CONTRIBUTIONS TO THE MINERALOGY OF THE OLIFANTS RIVER TIN-FIELD WITH SPECIAL REFERENCE TO THE TIN-BEARING PIPES ON STAVOREN, TRANSVAAL.

BY

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CONTENTS.

PART I

PART II

PART 1

THE MINERALOGY OF THE MOST IMPORTANT TIN-BEARING PIPES ON STAVOREN.

CONTENTS.

ABSTRACT.

Tin-deposits in the Bushveld granophyre are typically developed on the farm Stavoren 470 in the Potgietersrus District of Transvaal.

A study on zircons suggests a similar origin for the Bushveld granite and the Bushveld granophyre, and the evidence is in favour of a magmatic origin for both these rock-types.

The deposits on Stavoren occur characteristically in groups. This study is mainly concerned with the Western group of pipes of the "B" Line workings on Stavoren. This group comprises thirteen pipe-like bodies of albitised granophyre. Recent exploratory work exposed four of these pipes to a vertical depth of approximately 250 feet and the others, except for two, to a vertical depth of about 170 feet. The pipe-exposures made by the exploratory work are described in detail.

The ore occurs as disconnected shoots or ore-bodies erratically disposed through the masses of albitised granophyre. Three types of ore-bodies are recognised viz.

A. Zonal ore-bodies characterised by a zonal arrangement of the component minerals:

B. Breccia ore-bodies in which fragments of granophyre, in various stages of alteration, are cemented by ore- and gangue-minerals, and

C. Replacement ore-bodies characterised by the replacement of highly altered granophyre by irregular stringers, pockets, and blebs of ore- and gangue-minerals.

The occurrences are remarkable for their large and varied mineral associations. The primary minerals are native bismuth, joseite, sphalerite, chalcopyrite, galena, bismuthinite, pyrite, loellingite, arsenopyrite, molybdenite, magnetite, cassiterite, scheelite, ilvaite, quartz, chalcedony, calcite, fluorite, thuringite, stilpnomelane, adularia, tourmaline and fluorapatite. Optical, physical, X-ray, and spectrographic data of most of these minerals are given. Cassiterite and scheelite are economically the most important ore-minerals. Loellingite (identified by aid of X-ray powder patterns and a chemical analysis) is up to the present not reported from any of the South African tin deposits. This appears to be partially due to its macroscopic and microscopic similarity to arsenopyrite rather than to its absence in all the deposits. Joseite (identified by X-ray powder patterns and etch tests after detecting tellurium spectrographically) is intimately associated with native bismuth, bismuthinite and galena. Thuringite was described by Wagner (1921 p. 70) as "raven-mica" but X-ray powder data and differential thermal analysis indicate that this mineral is a true chlorite and its chemical analysis is in agreement with that of other thuringites.

The order of crystallisation of the minerals is discussed. It is suggested that the deposits are of composite origin: the adularia and early quartz are hypothermal whereas cassiterite and the accompanying sulphides and gangue-minerals are mesothermal. The decrepitation method to determine the temperature of formation of minerals was applied to some of the minerals of Stavoren but the results are regarded as of doubtful value.

The deposits are epigenetic and the ore-fluids were derived from some deep-seated source, possibly from a magma with affinities to the Bobbejaankop granite phase of the Bushveld Complex. The metasomatic alteration of the granophyre is discussed in detail and it is postulated that the granophyre was, in order, albitised, desilicified, and chloritised by rising solutions which leached sodium and potassium from granitic rocks along their (the solution's) channel-ways during processes of silification and tourmalinisation. The potassium was re-deposited as a potash feldspar in the ore-bodies.

1. INTRODUCTION.

Practically all the tin-occurrences in the Transvaal are genetically related to the granite of the Bushveld Igneous Complex and classified according to the type of rock in which the tin ore occurs, they are (Wagner, 1921 p. 60) :-

a) Deposits in red granite.

b) Deposits in granophyric granite.

c) Deposits in granophyre.

d) Deposits in felsite.

e) Deposits in sedimentary rocks of the upper portion of the Magaliesberg Stage of the Pretoria Series (this portion was formerly known as the Rooiberg Series).

The deposits in granophyre are typically developed on the farm Stavoren 470 situated in the Potgietersrus District, about 55 miles southeast of Potgietersrus (see fig. 1). The granophyre occurs here in the form of a thick sheet dipping at a low angle to the south. It is underlain by granophyric granite and is intrusive into the overlying quartzite of the Magaliesberg Stage of the Pretoria Series.

The first occurrence in this area was discovered in 1912. In that year cassiterite was found near the Olifants River in the bed of a water-course by which Stavoren 470 is drained, and the following up of this alluvial cassiterite led to the discovery of what are known as the "A" workings on Stavoren (Wagner, 1921 p. 12). This first discovery in that area gave an impetus to prospecting and Wagner (1921, p. 115) points out that when prospecting was suspended at about 1919 some fifty distinct occurrences had been opened up in the eastern portion of Stavoren. They occur characteristically in groups and Wagner (1921, p. 115) describes them under the following headings (see fig. 2):

1) The occurrences of the "B" line.
2) The "A" group of workings.
3) The Camp Line workings.
4) The Auret's Baby - Hillside Quarry group.
5) The deposits of the Morning Sun Area.
6) The "C" workings.
7) The Parallels.
8) The "D" pipe.
9) The "71 Yards Fissure".

Most of them are pipe-like in form and the occurrence of the "B" line is remarkable for its large and varied mineral association.

During the period 1915 to 1919 considerable amounts of cassiterite, scheelite and chalcopyrite, and also a few tons of "white arsenic" were recovered from these deposits. Owing mainly to the drop in the price of scheelite in 1919, operations were suspended in that year (Wagner, 1927 p. 85), and, except for some exploration work in 1921, the deposits have lain fallow until about 25 years later when Mr J.T. Wessels, at that time a geologist of the Union Geological Survey, investigated the abandoned mines and prospects at Stavoren and decided (unpublished report dated 1 July, 1947) that the "B" line of pipes is the most promising for further exploration. Most of the other occurrences are small and the excavations, if any, in a dilapidated state so that they were not considered of any consequence for the present study.

The "B" line of pipes can be subdivided into a Western Group in which the pipes are arranged in a line striking approximately from east to west, and an Eastern Group in which the pipes are arranged in a line striking about northeast to southwest. The total distance occupied by the former is about 700 feet and that by the latter about 850 feet. There is a gap of about 500 feet between the two lines.

The Western Group comprises thirteen pipes. Recent exploratory work, which was carried out by the Mineral Development Branch of the Mines Department, exposed the eastern four of these pipes to a vertical depth of 250 feet and the others, except the most westerly two, to a vertical depth of about 170 feet, both depths being measured from the collar of the Inclined Shaft (folder 1). The Eastern Group comprises seven pipes of which five are intersected by the drive on the first level of the mine (folder 2). The aim of the present investigation was to collect data on the mineralisation of these newly exposed portions of the pipes.

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III. PREVIOUS WORK.

In a short paper published in 1914 McDonald (1914) discusses the habit of the red feldspar, one of the common gangue-minerals in the pipes on Stavoren, and concludes that the feldspar variety is adularia, the prism faces being strongly developed whereas the clinopinacoidal ones are absent or only very poorly developed.

The general geology, the nature of the outcrops of the pipes, and the nature of exposures made by mining operations during 1915 to 1919 are recorded by Wagner (1921) in a Memoir of the Union Geological Survey. The mode of occurrence of a wide range of minerals is given by him but very little information is provided on their chemical and physical properties. In the same publication he discusses the paragenesis of the ore- and gangue-minerals and also the metasomatic processes involved in the formation of the deposits. He regards these deposits as replacements in bodies of pegmatite in granophyre, and is of opinion that they owe their origin to a long and involved succession of chemical and mineralogical changes. He suggests that the bodies of pegmatite probably occupy contraction cavities and that the cassiterite has developed mainly in these pegmatites at the expense of the pegmatitic quartz, which it replaces selectively, whereas scheelite and arsenopyrite developed mainly at the expense of the pegmatitic feldspar. According to him the later sulphide minerals such as chalcopyrite, galena, sphalerite, etc. replaced the earlier formed ore- and gangue-minerals but the late gangue-minerals like fluorite and calcite made room for themselves by pushing aside older minerals.

F.L. Hess (1923 pp. 97 - 100) gives a review of Wagner's Memoir and draws attention to a few of the statements with which he does not agree. He hesitates to accept that cassiterite replaces quartz more readily than feldspar. To him the "contraction" cavities seem much more likely to be solution cavities and the pegmatites products of replacement of the country-rock. He is of opinion that the same solutions from which the pegmatites formed, subsequently partially dissolved them and deposited the ore- and other minerals. Hess also criticizes Wagner for not clearly indicating the relationship of the pegmatite bodies to the pipes.

Wagner (1923 pp. 697 - 699) in his reply to Hess' criticism points out that the replacement of quartz (in preference to feldspar) by cassiterite is a common phenomenon in the area under review and that, according to Kynaston and Mellor (1909), it is a rule in the Waterberg Tin-fields. Wagner finds it difficult to follow Hess when he suggests that cavities lined with crystals of quartz and fresh feldspar are of the nature of solution cavities. Furthermore he protests against the statement that he did not clearly recognise the relationship of the pegmatite bodies to the pipes, and states that it ought to be obvious from the memoir that the term pipe is used by him in its morphological sense.

In subsequent publications the data presented on the Stavoren tin-deposits is merely a resumé of that given by Wagner in 1921. Amongst these are the Explanation of sheet 17 of the Union Geological Survey (Wagner, 1927 p. 85), "The Mineral Resources of the Union of South Africa* (p. 297)", Wagner's (1929 p. 197) contribution to the section on tin in the "Handbuch der Regionalen Geologie", and the Memoir of Hall (1932, pp. 490 - 491) on the Bushveld Igneous Complex.

IV. THE GRANOPHYRE.

A. Petrography of the granophyre.

The granphyre forming the country-rock of the cassiterite-bearing pipes on Stavoren is the typical red granophyre of the Bushveld Igneous Complex. It is a fine-grained rock in which the principal constituents have an average grain-size of approximately 1 mm. in diameter. The bulk of the rock consists of micropegmatite composed of differently orientated interlocking grains of potash feldspar holding quartz individuals of almost any shape. Quartz as isolated grains, plagioclase as idiomorphic crystals, and potash feldspar not intergrown with quartz, are present in small quantities and are scattered as phenocrysts through the micropegmatite framework.

The quartz of the micropegmatite is oriented in such a way that all the quartz rods intergrown with the same grain of feldspar extinguish simultaneously.

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*The first edition entitled "Mineral deposits of South Africa" was edited and large written by the late drs. P.A. Wagner and L. Reinecke and was published in 1930. Revised editions bearing the abovementioned title appeared in 1936 and 1940.

In some micropegmatite grains the quartz rods are elongated and radiate outwards from the centre of a feldspar grain. Some earlier feldspar crystals, not intergrown with quartz, are surrounded by several grains of micropegmatite in which elongated wedge-shaped quartz rods radiate outwards from the earlier feldspar. Both, potash and plagioclase feldspar, serve as nuclei for such "spherulites". In other micropegmatite grains the quartz individuals are only elongated in one direction throughout the feldspar, or may show no sign of elongation in any direction. In still other cases, as is also described by Kuschke (1950 p. 23) and Strauss (1954 p. 29), "The feldspar grains in many instances contain euhedral cores of another feldspar, and, although the quartz network is then optically continuous throughout such a feldspar unit, the shape and the arrangement of the quartz rods vary in the different sectors of the unit (Strauss 1954, p.29).

The shape of the quartz grains as they appear in thin section, is largely determined by the orientation of the section; a section cut normal to one in which the quartz grains are not rodlike will reveal the elongation. The size of the grains varies in width from 0.01 mm. or even less up to about 0.4 mm. and some elongated individuals measure up to about 1 mm. in length.

The potash feldspars are orthoclase ($2V\alpha = 68^{\circ} \pm 2^{\circ}$) and subordinate microcline ($2V\alpha = 82^{\circ} \pm 2^{\circ}$). They are red and almost opaque and are both intergrown with quartz. It is the colour of these feldspars that determines the colour of the rock. Rankama and Sahama (1950 p. 660) conclude that the red colour, which is characteristic of potash feldspar, has originated through unmixing and subsequent disintegration of the ferriferous component accompanied by the formation of hematite. Poldervaart and Gilkey (1954), however, sponsored another view with regard to the origin of the particles producing clouding in plagioclase and other minerals. According to them the material was introduced into the crystal some time after its formation. They believe that slight clouding in plagioclase is probably caused by exsolution of foreign ions but that the intense clouding of plagioclase is the result of the migration of iron and other elements into the crystal after its formation.

The plagioclase feldspar is albite-oligoclase (Ab89An11). In contrast to the potash feldspars it is usually colourless in thin section and exhibits characteristic polysynthetic twinning, that according to the albite law being the most common. Some of the phenocrysts are microperthite.

The ferro-magnesian mineral is strongly pleochroic hornblende (γ = deep green, nearly opaque; β = green; α = reddish-brown). It constitutes only about 8 per cent. of the typical rock and occurs in lath-shaped individuals which are interstitial to the micropegmatite grains.

The normal accesories are zircon, sphene, apatite, fluorite, and magnetite. In contact with the pipes the replacement of hornblende by chalcopyrite and occasionally by molybdenite is by no means rare.

In the neighbourhood of some of the pipes the granophyre is much fractured and traversed by numerous dark-coloured stringers mainly composed of dark-green chlorite; the ordinary constituents of the granophyre being subordinate. These stringers are dipping and striking in almost any direction and vary in width from a thin black line up to about 2 inches. They often carry blebs of chalcopyrite.

B. The origin of the granophyre.

Prior to 1944 the granophyre of the Bushveld Igneous Complex was generally accepted as an igneous rock genetically related to the quartzose facies of the pluton.

