He quotes apatite as the chief example. "With the pegmatites of gabbros and allied rocks should be classed the apatite and scapolite veins of Norway and Canada. Though they are allied to fissure veins in some features there is little doubt that they are really pegmatites belonging to a late stage of magmatic consolidation.

Both of these authorities therefore agree on the basic character though Lindgren expresses the view that the fluorapatite of Canada is possibly of a different type from chlorapatite of Norway as ordinarily fluorine in associated with acid and chlorine with basic magmas.

The South African apatite is a fluorchlor apatite and presents therefore further complications.

There is one last possibility that the great bulk of the parent magma was basic in character and gave rise to the basic gneissic rocks in the neighbourhood. These may have engulfed masses of schistose rocks and possibly limestones of sedimentary origin, during the intrusion. In the residual liquid of such a magma much of the acidic matter would be left, as well as a great deal of water and the chief part of all constituents more soluble at that temperature in water than in silicate solution. "They would include boric, carbonic, and hydrosulphuric acids, fluorides ....

fluorides, chlorides and borates of alkali metals and metals of rare earths." All these are constituents necessary for the formation of pegmatite such as occurs in the Northern Transvaal. The order of crystallisation was apparently orthoclase followed by a graphic intergrowth of feldspar and quartz, when the stage of eutectic crystallisation was reached. This would leave a liquid rich in water, phosphorus, fluorine, chlorine, sulphur and metals of the rare earths. The liquid would be at an even lower temperature than the normal pegmatitic solution, but would be more fluid by the concentration in it of so many volatile constituents. It would travel through cavities in the almost consolidated quartz and feldspar rock probably concentrating in shrinkage cracks and fissures which would naturally be most numerous at the margins of the pegmatite body. Its great fluidity would make intrusion in the finest apophyses possible so that it might penetrate the contiguous rocks to a considerable extent. In this way irregular veins and pockets of phosphate bearing rock would form along the borders of pegmatite bodies which would in addition be surrounded by a zone of country rock impregnated with phosphatic liquid. The constant association of hornblende with apatite is not explained by this theory, and it seems strange that none of the great pegmatite intrusions, into other than basic rocks, have been accompanied by similar apatite veins, if the source of the mineral lies wholly in the pegmatite.

The intrusion of acid igneous rocks into limestone is always accompanied by the formation of apatite in varying quantities, dependent on the percentage of phosphorus and fluorine presentin the magma. The suggestion is therefore put forward that the lime of the apatite is derived from

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the lime bearing minerals of the associated ferromagnesian rocks. These may, as in the Canadian types, be metamorphosed limestones but whatever their origin the percentage of lime they contain would be sufficient to combine with the other constituents of the pegmatite to form apatite. Such a theory could be applied to the deposits of all three continents and would explain more satisfactorily the marginal distribution of the mineral and the isolation of large bodies of apatite in pyroxenite such as those shown on Plate XXI.

The injection would be essentially the same as that described above, with the added factor that apatite would form around schist inclusions in the pegmatite.

The crystallisation point of monazite and apatite throughout these deposits must have been simultaneous the two minerals being essentially combined in solution. The monazite pegmatite can only be attributed to a local segregation of rare earth elements in that particular region. The increase of this constituent caused monazite to crystallise out first and so line the cavities along which the [illegible] travelled. The interior of any such fissure being f[illegible]h the ordinary combined apatite and monazite.

Lastly there is the question of barite to be considered. Barite of igneous origin is practically unknown and it doesnot occur in contact metamorphic or pegmatitic rocks.

Lindgren classifies almost all barite deposits as veins of crystalline mineral formed by aqueous solution in almost any kind of rock, sedimentary or igneous. "It is often associated with metallic sulphides, particularly galena. Quartz calcite and fluorite accompany it. Some of these veins result from precipitation in ascending hot waters for

barite ...

barite is often found at the mouths of springs. The original source of the barium is oft… not determined but is believed to be dissolved by water from barium bearing rocks encountered in its path. In most cases of economic importance it can be traced to limestones. Probably all limestones contain a little and most igneous rocks have about .1% Ba." In B the Zoutpansberg district both the limestones and metallic sulphides are missing. Pyrite is foundin very small quantities in the gneiss but no other sulphide is known. The only other possible source of sulphur is from the pegmatite in which it is a common mineraliser. The barium may have come from the gneissic rock. The possibility of its origin in barium feldspar was dismissed because analysis of the associated feldspar did not reveal any barium.. The source of the barite is therefore unknown but the possibility of its derivation from the vast tracts of heterogeneous country rock is greater than that of origin in igneous magma whose composition shows no traces of either constituent. The theory of igneous origin is therefore to not tenable and the barite must be regarded as of later date than the apatite crystals which it includes. The only alternative explanation is that some other mineral has been gradually replaced by barium sulphate.

As the second explanation is the one which was originally held it will be considered first. The nature of the rock has been discussed fully and the photographs submitted indicate very strongly that the present rock is the replacement of feldspar. Such a replacement would naturally commence along cleavage planes and the infilling mineral would therefore reach a stage where it consisted of intersecting plates following the crystalline structure of

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the original feldspar i.e. at right angles. If the unaltered feldspar were removed by a more powerful solvent, before the replacement was complete, a fretwork of barite would be left. The porosity of the rock would thus be secondary and subsequent to the distortion of the included apatite crystals by pressure. The chief objections to this theory have been expressed already. It is based on the existence of great masses of solid crystalline feldspar such as is not known to occur anywhere in the deposits and secondly, even where small masses of feldspar exist, apatite is not known to occur in them except accompanied by schist. This is a serious difficulty especially as the isolated and idiomorphic nature of the apatite crystals makes their subsequent injection impossible. In Canada perfect apatite crystals occur both in lenses of calcite and in pyroxenite. The replacement of the latter by barium sulphate would result in a right angled structure and would furnish the ferromagnesian element at the time of the crystallisation of apatite. Pyroxenite is known to occur in large crystalline masses so that the objections raised in connection with feldspar cannot be applied. Others however present themselves.

No reference can be found to any such alteration and as it is purely surmise no conclusions can be based on it. It seems scarcely probable that so dark a rock could be replaced by so white a substitute.

Further investigations will have to be made before accepting this theory.

The apatite deposits of Bandolier Kop are therefore pneumatolytic deposits connected with granitic pegmatites and concentrated in irregular bodies along the margins of both the intrusive and the intruded rocks. The latter are

believed ...

believed to have contributed the lime element of the mineral.

They are closely related to both the Canadian and Norwegian deposits but there are more features common to the South African and Norwegian, particularly in the association of monazite. The barite veins are however quite unique in character and probably also in origin.

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