In 1944 Strauss and Truter (1944) published a paper dealing with the Bushveld granites in the Zaaiplaats Tin Mining Area and describe granophyres which from field and microscopic evidence are nothing else than reconstituted sediments. To distinguish these rocks from the typical Bushveld granophyre the term "pseudo-granophyre" was suggested.

According to Strauss and Truter there is no suggestion of the replacement of quartz by feldspar in the Bushveld granophyre and the graphic texture seems to be due to simultaneous crystallisation of the two minerals whereas, for the "pseudo-granophyre" the outstanding texture in thin section is the replacement of quartz by feldspar. They do, however, suggest (p. 76) that the typical Bushveld granophyre may represent the end-point of such replacement and that this rock-type itself therefore may be a completely reconstituted sediment. Owing to lack of information on this problem they preferred to regard the Bushveld granophyre as a facies of the Main type of Bushveld granite.

In a recent publication Strauss (1954 p. 28) compares the Bushveld granophyre and the "pseudo-granophyre" in more detail. He points out firstly that it is impossible to base any petrogenetic theory on the Bushveld granophyre on chemical composition alone, secondly that the distribution of the Bushveld granophyre does not form positive evidence in favour of any theory of origin, and thirdly that neither the intrusive nature of the granophyre nor the transitional relationship between the granophyre and felsite precludes the possibility of a metamorphic origin for the granophyre. He argued that "Long-continued interaction between granite magma and quartzo-feldspathic xenoliths may give rise to a transitional contact, and rheomorphism may make the metamorphosed rock intrusive into overlying felsites" (p. 31.).

In the Stavoren area the Bushveld granophyre rests on granophyric granite and is overlain by quartzites of the Upper Magaliesberg Stage of the Pretoria Series (formerly regarded as Rooiberg quartzites). Near the contact the granophyre holds quartzite xenoliths which measure up to a few feet in diameter.

In order to obtain additional information on the origin of the Bushveld granophyre a comparative study of the zircons of this rock-type on Stavoren and of the accompanying granitic and sedimentary rocks was made. The results of grain counts carried out on zircon concentrates from the Bushveld Main granite, the granophyric granite, the granophyre, and the quartzite are presented diagrammatically in figure 3. At least five hundred zircon grains were counted in each of the concentrates and, following Koen (1955, p. 127), all the values in figure 3 are given in terms of a thousand zircon grains.

The colour of the zircons of the granitic rocks (including the granophyre) is greatly masked by a thin coating of iron oxide. It was therefore necessary to treat the zircon concentrates with hydrochloric acid. After such treatment the bulk of the zircons of the quartzite is clear, whether slightly coloured or not, whereas about 90 per cent. of those of the granitic rocks are gray to almost opaque and are characterised by a dirty, altered appearance. The marked contrast in colour between the zircons from the quartzites and those from the granitic rocks and the similarity of the granitic rocks (i.e. Bushveld granite and granophyre) in this respect are clearly shown on figure 3.

The zircons in these concentrates can also readily be classified according to the following recognised colour varieties (Morgan & Auer, 1941 p. 306):

1. Normal variety being clear (i.e. colourless and slightly yellowish).

2. Hyacinth variety being pink (i.e. clear pink and purple).
3. Malacon variety being gray (i.e. grayish, some with a yellowish, brownish, or reddish tinge, to almost opaque).

X-ray studies by Chudoba and Stackelburg (1936 & 1937) suggest that malacon is in the metamict state. These workers also contend that the metamict state is due to radioactive elements present in the zircon. Radioactivity measurements by Morgan and Auer (1941, p. 306) confirm that the malacon variety is more radioactive than the hyacinth and normal varieties of zircon.

To test the lattice perfection and radioactivity of the zircon grains from the rocks under discussion, x-ray powder diffraction patterns and autoradiographs were taken. The x-ray diffraction lines produced by the gray zircon of the granitic rocks are diffuse whereas the clear zircons exhibit a normal diffraction pattern (see plate 1). Autoradiographs, prepared by exposing the zircon concentrates to Kodak no-screen x-ray safety film for 30 days, show that the gray grains which are typical of the granitic rocks are radioactive whereas radioactivity is not perceptible in the clear grains characterising the quartzites.

To describe the shape of the grains the terms idiomorphic, rounded, and angular are used. The term idiomorphic is here reserved for euhedral grains only and the term rounded designates all the rounded (used in the strict sense of the term) grains and other roundish grains with no recognisable crystal faces. It does not seem correct to refer to rounded grains in granitic rocks if these rocks are of magmatic origin, but it was experienced that a large number of the grains from the granite, the granophyric granite, and the granophyre are oval-shaped and show no recognisable crystal faces. It is striking however, that only the gray zircons exhibit that shape whereas the clear ones from the same rocks are all sharply euhedral.

Idiomorphic zircons of which the crystal faces were formed by secondary growth and in which a rounded core is still visible, have been described by various authors inter alia Vermaas (1949 p. 63), Kuschke (1950 p. 32), and Poldervaart (1955ii p. 947). Such secondary crystals were not noticed among the zircons from the quartzite and although some of the zircons from the granitic rocks under discussion do exhibit outgrowths similar to those described by Butterfield (1936 p. 511) none seems to have a rounded core as is the case with secondary crystals.

In shape the zircons of the Stavoren granophyre and the other granitic rocks correspond remarkably closely and they contrast strongly in this respect with the zircons of the quartzites (see figure 3).

The zoning does not show much variation in the zircons from the different rock-types examined but it should be mentioned that it was impossible to determine whether the numerous almost opaque grains from the granitic rocks are zoned or not.

In conclusion then the similarity of the zircons of the granophyre to those of the other granitic rocks as regards colour and shape (fig. 3), and radioactivity, is in favour of a similar origin for these rock-types but that does not completely preclude the possibility of a metasomatic origin for the granophyre, unless it is assumed that a magmatic origin for the granite is proved.

Elongation-frequency curves (fig. 4) also favour a similar origin for the three types of granitic rocks but the curves show, as that of the zircon from the quartzite, maximums at elongation ratios less than 2 which is, according to Poldervaart (1950 p. 574 and 1955[1] p. 441), not normally the case for zircons from rocks of magmatic origin. The applicability of Poldervaart's rule to zircons of all magmatic rocks needs to be proved.

Evidence in favour of a magmatic origin for the granitic rocks including the granophyre from the Stavoren area is, however, provided by the high percentage of malacon in the zircon concentrates. The stability of malacon is lower than that of clear zircon. Consequently the former is relatively rare in arenites (Poldervaart 1955[1] p. 443). This would presumably also be the case in autocthonous granites formed by metasomatism of quartzites.

V. THE MOST IMPORTANT TIN-BEARING PIPES OF THE "B" LINE.

This study is mainly concerned with the Western Group of pipes of the "B" line, owing firstly to the fact that the exposures of the Eastern Group are poor in ore-minerals and, secondly, that they show very little variation as far as composition and internal structure of the pipes are concerned.

A. Distribution.

In Wagner's Memoir (1921) the Western Group of pipes is referred to as B5 East to B8 pipes, numbers being given only to the more important ones. For the purpose of this study a name or number is given to each pipe. To avoid confusion the names and numbers used by Wagner are retained as far as possible (see table 1).

TABLE 1. Names and numbers of pipes from east to west.

Present paper.	Wagner's Memoir.
B5 East	B5 East
B5a B5b B5c	B5
B5d	not numbered
B6a	B6
B6b	not numbered
B6c	not numbered
B6d	not numbered
Seelig	Seelig
B7	B7
Quarry	Quarry
B8	B8

The distribution of the pipes on the surface and on the various levels of the mine is indicated on folder 1 A, B, C and D whereas folder 1 E is a projected vertical section along the strike of the pipes.

Very little doubt exists about the correlation of the exposures on different levels of pipes B5 East, B5a, B5b and B5c but the position of the other pipes on the various levels has still to be proved.

The B5 East, the Seelig, and the pipes in between are arranged in a line striking approximately W 7° N, and the B7, Seelig, and B8 pipe are situated W 6° S of the Seelig pipe.

The linear arrangement of the pipes suggests that they are situated along potential lines of weakness in the granophyre. On the two lower levels of the mine they show, however, no relation to any visible fissure or fissure system whereas on the first level the B5 East, the Seelig, and the pipes in between are traversed by a well-defined fissure A-A' in folder 1 B, and B7 and the pipes to the west of it by a similar fissure (B-B' in folder 1 B). These fissures intersect at an angle of about 13° in the vicinity of the B6b and B6c pipes.

B. Form.

For descriptive purposes the direction along which the pipes are scattered will be referred to as the strike of the pipes and the inclination of the pipes in that direction as the plunge.

The shape and size of the pipes are subject to considerable variation. In plan they are usually elliptical or roughly so and are elongated in the direction of their strike. The B5 East is the largest individual pipe and measures 30 feet along the strike and 10 feet across on the first level, and on the second level a drive, 7 feet wide, cuts through 40 feet of it. On the third level it measures about 30 feet by 8 feet.

The vertical extent of the pipes is not yet known. The greatest depth to which any of the pipes on Stavoren are exposed is that of the third level (about 300 feet).

All the pipes are steeply inclined, the dip being steeply towards the north (see figure 5). Along the strike the pipes unite and split causing a variation in the angle of plunge; accordingly for the same pipe the plunge might vary from steeply to the east through vertical to steeply to the west. This anastomosing character of the pipes is best illustrated by the behaviour of the B7 and Seelig pipes, the B5a and B5b pipes, and the B6b and B6c pipes (see folder 1E).

On the surface the B7 and the Seelig pipes form two distinct outcrops whilst at a depth of 100 feet they have merged into an exceptionally large elliptical mass measuring 70 feet in length and about 20 feet across. On the second level they are again separated from one another by several feet of apparently unaltered granophyre.

The exposure of the B5a and B5b pipes is most interesting on the first level. On the surface and on the second level the two pipes are separated from each other by several feet of apparently unaltered granophyre, whereas on the first level they coalesce. The complete outline of this coalescence is exposed in a horizontal section on this level so that the form of the pipe could be studied in detail. The form suggests the merging of two pipes; in plan it is roughly elliptical but the central part is narrower than the slightly bulged ends (see fig. 11). The western bulge is smaller than the eastern one; this is in agreement with the fact that on the surface and on the second level the western pipe is the smaller of the two.

The behaviour of the B6b and B6c pipes is similar to that of the B5a and B5b pipes, except that they are very poorly mineralised on the first level.

In general the pipes show the tendency to plunge to a common point of origin, the eastern pipes plunge to the west and the western ones to the east.

C. <u>Composition and internal structure</u>.

The term "pipe" in this treatise refers to pipe-like masses of gray, altered granophyre. They are not ore-bearing throughout but the ore occurs as irregularly shaped bodies sporadically distributed through such masses of altered granophyre (see fig. 6). These ore-concentrations are referred to as ore-bodies; Wagner (1921) describes them as pegmatite bodies.

The gray-coloured "altered" granophyre varies from an albite-rich granophyre to an albitite. The contact between the normal red granophyre and the gray, altered product is usually sharp and often visible in a single slide (PLATE X11, fig 1 and 2) but the albite-rich granophyre and the albitite grades gradually into each other and are so similar in colour that it is difficult to distinguish them from each other with the naked eye. By means of a magnifying glass it is possible to tell the extreme varieties from each other and the author concluded that the albite-rich granophyre usually occurs in contact with normal granophyre whereas the albitite surrounds the ore-bodies (fig. 6). This conclusion was confirmed by microscopic study of thin sections of a number of samples collected from various parts of the pipes. The grain-size of the granophyre was not effected to any great extent by the alteration.

In the detailed description of the pipes (cf. figures 9 - 18) altered granophyre includes both albite-rich granophyre and albitite.

VI. COMPOSITION AND TEXTURE OF THE ORE-BODIES.

Generally the ore-bodies can be classified into three types, viz. zonal ore-bodies, breccia ore-bodies, and replacement ore-bodies.

A. Zonal Ore-bodies.

In these ore-bodies a concentric arrangement of the minerals, according to their order of crystallisation, gives rise to a zonal structure. The following zones could be recognised:

1. A wall zone consisting of thuringite.
2. A feldspar zone consisting mainly of a red potash feldspar and a little quartz.
3. An ore-bearing zone composed mainly of ore-minerals*.
4. A core composed of gangue-minerals of late formation.

The wall zone consisting of thuringite is usually continuous right round the ore-bodies and grades gradually into the albitite which it replaces. The feldspar zone is often to a large extent replaced by later minerals; in some bodies only remnants of the feldspar are left whilst in others this mineral is completely absent. The ore-zone is very seldom continuous right round the ore-bodies and carries, in addition to the ore-minerals which form massive patches and irregularly shaped crystal aggregates of varying size, also quartz and chloritic material. The most abundant ore-minerals are scheelite, arsenopyrite, chalcopyrite and cassiterite. Cassiterite usually occurs along the inner contact of the zone whilst scheelite is scattered along the outer contact.

The gangue-minerals forming the core are quartz, calcite and fluorite. They usually occur together in most of the ore-bodies but exceptionally the core

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*The term gangue-minerals designates all the non-opaque minerals with the exception of cassiterite and scheelite. These two, together with the opaque minerals, are referred to as the ore-minerals.

is composed of only one of them. Inclusions of quartz crystals of an earlier generation and of the earlier ore-minerals are common in the core. In some places a late generation chalcopyrite occurs as massive patches replacing the minerals forming the core.

In size the zonal ore-bodies vary from small pockets a few inches in diameter, up to bodies measurable in feet. The largest one encountered occurs in the B5a pipe on the first level of the mine and measures 12 feet by 3 feet.

The width of the various zones varies greatly. The thuringite zone and the feldspar zone seldom exceeds 2 inches. The ore-zone may be as wide as 15 inches, as in the B5d pipe on the second level (see figure 15), but such a width is exceptional and is only measurable over a distance of 12 inches, whereafter it decreases to about 1 inch and then pinches out to appear again a few inches further on. The core of gangue-minerals usually occupies three-quarters or even more of the ore-bodies. An exception is an ore-body of the B5b pipe on the second level where most of the gangue-minerals are replaced by chalcopyrite of late formation.

Replacement of older minerals by later ones is responsible for the fact that the contact between the zones is often ill-defined. The nature of the replacement is discussed in the section dealing with the paragenesis of the minerals.

The zones in the Stavoren ore-bodies cannot be correlated with those of sulphide-poor pegmatites discussed by Cameron, Jahns, McNair and Page (1949). Yet some of the characteristics of the zoned pegmatites (Cameron, Jahns, McNair and Page - 1949 p. 98) are also displayed by the zonal ore-bodies in the Stavoren deposits viz.

a. The presence of succesive shells, complete or incomplete, concentric about an innermost zone or core.

b. "The material composing an inner zone may transect an outer zone or replace any part of the outer zone".

c. Zoned ore-bodies "show definite sequences of mineral assemblages from the walls inward to the cores".

B <u>Breccia Ore-bodies</u>.

Wagner (1921, p. 111) points out that different periods of brecciation can be distinguished, and that brecciation is largely caused by the force of crystallisation of the late minerals.

The brecciation in the ore-bodies designated here as breccia ore-bodies, is prior to the introduction of the ore-minerals, in most cases prior to mineralisation, and is certainly not a crystallisation phenomenon.

The breccia ore-bodies consist of angular fragments of altered granophyre cemented by gangue- and ore-minerals. The average size of the fragments is about 12 inches in diameter. The degree of alteration of the fragments varies greatly: in some ore-bodies they are only slightly altered whereas in others they are completely changed to a greenish mass of chlorite.

The minerals occupying the interstices between the fragments are often zonally arranged in the same way as in the zonal ore-bodies. In such instances the zoning is occasionally just as complete as in the zonal ore-bodies.

The ore-minerals, and to a lesser extent the gangue-minerals, are not only confined to the interstices but often impregnate the chloritised fragments.

C. Replacement Ore-bodies.

This type of ore-body is typical of the B5c pipe on the first level of the mine, and of the B5a pipe on the second level. Such a replacement ore-body consists of a highly chloritised mass which is irregularly replaced by pockets, stringers, and blebs of ore- and gangue-minerals. Here again, as in the breccia ore-bodies, the largest pockets often show a zonal arrangement of the minerals.

It might be that these ore-bodies were originally of the breccia type and that the fragments have been chloritised and replaced to such an extent that their fragmental nature is no longer recognisable.

TABLE 2. Summary of characteristics of each type of ore-body, and of the pipe-exposures exhibiting these characteristics.

Type of Ore-body.	Characteristics.	Pipe-exposure. First level.	Second level
Zonal	Concentric arrangement of minerals.	B5 East, B5a, B5b, Seelig, and B7.	B5b and B5d
Breccia	Angular fragments of granophyre, in various stages of alteration, cemented by ore- and gangue-minerals. Minerals occupying interstices are often zonally arranged.	B5 East, B5a and B5b.	B5 East and B6c.
Replacement.	High degree of alteration of the granophyre and the irregular replacement of the altered product by stringers, pockets, and blebs of ore- and gangue-minerals.	B5c.	B5a and B5d.

VII. MINERALOGY OF THE ORE-BODIES.

A. Technique and Apparatus.

1. X-ray Analysis.

X-ray powder diffraction patterns were obtained by using Debye-Sherrer type of cameras with diameters of 114.59 mm. and 57.3 mm. The films were mounted according to the Straumanis method (Straumanis 1949) and unfiltered Co and Cu radiation was used. The wave-length values used were :- CuK_{α_1}= 1.54050 A and CoK_{α_1}= 1.78890 A.

The variation in temperature for different exposures of the same mineral (not same sample) did not exceed 3°C and the variation in temperature during exposures never exceeded 1°C.

The films were allowed to dry for at least one week before being measured. The measuring and shrinkage correction was carried out as described by Wasserstein (1951, p. 106). The diffraction angles were converted into interplanar spacings by using suitable tables (Tables for Conversion of X-ray diffraction angles to interplanar spacings. Applied Mathematics Series 10, National Bureau of Standards of the U.S. Department of Commerce.)

The cube-edges of the cubic minerals were derived from the higher angles by the extrapolation method of Bradley and Jay (1932).

2. Spectrographic Analysis.

The spectrographic analyses were carried out on a large Hilger Littrow type of spectrograph.

For qualitative analysis the material was arced between copper electrodes (hollowed anode and slightly pointed cathode) for 20 seconds at 5 amps; carbon electrodes were used for Cu determinations.

The spectrograph was usually set for the range 2750 - 4700 A; only for detecting Ge, Te, P and B was the setting changed to the range 2260 - 3000 A.

The elements analysed for are: Fe, Mg, Mo, In, Ga, Be, Cd, Ca, Sr, Ba, Al, Ge, Na, K, Li, Rb, Cs, Si, Sb, Pb, Bi, Hg, V, Mn, Zn, Co, Ni, Cr, As, Sn, Zr, Ti, Nb, Pt, Os, U, W. Th, Te, P and B. No element is reported unless its presence was definitely established; conversely failure to report an element means that it was not present in quantity above the limit of detection for the particular method used.

For semi-quantitive analysis and analysis where a higher sensitivity was required the technique was changed. The method used for such analyses are pointed out where the results are given.

3. Decrepitation Determinations.

The apparatus and method used is in principle the same as that described by Scott (1948, p. 647). The mineral was crushed in a mortar to particles ranging from about 2 mm. in diameter down to a coarse powder. About 2 cubic centimeters of the crushed material was placed in a pyrex glass tube of which one end is closed. The tube containing the material was heated in an electric furnace at a rate of about 15° per minute. To pick up the bursts of the mineral fragments the open end of the tube was connected with a doctor's stethoscope from which the diaphragm was removed.

The thermocouple measuring the furnace temperature was placed next to the glass tube holding the sample and the temperature was recorded on a pyrometer.

4. Specific Gravity Determinations.

Determinations were carried out with quartz specific gravity bottles of about 7 cc. capacity. Distilled water which was freed from air was used. Air bubbles adhering to the mineral particles were removed by heating the bottle with the particles and about $\frac{3}{4}$ of its volume of water to about 70°C under diminished pressure. Determinations were carried out in duplicate. A close check was kept on the temperature of the distilled water during determinations and the results corrected for the density of pure water at 4°C.

B. Ore-minerals.

The minerals are described in the order set out by Ramdohr (1950).

1. Native Bismuth.

No bismuth minerals were detected in macroscopic amounts in any of the pipe exposures made by present mining operations, but Wagner collected some specimens from the upper portions of the B5b, B6a and B7 pipes.

In these specimens, numbers 3502 and 3503 in the museum of the Union Geological Survey, native bismuth occurs in microscopic amounts intergrown with bismuthinite and joseite.

In polished section (742) the bismuth is creamish white and moderately anisotropic in bluish-gray to brownish. It appears to be replaced by bismuthinite and joseite.

2. Joseite.

In Wagner's Memoir (1921, p. 65) this mineral is referred to as galenobismutite but spectrographic analyses revealed a relatively large quantity of tellurium and the mineral was thereafter identified as joseite. Polished sections (742) of the material showed it to be intimately associated with native bismuth, bismuthinite, chalcopyrite and galena.

Wagner detected this mineral in the upper portions of the B7 pipe where it occurs in patches, up to 2 inches across, in narrow veins of bismuthinite cutting the earlier minerals. "In one specimen it is seen to have been deposited on an aggregate of prismatic crystals of arsenopyrite and bismuth-glance" (Wagner 1921, p. 129).

The specimen investigated is the one of which Wagner published a photo. (Plate II figure 1 is a reprint of this photo.) The joseite occurs in foliated masses and has a perfect cleavage. The curious corrugated appearance of the cleavage faces has been mentioned by Wagner and is visible in the plate. The laminae are flexible but inelastic. The lustre is metallic and is splendid on fresh cleavages but tarnishes dull. The mineral is almost isotropic in sections parallel to the cleavage plane but in sections normal to the cleavage it is moderately anisotropic in light-gray to yellowish-gray. The results of etch tests on this mineral are: HNO3 etches dark-gray, HCl stains light-gray, and $FeCl_3$ bluish-gray.

The specific gravity was determined as 7.90 ± 0.01. It should be mentioned, however, that accurate results are difficult to obtain owing to the ready cleavage of the mineral and to the fact that it is intimately associated with native bismuth, bismuthinite, and galena; enclosures of arsenopyrite grains with corroded edges were also detected in polished sections.

The x-ray powder pattern of this telluride is similar to that of joseite published by Peacock (1941, p. 94) and Thompson (1949, p. 366) but markedly expanded indicating a structure similar to that of other joseite but with smaller cell dimensions (see table 3).

TABLE 3. X-ray diffractions spacings of joseite.

1		2	
Int.	d A	Int. (est.)	d A
2	4.38	2	4.30
2	3.61	2	3.54
½	3.09	-	-
1	3.30	2	3.27
10	3.07	10	3.01
2	2.57	1	2.43
5	2.24	6	2.19
5	2.11	6	2.07
1	2.05	-	-
1	1.967	½	1.93
2	1.894	3	9.86
½	1.819	1	1.78
½	1.779	1	1.74
3	1.744	3	1.70
1	1.654	2	1.63
½	1.616	-	-
3	1.537	3	1.50
2	1.409	3	1.38
3	1.345	3	1.316
1	1.302	3	1.298
2	1.246	2	1.219
½	1.221	-	-
2	1.210	2	1.188
½	1.176	½	1.154
½	1.044	-	-
1	1.026	1	1.006
2	1.005	2	0.973

TABLE 3 continued.

1		2	
Int.	d A	Int. (est.)	d A
½	0.982	-	-
1	0.956	-	-
1	0.943	-	-
½	0.907	-	-
2	0.836	-	-
2	0.816	-	-

1. Joseite from British Columbia (Peacock 1941, p. 94; intensities after Thompson 1949, p. 366).
2. Joseite from Stavoren. Cu radiation. Camera radius = 57.3 mm.

3. Sphalerite.

Sphalerite is present throughout the mine in microscopic amounts only. It is patchy and usually associated with first generation chalcopyrite but was never detected as a contaminant of the later generation chalcopyrite. It is replaced by chalcopyrite and galena (Plate II, figure 2) and is often crowded with chl. inclusions of the former (polished sections numbers 741 and 736).

4. Chalcopyrite.

Chalcopyrite is abundant throughout the mine and in some pipe exposures it is in excess of cassiterite, scheelite,and arsenopyrite. It is the only primary copper mineral identified in the pipes under discussion.

Chalcopyrite, admittedly, has long been known to have a wide temperature range of deposition, and at Stavoren at least two generations of this mineral could be distinguished.

In the zonal ore-bodies, in which the sequence of deposition of the minerals can best be studied, the earliest generation of chalcopyrite occurs in the ore-zone replacing arsenopyrite and being itself replaced by quartz which constitutes the core of the ore-bodies.

The late, or second generation of chalcopyrite occurs as massive patches and veins in the core of the ore-bodies. Polished sections suggest that this generation of chalcopyrite replaces the gangue-minerals (quartz, calcite and fluorite) forming the core of the ore-bodies (plate III, figure 1) and is accordingly a later arrival than these minerals.

A further mode of occurrence of chalcopyrite is as impregnations in thuringite-rich parts of the albitised granophyre. In such cases it occurs with, and replaces pyrite. This is especially the case in the composite B7 and Seelig pipes on the first level of the mine.

The impregnation of ore-minerals in albitised rock is always accompanied by the development of thuringite; chalcopyrite or any of the other ore-minerals was never detected in thuringite-free portions of the albitite. Presumably the solutions from which the ore-minerals formed also gave rise to thuringite.

In the vicinity of some of the pipes, such as the B5 East on the first and second levels and the B5a and b on the first level, chalcopyrite also occurs as fine specks in the apparently unaltered granophyre.

The minor elements detected spectrographically in the chalcopyrite are: In, Pb, Bi, Zn, Sn,and W. Of these only In and Bi do not vary in quantity in the different generations of chalcopyrite. The others are more abundant in the early generation of chalcopyrite and owe their presence to contaminating minerals. This is in agreement with the fact that the early generation chalcopyrite is in closer association with galena, sphalerite, scheelite and cassiterite, than is the late chalcopyrite.

Although arsenopyrite is replaced by first generation chalcopyrite, As was detected in only one sample of this mineral. The presence of arsenopyrite impurities in this sample also causes an increase in the intensity of Bi lines and the appearance of Sb lines in the spectrum. These two elements occur as impurities in arsenopyrite, the former substitutes for Fe in part and the latter for As.

Although sphalerite is the most important ore-mineral of indium (Rankama and Sahama, 1950, p. 726) this element does not show a sympathetic variation in quantity with Zn in the spectrographic analysis of chalcopyrite and part of the indium is thus probably substituting for Fe in the chalcopyrite structure.

The specific gravity is, within the limits of error, the same for both generations of chalcopyrite, (S.G. $^{24}_{4}$ = 4.19 ± .01 and so are the interplanar spacings listed in table 4.

TABLE 4. <u>X-ray diffraction spacings of chalcopyrite from Stavoren. Camera radius = 57.3 mm. Cobalt radiation</u>.

No.	Int. (est.)	d A	No.	Int. (est.)	d A.
1	10	3.03	5	1	1.32
2	½	2.62	6	3	1.202
3	8	1.85	7	4	1.075
4	5	1.59	8	2	1.014

5. Galena.

Although galena is abundant in some of the pipes on Stavoren (Wagner, 1921, p. 65) only one patch measuring approximately an inch or so in diameter, was encountered during the present investigation. This patch occurred in the composite B5a - B5b pipe on the first level. Here the galena is associated with first generation chalcopyrite, cassiterite and sphalerite. It replaces the sphalerite (plate II, fig. 2) but appears to be contemporaneous with chalcopyrite.

The minor elements detected spectrographically in the galena are Sn, Bi, Cd, Zn, and Ag. Wasserstein (1951) did spectrographic and precision x-ray work on galena and concludes that only Bi substitutes for lead to any appreciable extent in this mineral. His cube-edge for galena with 0.01 per cent. or less Bi ranges from 5.9230 to 5.9240 kX units at 25°C, whereas galena containing about 1 per cent. Bi has a cube-edge of 5.9223 kX units at 25°C. The unit-cell dimension for the Stavoren galena, using the same method and apparatus as Wasserstein, is 5.9359 ±.0005 A (5.9241 kX units) at 25°C. This value is comparable - within the limits of error - with that of bismuth-poor galena.

Ag is known to be common in galena in the form of minute inclusions of a mineral bearing that element. The presence of Zn, Cd and Sn is due to the contamination of sphalerite and cassiterite.

6. Bismuthinite.

Wagner reported bismuthinite from the upper portions of the B5b, B6a and B7 pipes. On the mode of occurrence of the bismuth-bearing minerals in the B7 pipe he writes: "These occur as narrow veins cutting earlier minerals. One such vein, three quarters of an inch wide, was found to be made up of lamellar anhedrons of bismuthinite arranged at right angles to the vein walls. These (meaning the vein walls) consist in this instance of arsenical tin ore composed of crystals of cassiterite and arsenopyrite in a matrix of quartz and red feldspar" (Wagner 1921, p. 129).

In the samples collected by Wagner from the pipes at Stavoren bismuthinite occurs in striated prismatic crystals associated with arsenopyrite, cassiterite and thuringite. In some of the specimens it is accompanied by joseite and native bismuth. In polished sections (742) it is distinguished from joseite by a whiter colour, stronger anisotropism (bluish-gray to yellowish) and a weak pleochroism. It replaces the native bismuth.

During the present investigation bismuthinite was merely detected in microscopic amounts in samples collected from the E5b pipe on the first level. In these samples it occurs as thin veins cutting arsenopyrite (polished section No. 741).

7. Pyrite.

This mineral occurs sparingly in the Western Group of pipes and was detected only on the first level and higher up. On the first level it does not occur as a constituent of the typical ore-bodies but as impregnations in thuringite-rich portions of the albitised granophyre. It is most abundant in the B7 and Seelig pipes where it occurs as aggregates, and is partially replaced by chalcopyrite (plate III fig. 2).

Wagner (1921, pp. 120 and 129) mentions the presence of pyrite in some of the ore-bodies in the upper portions of the pipes and in polished sections of material collected by him from these localities it was found associated with cassiterite.

The pyrite tends to be strongly magnetic and is easily attracted by a ~~steel~~ magnet. Microscopic investigation reveals, however, that the pyrite crystals and grains are fractured and that these fractures and the interstices between the grains are filled by magnetite, ilvaite, sphalerite, chalcopyrite and gangue.

Owing to the fractured nature of the pyrite no pure material could be extracted for spectrographic analysis. The material analysed shows the following minor elements:- Ca, Mn, Cu, In, Pb, Bi, Zn, Sn and W, all occurring presumably as constituents of contaminating minerals.

The absence of Ni in this pyrite is confirmed by x-ray diffraction data. Peacock and Smith (1941, pp. 107 - 117) did precision measurements on the cube-edge of pyrite and confirmed Bannister's (1940 pp. 609 - 614) findings that the replacement of Fe by Ni causes an increase in the unit-cell of pyrite. The cube-edge for pure pyrite (FeS_2) from Leadville, Colorado is given by Peacock and Smith as 5.4079 ± .0005 A, while Kerr, Holmes and Knox (1945) published a value of 5.40667 ± .00007 A for pyrite from the same locality. These rather divergent results for pyrite from the same locality have been discussed by Wasserstein (1949) in a paper in which he indicates that the differences are apparent rather than real. He points out that although Kerr and his colleagues give their results in Angstroms there are sufficient data to prove that kX units have in fact been used. Peacock and Smith on the other hand used a wavelength of $FeK\alpha_1$ = 1.93239 A whereas in more recent tables issued by the U.S. Department of Commerce in 1950 the wavelenght of $FeK\alpha_1$ is given as 1.93597 A. If the cube-edge given by Kerr et al is recalculated to Angstroms it becomes 5.4176 ± .00007 A and that of Peacock and Smith, if corrected for wavelength, 5.4180 ± .0005 A.

The x-ray data for the Stavoren pyrite is given in table 4. The cube-edge of 5.417 ± .001 A is in good agreement with the more accurate existing values for pure pyrite and therefore supports the absence of Ni as indicated by spectrographic analysis.

TABLE 4. <u>X-ray data of pyrite from Stavoren</u>.

No.	Int. (Est.)	d A	hkl	No.	Int. (est.)	d A	hkl
1	2	3.12	111	11	3	1.208	420
2	10	2.70	200	12	3	1.180	421
3	9	2.42	210	13	2	1.151	332
4	9	2.20	211	14	2	1.105	422

TABLE 4 continued.

No.	Int. (est.)	d A	hkl	No.	Int.(est.)	d A	hkl
5	7	1.91	220	15	10	1.04	333, 511
6	9	1.63	311	16	6	1.006	520, 432
7	3	1.56	222	17	6	0.989	521
8	5	1.50	320	18	8	0.957	440
9	6	1.45	321	19	6	0.903	600
10	2	1.24	331				

$a_o = 5.417 \pm .001$ A.

Cobalt radiation. Camera radius = 57.3 mm.

In a hand-specimen collected on the old dumps of the B3 pipe, this mineral occurs as perfect cubes, measuring up to 3 mm. across, in a slightly chloritised, quartz-rich albitite.

8. <u>Loellingite</u>.

Loellingite, the diarsenide of iron, is a less common arsenic mineral than arsenopyrite and up to the present has not been reported from any of the South African tin deposits.

At Stavoren this mineral is much less abundant than arsenopyrite and was found only in the exposures of the B7 and Seelig pipes on the second level of the mine. Unfortunately the mineralised parts of these pipes were removed on the first level and therefore not available for examination, and the pipes are not yet exposed on the third level. Consequently no conclusion could be drawn as to the vertical distribution of this mineral. The samples which were originally collected by Wagner from the upper portions of these pipes were examined by the present author without detecting any loellingite in them.

The loellingite occurs in large massive patches (see fig. 18) which under the microscope is seen to be composed mainly of lenticular crystals of loellingite, some quartz and chlorite. Occasionally these lenticular crystals are grouped together in radiating aggregates.

The loellingite is much more cracked than the arsenopyrite which accompanies it, and shows abundant fractures which are filled in by quartz. Quartz replaces loellingite along cracks and arsenopyrite replaces it in the form of feathery veinlets (polished section No. 743).

Macroscopically and microscopically the colour of the arsenopyrite and loellingite is so much the same that it can by no means serve to distinguish the one from the other. When occurring next to each other in a polished section loellingite may be distinguished by being more anisotropic than arsenopyrite and by a faint pleochroism. The hardness of the two minerals differ slightly but not enough to be diagnostic.

In hand-specimen the lenticular form of the loellingite crystals (plate IV fig. 1) offers a fairly reliable method by which the mineral can be distinguished from the fine-grained masses of arsenopyrite.

Concerning the effect of etch-tests on these two minerals there seems to be a disagreement in the literature (see table 5). The writer's findings on material that was first identified by means of x-ray methods support Short:

TABLE 5. Etch tests on arsenopyrite and loellingite.

Reagent.	Short (1940, p. 161)	Uytenbogaardt (1951, pp. 156 and 190).
HNO_3	Arsenopyrite stains differentially iridescent and loellingite gray.	Arsenopyrite tarnishes through iridescent to deep-brown and loellingite stains brown to iridescent.
$FeCl_3$	Negative for both minerals.	No effect on arsenopyrite but tarnishes loellingite permanently brown after one minute.

Tests with 20% $FeCl_3$ are negative on both minerals whereas concentrated HNO_3 after one minute stains arsenopyrite brown to iridescent and loellingite gray. This HNO_3 test is the most useful to distinguish between arsenopyrite and loellingite in polished section.

The most reliable method for the identification of loellingite is probably by means of x-rays. The powder diffraction pattern differs distinctly from that of arsenopyrite (see plate V). De Jong (1926, p. 325) claims that Debye x-ray patterns of loellingite, rammelsbergite, and safflorite are indistinguishable. Holmes (1935, p. 198) however, points out that Debye patterns of these minerals show sufficient variation to permit recognition by x-ray methods. The powder data listed by Harcourt (1942) confirms Holmes' statement as far as rammelsbergite and safflorite is concerned but the spacings given by him for loellingite are in better agreement with those of arsenopyrite than with those of loellingite which are listed in table 6.

Owing to the replacement by arsenopyrite an absolutely pure sample could not be obtained for chemical analysis and most, if not all the S given in the analysis (table 7 column 2) is probably due to arsenopyrite impurities. To isolate quartz and chloritic impurities the loellingite was crushed to -100 +200 Tyler mesh. From this coarse powder the quartz was removed with bromoform and the chlorite by means of a Franz-Isodynamic Separator; the chlorite is attracted more easily by the magnet than the loellingite.

TABLE 6. Diffraction-spacings of loellingite.

Cobalt radiation. Camera radius = 57.3 mm.

	1		2	
No.	Int. (est.)	d A	Int. (est.)	d A
1	3	3.29	-	-
2	10	2.57	10	2.57
3	4	2.37	4	2.39
4	8	2.33	10	2.32
5	10	1.85	10	1.84
6	4	1.67	4	1.67
7	9	1.63	10	1.63
8	1	1.56	1	1.55
9	2	1.50	2	1.49
10	2	1.45	2	1.45
11	-	-	4	1.24
12	1	1.168	1	1.167
13	1	1.142	1	1.140
14	2	1.108	3	1.109
15	4	1.099	3	1.096
16	2	1.077	1	1.077
17	5	1.058	5	1.055
18	5	0.974	5	0.974
19	2	0.967	2	0.966
20	2	0.962	1	0.961

1. Stavoren 470, Potgietersrus District.
2. Frankenstein, Silesia (Union Geological Survey Museum No. 959).

TABLE 7. Chemical analyses of loellingite.

	1	2	3
Fe	27.15	28.08	26.91
Bi		1.97	1.75
Co		1.62	2.01
Ni		trace	trace
As	72.85	65.00	69.33
S		2.92	-
Total	100.00	99.59	100.00
S.G. $^{24}_{4}$		7.14 ± .03	7.32.

1. $FeAs_2$ (Palache, Berman and Frondel, 1944, p. 305, analysis 1).

2. Loellingite, B7 pipe, second level, Stavoren. Sample No. JGS 7. Analyst: Abraham Kruger, Division of Chemical Services, Pretoria.

3. Analysis 2 after correcting for arsenopyrite on the assumption that all the S forms arsenopyrite and that the composition of the arsenopyrite is that given in table 8. The specific gravity was recalculated correspondingly.

Spectrographic analysis reveals, in addition to the elements determined chemically, traces of Si, Mo, Pb, Sb, W and Sn. Except for Sb which may substitute for As in part, all these elements are presumably present as contaminating minerals such as quartz, molybdenite, galena, scheelite and cassiterite.

The fact that loellingite has not yet been reported from any of the other cassiterite deposits associated with the granite of the Bushveld Igneous Complex appears to be partially due to its macroscopic and microscopic similarity to arsenopyrite rather than to its absence. It was for instance detected by the writer in samples of the Groenvlei 610 cassiterite deposits. These samples (numbers 3849 and 3851) were obtained from the museum of the Union Geological Survey. In hand-specimen the Groenvlei loellingite resembles that of Stavoren; it occurs as lenticular crystals. Etch tests on this mineral and also its x-ray interplanar spacings are in exact agreement with that of the Stavoren mineral.

Strauss (1954 p. 154) claims that in the deposits examined by him two generations of arsenopyrite are present; the one being an early hypothermal mineral and the other an early mesothermal one. He points out that the former type is invariably cracked and granulated and that it is present in the quartz-tourmaline bodies of Groenvlei 610. The fracturing is characteristic of the loellingite examined by the writer and it may be that the early generation of arsenopyrite described by Strauss is loellingite.

9. Arsenopyrite.

Arsenopyrite is a common mineral in high temperature tin veins and Stavoren is no exception. Being the principal constituent of the ore-zones in the zonal ore-bodies it is by far the most abundant of the ore-minerals at Stavoren.

When present in the ore-zone it occurs as fine-grained massive patches somewhat brecciated and replaced by quartz (plate IV fig. 2) and to a lesser extent by chalcopyrite. In some places arsenopyrite is the only constituent of the ore-zone whereas in others it may occur as fairly broad zones, up to 12 inches in width, with scheelite scattered along the outer contact and cassiterite and chalcopyrite along the inner contact of the zone.

In the breccia ore-bodies arsenopyrite very rarely occurs in large masses but more commonly as blebs ranging up to about 2 inches in diameter, and even as small prismatic crystals scattered along the contacts of the fragments with the gangue-minerals. Isolated grains enclosed by quartz are also common but inclusions in calcite and fluorite are rare.

The arsenopyrite is silver-white, being more so than normal arsenopyrite. This is most probably caused by the partial replacement of Fe by Co and Bi and that of S by As. Compared with the analysis of FeAsS (table 8 column 1) this arsenopyrite shows, in addition to the presence of Co and Bi, a decrease in Fe and S and an increase in As. The sum total of Fe + Co + Bi is in good agreement with the total Fe content of FeAsS, and As + S is more or less the same for both analyses. When expressed in atomic proportions Fe:As + S = 1:2 in FeAsS whereas for Stavoren arsenopyrite Fe + Co + Bi : As + S = 1:2.

The decrease of Fe and S together with the increase of As may also indicate the presence of loellingite as an impurity in the analysed sample. Polished sections of the arsenopyrite chemically analysed, were examined after etching with HNO_3 without, however, detecting any loellingite. This etch-test may fail to reveal the presence of small quantities of loellingite but certainly not 10.29 per cent which remains, as is shown in table 8, after the analysis of the arsenopyrite is recalculated to correspond to the formula (Fe, Co, Bi) AsS. For this calculation all the S was assumed to occur in the arsenopyrite and the atomic proportions of As and of Fe + Co + Bi was decreased so as to correspond to the atomic proportion of S. It is therefore concluded that loellingite is not present as an impurity but that part of the S is replaced by As, and part of the Fe by Co and Bi in the arsenopyrite.

In order to determine whether the minor element content of the arsenopyrite varies with increase in depth or in the various pipes spectrographic analyses were carried out on seventeen samples collected from the various pipe exposures on the different levels. In addition to the elements given in the chemical analysis W, Mo, Pb, Zn, Sn and Sb were detected.

Sb is present in comparable quantities in all the samples and most probably substitutes for As in

TABLE 8. Chemical analyses of arsenopyrite.

	1		2		3		4	
	% by weight.	Atomic proportions.	% by weight.	Atomic proportions.	% by weight.	Atomic proportions.	% by weight.	Atomic proportions.
Fe	34.30	.6142	31.84	.5702	29.18	.5227	2.66	.0476
Co	-		0.84 } 34.31	.0143 } .5923	0.78	.0132 } .5430	0.06	.0011 } .0494
Bi	-		1.63	.0078	1.49	.0071	0.14	.0007
Ni	-		trace					
As	46.01 } 65.70	.0142	48.12 } 65.53	.6422 } 1.1852	40.69	.5430	7.43	.0992
S	19.69	.6142	17.41	.5430	17.41	.5430		
Total	100.00		99.84		89.55		10.29	
S.G.$^{24}_{4}$			6.24 ± .03					

1. FeAsS (Palache, Berman and Frondel, 1944, p. 319, analysis 1.)

2. Arsenopyrite, Seelig pipe, second level, Stavoren. Analyst:- Abraham Kruger, Division of Chemical Services, Pretoria. Sample No. JGS 21.

3. Analysis 2 recalculated to correspond to the formula (Fe, Co, Bi) AsS.

4. Balance after recalculating 2. Can be expressed as (Fe, Co, Bi) As_2= loellingite.

part. The quantities of the other elements, which are due to mineral impurities, vary in the different samples. Pb, Sn and W are present in all the samples whereas, Mo was detected in only about half and Zn in only four. Pb is the only element that reveals a relationship between the quantity present and the depth from which the samples were collected. It is present in greater quantity, although still in traces, in the samples from the first level. This is in agreement with the distribution of galena. Zn was detected only in samples from the B6a pipe on the first and second levels, and from the B5a and B5c pipes on the first level. Mo is present in several samples from the first and second levels and is not necessarily confined to certain pipes or depth-horizons.

TABLE 9. Diffraction spacings of arsenopyrite from Stavoren. Cobalt radiation. Camera radius = 57.3 mm.

No.	Int. (est.)	d A	No.	Int. (est.)	d A
1	7	2.64	9	5	1.59
2	10	2.41 *	10	4	1.54
3	2	2.20	11	4	1.33
4	2	2.08	12	3	1.222
5	2	1.94	13	2	1.108
6	7	1.81 *	14	2	1.072
7	3	1.75	15	5	1.046
8	4	1.63	16	5	1.009

10. Molybdenite.

This mineral was fairly common in the upper, now inaccessible portions of some of the pipes where it occurred in small flakes and scales scattered through the thuringite zone, and also in compact lamellar masses. From the B6a pipe several tons of molybdenite were recovered (Wagner 1921, p. 129).

In the portions of the pipes examined by the writer molybdenite is scarce. It occurs occasionally as flakes of microscopic size in the thuringite zone. In the vicinity of some of the pipes it is also present as blebs in the granophyre surrounding the pipes.

11. Magnetite.

Magnetite occurs in microscopic amounts only and was merely detected as filling fractures in pyrite and interstices between pyrite grains.

By aid of a sharp needle enough material could be removed from polished sections to obtain a x-ray powder diffraction pattern from which the cube-edge was calculated as 8.385 ± .005 A.

12. Cassiterite.

Although not being the most abundant, cassiterite is, from an economical standpoint, one of the two most important ore-minerals. The other one is scheelite.

Owing to its strong force of crystallisation cassiterite occurs as idiomorphic crystals and crystal aggregates, rarely as irregularly shaped masses. The habit of the crystals are pyramidal and they range in size from microscopic dimensions up to a diameter of 1½ inch. Twins, with the second order pyramid as twinning plane, are common and often repeated, producing complex forms.

Cassiterite suffered much brecciation during or prior to the crystallisation of the late gangue-minerals which occupy the fractures (plate VI fig. 1).

This mineral is much more abundant in the breccia- than in the zonal ore-bodies. In the former it is not only confined to the interstices between the fragments but more commonly occurs disseminated through the highly chloritised fragments. In the zonal ore-bodies it is present along the inner contact of the ore-zone and is often enclosed by the gangue-minerals forming the core of the ore-bodies; inclusions of cassiterite in quartz are abundant whereas in calcite it is less common and in fluorite exceptional.

Cassiterite shows no visible variation in abundance from the first to the second level but on the third level it is very poorly present.

In hand-specimen the colour of the cassiterite varies from light-yellow to brownish-black, whereas under the microscope the colour of the same grain varies from colourless through lemon-yellow to reddish-brown. The yellow and lighter colours are the most common.

This type of colour variation is common in the Bushveld cassiterite; Strauss (1945, p. lxxxv) describes the same phenomena in the cassiterite from the Zaaiplaats - Groenfontein tin mining area, and it was also observed by the writer in thin sections of Mutue Fides cassiterite.

In a single crystal the reddish-brown variety usually occurs as disconnected patches in a yellowish to colourless groundmass. In some crystals the arrangement of the colours is completely irregular whereas in others they are zonally arranged. Such crystals show a core of reddish-brown followed outwards by yellow or by alternating zones of yellow and colourless varieties. The contact between the reddish-brown and yellow zones or areas is usually fairly sharp whereas the yellow and colourless zones or areas fade into each other. In still other crystals reddish-brown patches cut across zonally arranged yellow and colourless areas. Strauss (1945, p. lxxxv) also observed that in twinned crystals the zones or areas may pass undisturbed across the twinning plane.

The cassiterite is pleochroic, the pleochroism being dark reddish-brown to reddish-brown for the dark coloured patches, and lemon-yellow to light-yellow for the light coloured areas. Strauss (1945, p. lxxxv) also describes non-pleochroic reddish-brown and pleochroic, colourless to deep wine-red varieties. None of these were observed in the cassiterite from

Stavoren. Liebenberg (1945, p. lxxxix) points out that the pleochroism exhibited by the Bushveld cassiterite can be regarded as very weak when compared with that of cassiterite from pegmatites.

In order to determine whether there is any variation in the minor element content of the differently coloured varieties of the Stavoren cassiterite, a single crystal was crushed to -32 + 50 Tyler mesh and the most intensely coloured as well as the slightly coloured particles separated from this crush by means of a binocular microscope.

For the spectrographic analysis 10 mg. of each of these separations was mixed with 100 mg. graphite so as to eliminate selective volatilization. In order to obtain greater sensitivity carbon electrodes were used. The arcing time was 100 seconds at 10 amps., allowing exposures of 100, 50, 25, 12½, 6¼ and 3 seconds by using a step sector. For the determination of Nb, 7 mg. of the cassiterite separations was mixed with 15 mg. sodium carbonate and 30 mg. graphite. This mixture was arced on carbon electrodes using cathode layer excitation. The spectrograph was set on glass.

The minor elements detected in the cassiterite are Bi, Mn, Cr, W, Fe and Cu; Mg, Ca,and Al were also present but there presence is entirely due to impurities in the electrodes used. The only elements that are not present in more or less similar quantities in the differently coloured varieties of cassiterite are

W and Mn, and to a lesser extent Cu. W is present in detectable amounts only in the dark-coloured specimen whereas Mn and Cu are more abundant in the light-coloured material (see plate VII fig. 1).

According to Schröcke (1955 p. 438 and table 10) spectrographic analysis of cassiterite from the Zaaiplaats tin-mine yields, in addition to the above-mentioned trace elements, also traces of Nb, Ta, Sc, Si and Ti. Sc was not looked for in the Stavoren mineral by the present author and, although special care was exercised no Nb, Ta or Ti could be detected. Si, as is admitted by Schröcke, occurs as impurities in the samples analysed by him. His data on the Zaaiplaats cassiterite (table 10) is, however, in agreement that Cu is more abundant in the light-coloured variety and W in the dark-coloured variety.

There still exists considerable uncertainty in regard to the nature of the pigmentary agent in cassiterite. Gotman (1938) suggests that the colour variation of the cassiterite is not caused by pigmentary impurities but rather by changes in the crystal lattice of cassiterite, caused partially by various impurities in the lattice. Noll (Schröcke 1955, p. 452) on the other hand, ascribes the colour variation to the quantity and dispersion grade of submicroscopic exsolusion particles of foreign minerals in cassiterite, but also suggests that the pigmentation may be caused by unoccupied oxygen positions in the crystal lattice of cassiterite.

Schröcke (1955, p. 452) experienced that the variation in minor element content from dark-brown to light-brown cassiterite is very small. Accordingly he is not convinced that the colouring is caused by pigmentary impurities and states that Noll's second suggestion is a probability but points out the possibility that the opposite may be the case viz., that the colour intensity is inversely proportional to the vacant oxygen positions.

The data on the Stavoren cassiterite is also not in favour of pigmentary impurities; the fact that Fe is present in equal quantities in both coloured varieties, together with the behaviour of Mn (less abundant in the W-rich variety) clearly suggests that W is not present in the cassiterite as an impurity in the form of any of the common tungsten minerals, furthermore, if Mn is present as a mineral pigment one would rather expect the greater amount of Mn in the dark-coloured material.

X-ray studies reveal that the variation in minor element content does not effect the interplanar spacings to any measurable extent (table 10).

Determination of the specific gravity of the differently coloured varieties was also attempted. The small amount of material available (about 100 mg.) together with the apparatus on hand (ordinary specific gravity bottles of 7 cc capacity, etc.) made such determinations not accurate enough to arrive at any conclusion. The average for several determinations are: G_4^{24} = 6.85± .02.

A comparison of minor element content of cassiterite collected from various pipes on the different levels, has also been carried out. The only element that shows any variation is Cr.; all the samples of cassiterite from the first level of the mine give strong Cr-lines whereas those from the lower levels show only weak or no Cr-lines (see plate VII fig. 2).

TABLE 10. X-ray data of cassiterite.

No.	Int. (est.)	dA (Cu radiation)
1	10	3.34
2	10	2.64
3	4	2.36
4	.5	2.10
5	10	1.76
6	6	1.67
7	1	1.58
8	6	1.49
9	2	1.43
10	4	1.41
11	1	1.32
12	5	1.213
13	1	nm.
14	2	nm
15	2	nm
16	3	nm
17	3	1.075
18	1	1.056

TABLE 10 continued

No.	Int. (est.)	dA (Cu radiation)
19	1	1.031
20	8	0.948
21	3	0.928
22	3	0.912
23	9	0.907
24	9	0.879
25	9	0.847
26	2	0.836
27	7	0.825
28	3	0.811
29	4	0.802
30	5	0.797
31	9	0.780
32	9	0.778
33	5	0.775

nm observed but not measured.   Camera radius = 57.3 mm.

13. Scheelite.

Next to cassiterite scheelite is economically the most important ore-mineral. It is fairly abundant right down to the third level of the mine where it is more abundant than cassiterite.

It occurs in large massive patches ranging in size up to approximately 5 inches in diameter, and also in pyramidal crystals. It generally occupies the outer portions of the ore-zones and replaces the red feldspar of which remnants were found in scheelite patches.

It also occurs as crystals and patches in the thuringite zone and occasionally as isolated blebs in the albitite. In the latter instance it is, however, always bordered by a rim of thuringite. The association of the thuringite with scheelite is in this deposit just as characteristic as the association of a light-green, fine-grained chlorite with cassiterite. In the breccia ore-bodies scheelite is, in contrast to cassiterite, usually confined to the interstices between the fragments of altered rock.

Scheelite is replaced by the younger minerals (such as arsenopyrite). Inclusions of it in the late gangue-minerals do occur but are usually less common than those of cassiterite in these minerals. An exception is on the third level where much scheelite was found enclosed by fluorite. Typical of the inclusions in fluorite are that they are much less brecciated than those in quartz. The fractures in such brecciated scheelite grains are usually filled by quartz, calcite,and fluorite. Scheelite is also veined by stringers of chlorite.

Wagner (1921, p. 62) points out that scheelite taken from near the outcrops of the ore-bodies at places shows alteration to tungstite.

No variation in the minor element content of this mineral was detected. The elements present are Mg, Mo, Al, Sr, Si, K, Mn and Fe. Vermaas (1952, p. 720) reported also Cr and V. He used copper electrodes and the Cr 4275 A and V 3184 A lines. The presence of these two elements could not be confirmed by the present analysis. As to the Cr it should be mentioned that both the Cu 4275.1 A and the W 4274.6 A lines interfere with the 4274.8 A Cr-line making it unreliable for detecting Cr in scheelites by using copper electrodes.

Apart from the spectrographical analysis the following data on this scheelite are given by Vermaas :

Chemical Composition. Analyst: C.J. Liebenberg.

CaO	19.6
WO_3	78.84
MoO_3	0.0004
Total	98.4404

Fluorescence.

Pale-blue.

Specific gravity.

$$G_4^{25} = 6.09$$

Refractive indices for Na-light at 22°C.

$W = 1.921 \pm .003$ $E = 1.938 \pm .003$

14. ILVAITE (LIEVRITE).

This mineral was detected only in a sample of pyritic-ore from the exposure of the B5d pipe on the first level of the mine. Here it occurs merely in microscopic amounts and is associated with magnetite. It replaces the magnetite and fills, as the latter, interstices between pyrite grains, and also fractures in the grains (plate VI fig. 2).

In transmitted light the mineral is almost opaque; a strong pleochroism (yellowish-brown to opaque) is noticeable in very thin section only. In reflected light it is, in contrast to magnetite, strongly pleochroic and anisotropic. The reflection pleochroism is from bluish-gray to gray with a brownish tinge, and the polarization colours are yellowish-brown and reddish-brown. The reflectivity is also lower than that of magnetite. The ilvaite is magnetic, but only moderately so, being only slightly attracted by a steel magnet.

TABLE 11. X-ray diffraction spacings and estimated intensities of ilvaite from Stavoren. Co radiation. Camera radius = 57.3 mm.

No.	dA^o	Int.	No.	dA^o	Int.
1	4.52	4	16	1.62	9
2	3.85	4	17	1.52	1
3	3.23	4	18	1.49	4
4	2.84	10	19	1.46	9
5	2.70	10	20	1.42	5
6	2.55	2	21	1.37	3
7	2.41	6d	22	1.30	1
8	2.34	6d	23	1.28	5
9	2.17	8	24	1.246	1
10	2.10	9	25	1.099	2
11	1.95	1	26	1.069	5
12	1.89	5	27	1.028	4
13	1.73	3	28	0.999	5
14	1.70	3	29	0.947	1
15	1.67	4			

The author experienced difficulty in identifying this mineral, and a polished section was forwarded to Prof. Paul Ramdohr, University of Heidelberg, Germany, who kindly carried out the identification. The difficulty to identify this mineral was not merely due to its occurrence in microscopic amounts, but rather to the fact that ilvaite is not mentioned in Short's (1940) nor in Uytenbogaardt's (1951) tables for the microscopic identification of ore-minerals. Schneiderhöhn and Ramdohr (1931^{i} p. 610) and also Ramdohr (1950 p. 761) do give a detailed description of the optical properties of ilvaite but in their tables for the microscopic identification of opaque minerals (Schneiderhöhn and Ramdohr 1931^{ii}) the characteristic bluish-gray reflection pleochroism, and distinct polarization colours are not given, making it hardly possible to identify this rather scarce mineral by using these tables. Furthermore, no x-ray data for comparison occur in the first three sets of cards, of the American Society for Testing Materials, that were available to the author; the x-ray powder diffraction spacings (table 11) could not be interpreted by comparison with any of those given in the cards mentioned.

Chemically ilvaite shows some correspondence to lombaardite a mineral from Zaaiplaats tin-deposits (Nel, Strauss and Wickman 1949, p. 45; also Strauss 1954, p. 169). The former is essentially a calcium-iron silicate and the latter a calcium-iron-aluminium silicate. However, according to Strauss (1954 folder 12) lombaardite was the last mineral to form in the

Zaaiplaats deposits whereas ilvaite occupies a much higher position in the paragenetic sequence of the minerals in the Stavoren deposits (see Figure 8).

This mineral was first found on the Elba island where it occurs as large solitary crystals, and in aggregates in dolomite. Thereafter it was reported from near Herborn in Hessen-Nassau; Mte. Mulat in Italy; Cap Bougaroun in Algeria; South Mountains mine, Owyhee Co., Idaho; various points in Japan; and from the sodalite-syenite in the Julianehaab District of Southern Greenland (Ford 1932 p. 631).

Barsanov (1941) reports the mineral from sulphide skarns in limestone near a granite contact at Maly Mukulan in the Kabardin Balkar Republic, Caucasus. Here it occurs together with chlorite, actinolite, hastingsite, pyrrhotite, magnetite, sphalerite, and small amounts of stannite and cassiterite. Another occurrence in skarn is that in pneumatolitic skarns at the contact of Palaeozoic limestone and a pipe of Tertiary volcanic breccia at the Stantrg lead-zinc mine in Yugoslavia where it occurs associated with silicates and magnetite (Forgan 1950). It is also associated with magnetite on the island of Serifos, Greece (Marinos 1951). Brown (1936) describes secondary ilvaite from Balmat, New York, where it occurs with supergene sphalerite, galena, and willemite. A manganiferous variety occurs in Tuscany at Campiglia Marittima (Gramling-Mende 1942). In South Africa up to the present it has been reported only from a beryllium-bearing pegmatite near Klein Spitzkoppie, South West Africa (Ramdöhr 1940).

C. Gangue-Minerals.

The minerals are described in the order set out by Ramdohr (1950).

1. Quartz.

Quartz is by far the most abundant of the minerals in the Western B group of pipes on Stavoren, and occurs as crystals and as aggregates of interlocking grains.

At least three generations of quartz were distinguished. The earliest of these occur as well-formed crystals which are enclosed by later quartz, calcite and fluorite. These prismatic crystals measure up to 5 inches in length and 1 inch across, and are usually encrusted by a thin film of stilpnomelane. This encrustation is the most prominent on crystals that are enclosed by calcite.

Microscopic examination suggests a secondary enlargement of the crystals. In such cases the original outline of the crystals is marked by a thin band of inclusions (see plate VIII fig. 1 and 2). The crystallographic orientation of the added material is the same as that of the original crystal. This secondary development is prior to the stilpnomelane encrustation.

The second and also main period of quartz deposition is represented by aggregates of quartz which occur as a filling of the interior of the zonal orebodies, as a cementing material in the breccia orebodies, and also as replacement veins and stringers in the older minerals and chloritised country-rock.

In thin section this massive quartz is seen to consist of interlocking anhedrons with no suggestion of prismatic development or any other crystal form. Generally this quartz shows very little variation in texture but where it encloses crystals of the first generation quartz some striking textures are developed. In such cases the crystals acted as nuclei from which the later quartz had grown outwards to form micro-crystalline comb quartz in peripheral development about the crystals. The combs are normal to the prism faces. Macroscopically the quartz combs appear as a light-greenish zone and under the microscope, with ordinary light, the combs are characterised by a turbidity resulting from numerous inclusions of minute shreds and dust-like particles, too small to identify but probably representing remnants of the stilpnomelane that originally encrusted the crystals. Plate VIII fig. 1 and 2 serves to illustrate the above. The large amount of inclusions in the comb quartz is prominent in figure 2.

Combs of second generation quartz also occupy fractures in the crystals of first generation quartz (thin section No. 18038). Of interest here is that these combs are not marked by inclusions. This probably indicates that the fracturing of the crystals is later than the stilpnomelane development.

Plate IX figure 1 shows that not only crystals of first generation quartz acted as nuclei around which the later quartz grew but that fragments of scheelite also served that purpose.

The deposition of the third generation quartz was probably the closing event in the formation of the ore-bodies and this quartz is as a on the whole very sparsely present. It usually occurs in small stringers cutting the older minerals but was also found as small pyramidal crystals encrusted on calcite and fluorite cleavage-fragments. Wagner (1921, p.113) also described the replacement of large calcite crystals by this quartz "giving rise to hollow pseudomorphs in which the minutest details of the structure of the original calcite crystal are preserved".

Wagner regarded the quartz accompanying the feldspar in the peripheral portions of the ore-bodies as the earliest quartz and thus claimed that four generations of quartz could be distinguished. No irrefutable evidence to su port Wagner could be collected; the quartz accompanying the feldspar replaces it and was most probably deposited contemporaneous with the second generation quartz.

2. <u>Chalcedony</u>.

Chalcedony was encountered in three exposures only, viz., in that of the B5 East pipe on the first and second levels, and in the B6b pipe on the second level.

It is fairly abundant in these three exposures and occurs in the breccia type of ore-body as a cementing material for the fragments. The chalcedony was deposited contemporaneous with second generation quartz.

3. Calcite.

Calcite is one of the commonest gangue-minerals in the mine and quantitively it is second only to quartz.

Two periods of calcite deposition were observed. The earliest calcite is the most abundant and occurs as a constituent of the ore-bodies. It generally occupies, together with fluorite and quartz, the interior of the zonal ore-bodies and in the breccia ore-bodies serves as a cement for the fragments of country-rock and older minerals. It frequently veins the older minerals or encloses them; the commonest inclusions are crystals of first generation quartz and less abundant some of the ore-minerals.

This calcite is creamish-white, coarsely crystalline and often occurs as well-formed rhombohedral crystals, the rhombohedron being the $(10\bar{1}1)$ form. The crystals are occasionally coated by a film of chlorite. This chlorite, being younger than the calcite, is also introduced along the cleavage planes of this mineral.

In some exposures of the B6a pipe on the first level, the calcite is dark-red in colour. This colour divergence is a secondary phenomenon caused by the infiltration of hematite along the cleavage planes of the calcite; the identification of the hematite was carried out on a residue that remains after dissolving the calcite in dilute HCl. That none of the iron has entered the calcite structure is indicated by the fact that the refractive indices and the x-ray diffraction spacings of the red calcite is in agreement with that of the normal creamish calcite.

The second generation calcite is a very late arrival and occupies fissures which cut through the granophyre, the altered rocks, and the ore-bodies. The thickness of these calcite veins ranges from a thin film up to about 2 inches.

The refractive indices (table 12) and the interplanar spacings (table 13) of the two generations of calcite are not in agreement and also differ from that of pure calcite.

TABLE 12. Refractive indices of calcite.

	ϵ	ω
Pure calcite [i]	1.486	1.658
Coarse crystalline calcite (Stavoren)	1.490 ± .002[ii]	1.663 ± .001[ii]
Late vein calcite (Stavoren)	1.488 ± .002[ii]	1.661 ± .001[ii]

i) Palache, Berman and Frondel (1951, p. 151).
ii) For sodium light at 23°C.

The spectrographic analyses listed in table 14 suggest that the high refractive indices and small interplanar spacings of the Stavoren calcite are due to the partial replacement of Ca'' (Radius = 1.06 kX) mainly by Fe'' (radius = 0.83 kX) and Mn'' (radius = 0.91 kX) and to a lesser extent Mg'' (radius 0.66 kX)

TABLE 13. Diffraction spacings and estimated intensities of calcites.

	1	2		3		4	
No.	d A	d A	Int.	d A	Int.	d A	Int.
1		3.834	3	3.834	3	3.835	3
2	3.075	3.015	10	3.010	10	3.032	10
3	2.522	2.483	4	2.478	4	2.504	3
4	2.300	2.275	5	2.275	5	2.284	5
5	2.110	2.084	5	2.086	5	2.094	5
6	1.935	1.902	6	1.901	6	1.918	6
7	1.880	1.864	5	1.863	4	1.874	4
8	1.613	1.591	3	1.595	2	1.602	2
9	1.525	1.513	4	1.510	3	1.521	3
10	1.450	1.431	1	1.433	1	1.439	1
11	1.347						
12	1.306						
13	1.242						
14	1.190	1.175	1	1.175	1	1.177	$\frac{1}{2}$
15	1.156	1.149	2	1.149	2	1.150	$\frac{1}{2}$
16	1.045	1.042	3	1.041	3	1.044	2
17	1.017	1.009	2	1.008	2	1.013	1
18	0.988						
19	0.970	0.961	3	0.961	2	0.965	2
20	0.945	0.941	2	0.941	2	0.943	1
21	0.895						
22	0.854						
23	0.836						
24	0.799						
25	0.790						

1. Pure calcite (Kreiger 1930).
2. Coarse crystalline calcite - Stavoren.
3. Red modification of coarse crystalline calcite - Stavoren.
4. Late or vein calcite - Stavoren.

These divalent cations are known to substitute for Ca in calcite; Fe'' and Mg'' substitutes for Ca'' at least up to Fe: Ca, etc. = 1:4.5 and Mg: Ca, etc. = 1:45, and a complete series extends to rhodochrosite through the substitution of Mn'' (Palache, Berman and Frondel 1951, pp. 153 - 154).

TABLE 14. <u>Spectrographic analysis of calcites</u>.

	1.	2.
Ca	10	10
Mg	4	5
Sr	5	5
Si	½	1
Ba	½	8
Mn	7	7
Fe	7	7

Qualitative; estimated intensities using an arbitrary scale 0 - 10.

MgO	trace
SiO_2	0.33%
MnO	0.66%
FeO	1.25%

Quantitative; carried out by Mr Russel of the Union Geological Survey.

1. Coarse, crystalline calcite - Stavoren.
2. Late vein calcite - Stavoren.

The small differences in the properties of the two generations of calcite are caused by a difference in Ba content. The spectrographic analyses of these calcites indicate that Ba is the only element that is not present in more or less equal quantities in both; this element is more abundant in the late vein calcite. The larger interplanar spacings of this calcite suggest that it must contain a higher percentage of an element with larger ionic size than that of Ca''. The radius of Ba'' (1.43 kX) fulfils this condition and it therefore seems that the Ba detected spectrographically in the late vein calcite substitutes partially for Ca''. This is supported by the fact that no other Ba-bearing mineral could be detected microscopically. Calcite which contains small amounts of Ba in substitution for Ca is known to occur in nature (Palache, Berman and Frondel, 1951, p. 154).

4. Fluorite.

Fluorite is common throughout the mine and is most abundant in the zonal ore-bodies where it, together with calcite and quartz, forms the core of these ore-bodies. The most abundant is a pale-greenish to colourless variety and much less common a violet variety.

The refractive index, determined by the method of minimum deviation using sodium light, is 1.4343 ± .0002 at 22°C for the pale-greenish variety whereas for the violet fluorite it is 1.4337 ± .0002 at 22°C. The premise that refractive index variations accompany colour variations in fluorite is supported by several publications. In one of the latest Allen (1952 p. 917) claims that violet fluorites have indices below normal and that in general green fluorites have indices which are either considerably above or considerably below normal. The value given by him for optical fluorite is 1.43385 (20°C) and he points out that it is in exact agreement with findings of Gifford (1902) and Merwin (1911).

Both varieties show a bluish fluorescence when exposed to long-wave (3660A), ultra-violet light but are not effected by short-wave (2540A), ultra-violet light.

The minor element content as revealed by spectrographic analyses, is listed in table 15 and the x-ray data in table 16. Previously the present author (1954, p.330) claimed that some impurities in fluorites such as Pb, Cu, Fe, etc. are due to contaminating minerals and that owing to similarity in ionic size some elements may partially replace Ca'' in the fluorite structure without affecting the cube-edge to any measurable extent, but that an increase in the cube-edge is caused by the replacement of Ca'' (radius = 1.06 kX) by Sr'' (radius = 1.27 kX).

Allen's (1952, p. 930) cube-edge for synthetic fluorite of optical grade is 5.46295 A at 28°C. If this value is corrected to correspond to the temperature of 25°C it becomes 5.4626 A which is identical to the value given by the present author (1954, p. 330) for optical fluorite from the Marico District in the Transvaal. The cube-edge of the violet fluorite from Stavoren is in close agreement with that of optical fluorite but that of the pale-greenish fluorite is a little larger, although within the limits of error. This larger cube-edge is, however, most probably due to the pertial substitution of Ca'' by Sr'' in the greenish fluorite.

TABLE 15. Spectrographic analyses of fluorite, minor elements only.

(Estimated intensities using an arbitrary scale 0 - 10)

	Fe	Mg	Be	Sr	Al	Pb	Mn	Cu	Sb	Si
Pale-greenish	4	2	2	3	2	-	1	-	2	-
Violet	5	1	-	-	3	6	-	3	2	2

TABLE 16. X-ray data of fluorites from Stavoren.

			Pale-greenish		Violet	
No.	hkl	Wavelength	Int.(est.)	d A	Int.(est.)	d A
1	111	K_{β}	5	3.150	5	3.150
2	111	K_{α_1}	10	3.151	10	3.149
3	220	K_{β}	5	1.930	6	1.928
4	220	K_{α_1}	10	1.929	10	1.928
5	311	K_{β}	1	1.644	2	1.641
6	311	K_{α_1}	9	1.646	9	1.643
7	400	K_{α_1}	4	1.366	4	1.364
8	331	K_{α_1}	5	1.252	5	1.251
9	422	K_{α_1}	8	1.114	8	1.114
10	511	K_{α_1}	3	1.049	3	1.050
11	440	K_{α_1}	3	0.965	3	0.964
12	531	K_{α_1}	4	0.922	6	0.922
13	620	K_{α_1}	6	0.864	5	0.864
14	533	K_{α_1}	5	0.833	5	0.833
15	642	K_{β}	3	0.730	3	0.730
16	444	K_{α_1}	5	0.789	5	0.789
a_0 at 25°C			5.4632 ± .0005 A		5.4628 ± .0005 A	
Cu-radiation. Camera radius = 114.59 mm.						

5. Thuringite.

This mineral was described by Wagner (1921, p. 70) as "raven-mica", the term being derived from rabenglimmer, a variety of zinnwaldite occurring in the tin deposits of Altenberg in Saxony. Wagner based his identification mainly on the mode of occurrence of this mineral and on its lithium content which was established spectroscopically by Dr. B. de C. Marchard.

X-ray data and differential thermal analyses indicate that the mineral from Stavoren is a true chlorite and its chemical analysis is in good agreement with that of thuringite; this analysis shows only 0.04 per cent. Li_2O.

The thuringite is one of the most characteristic minerals in the pipe-like deposits on Stavoren. The zonal ore-bodies are invariably surrounded by a narrow zone composed of hexagonal flakes of this chlorite. The thuringite zones are usually continuous right round the ore-bodies although they seldom exceed two inches in width. In the breccia type of ore-body this mineral usually occurs on the contacts between the fragments and the interstitial material. Occasionally it occupies the entire space between the fragments.

The diameter of the flakes are usually less than 5 mm. but are occasionally almost twice that size. Often these flakes are grouped together in such a way as to form prismatic crystals.

The thuringite has developed mainly by replacing the red feldspar of the feldspar zone and the feldspars of the surrounding altered granophyre. Owing to this phenomenon the contact between the thuringite zone and the altered granophyre is a transitional one and the contact with the red feldspar zone is very irregular due to replacement of the feldspar along fractures. Occasionally the solutions from which the chlorite was deposited gained access to the interior of the zonal ore-bodies and then replaced the red feldspar along its (meaning the feldsp r's) inner contact.

The optical and physical properties of the thuringite are listed in table 17. The refractive index, $n\overset{\alpha}{\gamma}$, was determined on thin slices that were cut normal to the basal cleavage by aid of a safety razor blade.

TABLE 17. <u>Physical and optical properties of thuringite from Stavoren</u>.

Colour in hand-specimen:	dark-greenish to almost black.
Pleochroism:	strong; α = brownish, $\gamma = \beta$ = deep-green.
Cleavage:	distinct basal
Optic angle:	$-2V = \pm 0^{\circ}$.
Refractive indices	$n_{\alpha} = 1.657 \pm .005$ (Na light at 24°C) $n_{\gamma} = n_{\beta} = 1.669 \pm .003$ (Na-light at 24°C)

Sections normal to the cleavage shows the presence of quartz lenses interbedded in parallel arrangement with the cleavage flakes (plate IX fig. 2). This quartz has crystallised later than the thuringite and its crystallisation in places led to the brecciation of the thuringite.

Wagner (1921, p. 71) points out that the flakes often present a curious mottled appearance under the microscope. He ascribes this phenomemon to alteration which proceeds irregularly from the cleavage planes and claims that the alteration product is a dark-green chlorite of the chamosite-thuringite group. In addition the present author also observed that in places the thuringite along the inner contact of the feldspar zone, has disintegrated into a much finer-grained mass which microscopically could not be distinguished from the chlorite into which the fragments of the breccia ore-bodies are altered. In view of Winchell's conclusions that the chlorites are probably all strictly ferrous minerals as originally formed but liable to an oxidation of the type $Fe'' OH \rightarrow Fe''' O$ (Hey 1954, p. 278), it seems likely that the "alteration" of the thuringite is due to oxidation whereby some of the original ferrous iron is changed into ferric iron.

Wagner (1921, p. 71) publishes an analysis of "highly chloritised mica" analysed by Moir. Unfortunately in this analysis no precautions were taken against the presence of free quartz so that it presumably does not represent the truecomposition of the mineral. In order to isolate the mineral for another chemical analysis the most dark-coloured flakes, which are apparently the least altered, were selected and crushed to -100,+ 200 mesh. To separate the free quartz from this coarse powder a Frantz-Isodynamic-Separator and thereafter bromoform was employed.

The average volumetric content of free quartz in the thuringite is about 15 per cent; this value becomes 12.4 per cent. by weight if the specific gravity of the quartz is assumed as 2.65 and that of the thuringite as 3.3. The new chemical analysis (table 18 column 1) still shows the presence of 2.82 per cent. free quartz* which indicates that all the quartz could not be removed by physical methods. In the analysis of Wagner (table 18 column 3) the total SiO_2 content is 30.65 per cent. If this value is corrected to correspond to the true SiO_2 content as given in column 2 of table 16, the original free quartz content is found to be 10.63 per cent.

TABLE 18. Chemical analyses of thuringites.

	1	2	3	4	5
SiO_2	24.49^x	22.4	30.65^x	22.4	23.7
Al_2O_3	16.31	16.85	11.3	12.64	16.54
Fe_2O_3	9.82	10.15	4.15	4.65	12.13
FeO	34.77	35.93	40.8	45.65	33.14
MgO	0.87	0.90	1.6	1.79	1.85
CaO	1.22	1.26	0.1	0.11	-

---

*The procedure followed by mr. Abraham Kruger, Division of Chemical Services, Pretoria, to determine the free quartz is as follows:- "0.5 gm. of the finely powdered mineral was treated with 25 ml. of 80% ortho-phosphoric acid in a Phillips beaker containing a funnel in the neck. The acid was heated on a flame and regularly stirred during heating. Twelve minutes after boiling has subsided the beaker was removed from the flame, cooled, and the acid diluted with 125 ml. hot water.

The upper part of the beaker was rinsed with 10 ml. fluoboric acid (prepared by adding 180 ml. hydrofluoric acid to 200 ml. saturated solution of boric acid) and 25 ml. water. The quartz was filtered off through a No. 42 Whatman filterpaper, washed with diluted hydrochloric acid and determined as usual."

PART II

TYSONITE FROM MUTUE FIDES.

Table 18 continued.

	1	2	3	4	5
Na_2O	0.30	0.31	0.19	0.21	0.32
K_2O	0.55	0.57	1.48	1.64	
Li_2O	0.04	0.04	absent	absent	-
TiO_2	0.40	0.41	0.40	0.45	-
MnO	0.49	0.51	-	-	1.16
H_2O+	9.19	9.50	9.35*	10.46	10.90
H_2O-	1.13	1.17			
Total	99.58	100.00	100.02	100.00	99.74
Free quartz	2.82	2.82		10.63	

x SiO_2 from free quartz included.

* Ignition water corrected for oxygen.

1. Thuringite, B5a pipe, second level Stavoren, Potgietersrus District, Analyst, Abraham Kruger, Division of Chemical Services, Pretoria.

2. Analysis (1) after deducting free quartz from total SiO_2 and recalculating to 100.

3. "Highly chloritised raven-mica", Stavoren, Potgietersrus District. Analyst, Dr J. Moir. Wagner (1921, p. 71)

4. Analysis 3 after correcting SiO_2 to correspond with that in column 2, and recalculating to 100.

5. Thuringite, Arkansas. Analyst, J.L. Smith. Dana's System of Mineralogy, 6th edition p. 657, analysis 7.

Column 5 of table 18 gives an analysis of thuringite from Arkansas. The Stavoren thuringite differs from this one in containing less Fe_2O_3 but comparatively more FeO.

Holzner (1938, p. 389) recalculated various chemical analyses of chlorites and found that in the chlorites low in water content the summation of the metal ions is

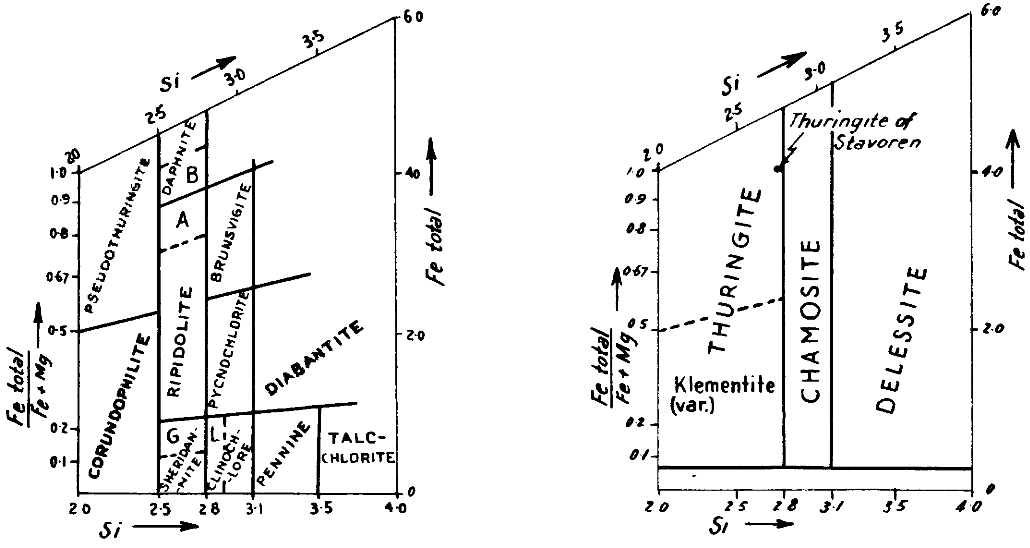

Fig. 1a   Fig. 1b

Fig. 1a. *The orthochlorites, on basis of 14 oxygen (anhydrous), showing the proposed species and variety boundaries.*
L = Leuchtenbergite, var. of Clinochlore;
G = Grochauite, var. of Sheridanite; A = Aphrosiderite, var. of Ripidolite;
B = Bavalite, var. of Daphnite.

Fig. 1b. *The oxidized chlorites ($Fe_2O_3 > 4\%$) on basis of 14 oxygen (anhydrous) calculating all iron as ferrous.*

Fig. 7. *Thuringite of Stavoren in Hey's classification of chlorites (Hey 1954, figs. 1a & 1b)*

40 per 56 oxygen ions when all the iron is reckoned as ferrous, whereas the chlorites with normal water content ($4H_2O$ per unit cell of $O = 14$) yield 40 metal ions per 56 oxygen ions when the ferric content is counted as such. He concludes that in the former type of chlorite the ferric content is due to oxidation of the ferrous ions subsequent to the formation of the mineral, whereas the latter type of chlorite contained ferric ions at the time of formation. Table 19 shows that the atomic content of the unit cell of the Stavoren thuringite (3.67 H_2O per unit cell of $O = 14$) also yields a low summation of metal ions if the ferric iron is calculated as such, whereas, if all the iron is calculated as ferrous the summation of metal ions is slightly too high but closer to the ideal value of 40 per 56 oxygen ions. It thus seems that the thuringite originally contained less ferric iron and that the "alteration" of the mineral is due to oxidation of the bivalent iron.

Hey (1954, p. 278) proposes a revised classification in which the division of chlorites is made into the unoxidised normal series of **orthochlorites** and the oxidised chlorites. He suggests that an arbitrary figure of 4 per cent. Fe_2O_3 be taken as the dividing line; any chlorite with more than 4 per cent. Fe_2O_3 being regarded as oxidised. According to this classification the thuringite of Stavoren is the oxidised equivalent of daphnite (see fig. 7).

The most dark-coloured flakes which are considered as the least altered, the greenish flakes, and the fine-grained masses yield similar x-ray patterns in which no line shifts could be detected. It should be mentioned, however, that the diffraction lines are broad which makes the detection of small line shifts, if present, impossible.

TABLE 19. <u>Atomic content of the unit cell of Stavoren thuringite</u>.

	1		2	
Si	10.4	16.0	11.09	16.0
Al	5.6		4.91	
Al	3.62	23.42	4.92	24.14
Fe'''	3.54			
Fe''	13.94		16.77	
Mg	0.62		0.66	
Ca	0.63		0.67	
Na	0.28		0.30	
K	0.34		0.36	
Li	0.07		0.07	
Ti	0.18		0.19	
Mn	0.20		0.20	
H	29.39		31.83	
Metal ions		39.42		40.14

1. Calculated from the chemical analysis in column 2 of table 18, assuming 56 oxygen ions per unit cell. Ferric iron calculated as such.

2. Ditto but assuming that all the iron was originally ferrous.

Dschang (1931, p. 410). claims that iron-rich orthochlorites can be oxidised by careful heating in air without change in crystal structure. Brindley and Youell (1953, pp. 57 - 70) show that ferrous chamosite (with kaolinite structure) is oxidised to ferric chamosite by heating it in air for 2 hours at 400°C. The ferrous and ferric chamosite have an essentially similar structure but the unit-cell dimensions are somewhat smaller for the ferric form.

An examination of the effects of heat treatment on the Stavoren thuringite was carried out by heating powdered material in air for periods of 2 hours at temperatures of 500, 600, 700, 800 and 1100°C. X-ray powder photographs were taken after each heat treatment; the diffraction spacings obtained from these photographs are listed in table 20.

The material heated to 500°C yielded, as is shown in the photographs depicted in plate X, somewhat weaker diffraction lines and smaller diffraction spacings than the unheated material. In view of Brindley's and Youell's findings on chamosite it seems likely that the decrease in the interplanar spacings is due to more or less complete oxidation of the ferrous ions to ferric ions. The lines at 4.25, 3.35 and 1.81 A are entirely due to quartz impurities and show a slight increase in intensity at 500°C. The broad and diffuse line at 2.52 A is caused by the interference of quartz and chlorite lines.

TABLE 20. X-ray diffraction spacings and estimated intensities of thuringite from Stavoren, before and after heat treatment. Co radiation. Camera radius = 114.59 mm.

Untreated.		Heated to 500°C.		Heated to 600°C.		Heated to 700°C		Heated to 800°C.		Heated to 1100°C.	
Int.	d A	Int.	d A	Int.	d A	Int.	d A	Int.	d A	Int.	d A
5	14.37	5	13.84	3	13.84					5	3.66
10	7.07	5	6.94	3	6.95					6	3.36
6	4.70	2	4.46							3	2.93
1	4.25q	3	4.26q	1	4.25q	1	4.25q	2	4.25q	10	2.69
1	3.87									8	2.51
7	3.54	4	3.45	2	3.45					4	2.44
4	3.35q	6	3.35q	3	3.35q	3	3.35q	6	3.35q	3	2.21
3	2.83									3	2.18
3	2.69									5	1.831
5b	2.52	4	2.51	1	2.51			1	2.44q	7	1.688
1	2.28							1	2.30q	1	1.590
2	2.12							1	2.05q	1	1.544
½	1. 2q	1	1.82q	½	1.82q			1	1.81q	3	1.481
1	1.77									4	1.449
4	1.56	1	1.54								
1	1.52										
1	1.42										
1	1.37q										

b = broad and diffuse. q = quartz.

At 600°C the photograph is the same as at 500°C except for a further decrease in line intensity. At 700°C the thuringite lines do not show up on the photograph and the only lines that do occur are those of quartz at 4.25 and 3.35 A. At 800°C these lines show an increase in intensity and additional quartz lines appear at 2.44, 2.30, 2.05 and 1.81 A. The lines at 2.44 and 2.05 A may also indicate the formation of spinel. Thuringite heated to 1100°C yields a hematite spectrum with additional lines which are presumably due to mullite.

Differential thermal analysis indicates that the dehydration of the thuringite proceeds, as is typical for chlorites, in two stages. The first stage reaches its maximum at about 580°C and the second at about 810°C.

6. Other Chlorites.

In addition to the crystallisation of thuringite at least two other periods of chlorite formation were distinguished. The earliest of these chlorites developed prior to the introduction of second generation quartz by which it is enclosed but later than some of the ore-minerals, such as scheelite, in which the chlorite occurs as stringers. This chlorite occurs mainly as the principal constituent of the chloritised granophyre and as fine-grained massive aggregates that have replaced the red feldspar remnants in the ore-zone of some of the ore-bodies.

The more or less constant association of this fine-grained chlorite with cassiterite probably suggests that the chlorite formation was brought about by reagents that accompanied the stanniferous solutions. In almost every instance the degree of chloritisation of the granophyre fragments of the breccia ore-bodies depends on the abundance of cassiterite; the higher the cassiterite content the intenser the chloritisation. This is best illustrated on the second level of the mine where some of the granophyre fragments of the cassiterite-poor ore-body in the B6c pipe are so slightly altered that it still exhibits a red colour whereas the fragments of the highly stanniferous ore-body in the B5 East pipe are completely changed to a greenish chlorite rock.

The relation of this chlorite to the thuringite flakes is not clear. In some places it seems as if the thuringite flakes had disintegrated into fine-grained masses that resemble, in grain-size and colour, the masses of this chlorite. In other places the thuringite flakes occur in direct contact with the highly chloritised fragments without showing any signs of disintegration. The x-ray diffraction spacings are also in exact agreement for both chlorites and the refractive index (n_m = 1.660 + .005) of the fine-grained chlorite is also in close agreement to that of the thuringite flakes.

No chemical analysis of this fine-grained chlorite is available but the analysis of the chloritised granophyre (table 27 column 4) clearly shows that the chlorite is an iron-rich one. All the ferrous and ferric iron in this analysis are presumably derived from the chlorite and the ratio Fe_2O_3 : FeO = 1:3.1 whilst for the thuringite flakes the ratio is Fe_2O_3: FeO = 1:3.5. It thus appears as if the fine-grained chlorite is also a thuringite but with more of its ferrous ions oxidised to ferric ions.

The third chlorite is clearly a very late arrival and occurs in aggregates of light-green flakes which are most commonly introduced along the cleavage-planes of the coarse, crystalline calcite.

This chlorite is also an iron-rich one. It has a refractive index of n_m = 1.663 ± .005 (sodium light) and 2V = ± 0. Its pleochroism is α = yellowish, β = γ = light green.

7. Stilpnomelane.

This is by far the rarest gangue-mineral in the western group of pipes of the "B" line, and occurs as microcrystalline fibrous plates forming spherical radial aggregates. Most commonly these aggregates form a thin coating around crystals of first generation quartz. These encrustations are very seldom composed of stilpnomelane alone. The stilpnomelane aggregates are usually enclosed by calcite and often accompanied by minute specks of arsenopyrite.

The encrustations are more or less always present around quartz crystals that are enclosed by calcite but are less common around crystals that are enclosed by second generation quartz. It thus seems as if the conditions during the deposition of calcite around the quartz crystals were favourable for the survival of stilpnomelane flakes of recognisable size, whereas, during the deposition of the later quartz that has grown outwards from the crystals, the stilpnomelane was broken up into cryptoscopic flakes now occurring as dustlike inclusions in the later quartz (plate VIII).

A second mode of occurrence of stilpnomelane is as inclusions in veinlets of second generation quartz in arsenopyrite. In such cases the flakes are of recognisable size and cause the greenish colour of these veinlets.

TABLE 21. Physical and optical properties of stilpnomelane from the B7 pipe, second level, Stavoren.

Colour in hand-specimen;	almost black.
Pleochroism:	strong; α = yellowish-brown $\beta = \gamma$ = very dark-brown.
Optic angle:	-2V = ± 5° (determined by the Mallard Method).
Refractive indices:	$n\alpha = 1.554 \pm .005$ $n\beta = n\gamma = 1.611 \pm .005$ Na-light at 24° C

The physical and optical properties of stilpnomelane from Stavoren are given in table 21. The optical resemblance of stilpnomelane with biotite has been emphasized by various authors and except for chemical analyses, the distinct difference in x-ray diffraction

TABLE 22. X-ray diffraction spacings and estimated intensities of stilpnomelane.

	1		2		3	
No.	Int.	d A	Int.	d A	Int.	d A
1	7	12.9	6	13.0	4	13.5 K_{α_1} (=12.18K_β)
2	10	11.9	10	11.9	10	12.09
3	½	6.03	½	6.06	1	6.07
4	½	4.74	½	4.74		
5	1	4.476	1	4.446		
6	½	4.138				
7	5	4.045	5	4.035	6	4.04
8	1b	3.566	1b	3.555	1b	3.541
9	1	3.349	1	3.339	1	3.343K_α. (=2.720 K_β)
10	4	3.036	4	3.026	4	3.021
11	1	2.831	1	2.818	½	2.80
12	2	2.693	2	2.702	2	2.721
13	4	2.549	4	2.560	4	2.583
14	1	2.481	1	2.508		
15	½	2.418	½	2.421		
16	3	2.341	3	2.341	3	2.356
17	½	2.188	½	2.187		
18	2	2.109	2	2.105	1	2.117
19	½	1.964	½	1.955		
20	2	1.888	1	1.886	½	1.876
21	½	1.739	½	1.732		
22	2	1.686	1	1.686		
23	3	1.576	3	1.577	1	1.568
24	3	1.561	3	1.563	1	1.560

Table 22 continued

	1		2		3	
No.	Int.	d A	Int.	d A	Int.	d A
25	2	1.519	2	1.517		
26	1	1.416	1	1.416		
27	½	1.397	½	1.399		
28	½	1.359	½	1.351		
29	1	1.339	½	1.341		
30	½	1.322	½	1.323		
31	½	1.305	½	1.309		
32	½	1.287				
33			½	1.229		
34	½	1.151	½	1.150		
35			½	1.093		
Average d001		12.13		12.11		12.10

b = broad i = indistinct.

1. From Baern, (Sternberg-Bennish), Moravia. Unfiltered Fe radiation. Camera radius=57.3 mm (Gruner 1937, p. 919).

2. From Genoa Mine, Mesabi Range. Unfiltered Fe radiation. Camera radius 57.3 mm (Gruner 1937, p. 919).

3. From Stavoren tin-mine, Potgietersrus District. Unfiltered Co radiation. Camera radius 114.59 mm.

spacings is the most conclusive method of identification of the two minerals.

The intensities and spacings of the strongest, and most diagnostic, x-ray reflections of the mineral from Stavoren are in good agreement with those of other stilpnomelanes (table 22) but a large range of weak reflections does not show up on the x-ray photograph of the Stavoren stilpnomelane; this is presumably due to the difference in target used.

The number 1 and 9 reflections of the Stavoren sample (table 22, 3) are K_β reflections corresponding respectively with the number 2 and 12 K_{α_1} reflections. Gruner reported (number 1 and 9 reflections of Baern and Genoa Mine samples (table 22, 1 and 2) as K_β reflections but calculated the spacings as for K_{α_1} reflections. For comparative purposes the writer did the same but included in brackets the figures obtained by calculating them as K_β reflections.

8. Potash Feldspar.

It appears as if the first event in the formation of the ore-bodies was the deposition of a feldspar. This is a red potash feldspar, the colour being due to minute inclusions of iron oxide.

This feldspar is replaced by later minerals such as thuringite and quartz to such an extent that in the zonal ore-bodies it occurs only as a narrow discontinuous zone which in this treatise is referred to as the feldspar zone. In some of the ore-bodies this zone is represented only by remnants enclosed in the later minerals whereas in still others it is completely replaced. In the breccia type of ore-body this feldspar occurs either as small fragments in the later quartz or as a thin discontinuous zone near the contact of the cementing material and the rock fragments.

In hand-specimen the feldspar appears fresh but in almost every thin section partial alteration to chlorite is visible. This alteration starts from numerous isolated points.

It was noticed by McDonald (1914, pp. 57 - 59) and by Wagner (1921, p. 69) that, where the feldspar developed freely in druses, the habit of the crystals is that of adularia, the prism faces being very strongly developed whereas the clinopinacoidal faces are entirely absent or only very poorly developed. Vugs, which seem to have been fairly abundant in the upper portions of the pipes, are scarce in the areas examined by the writer and the few that exist do not contain any crystals of this feldspar so that the findings of McDonald and Wagner could not be confirmed.

Although "true" orthoclase and adularia is optically similar some writers, for example Spencer (1937, p. 488), report that "true" orthoclase has a smaller axial angle than adularia. Chaisson (1950, p. 538) modified Spencer's classification and shows that the axial angle of "true" orthoclase varies from 25° to 50° and that of adularia from 50° to 70°. The axial angle for the Stavoren feldspar, being 68 ± 2°, is well within the range of that of adularia and thus supports the findings of McDonald and Wagner.

The spectrographic analyses (table 23) indicate that the potash feldspar from the ore-bodies has a much lower Ga and Ti content than the feldspars of the albitite and granophyre, and further that no Mn was detected in it whereas traces of this element occur in the other feldspars.

TABLE 23. Spectrographic analyses of feldspars (Estimated intensities using an arbitrary scale 0 - 10).

	Ga	Ca	Ba	Na	K	Si	Mn	Cr	Fe	Al	Ti
Feldspar of ore-bodies.	1	3	2	5	10	8	-	2	5	9	-
Feldspar of granophyre.	6	7	2	7	10	8	2	1	5	9	5
Feldspar of albitite.	6	2	-	10	1	8	1	-	1	9	3

The spectrographic sensitivity of the elements differ greatly and the intensities of the lines should therefore be used only comparatively for each separate element.

9. Tourmaline.

Tourmaline is a common gangue-mineral in the Potgietersrus tin-fields examined by Strauss (1954, p. 152) but at Stavoren it is conspicuous by its rarity. In the Western group of pipes of the "B" line it occurs only in the B5a pipe at a depth of about 220 feet (second level) and although an increase of this mineral with increase in depth was expected it could not be detected in the B5a or any other pipe on the third level of the mine.

It does not occur in all the exposed ore-bodies of the B5a pipe on the second level but is confined to only one which measures approximately 3 feet by 5 feet. In this ore-body it occurs as rosettes which are about half-an-inch in diameter. The tourmaline replaced the red feldspar of which numerous remnants occur interstitially among the rosettes. These remnants are partially replaced by quartz of the second generation, calcite, and fluorite. In almost every hand-specimen the preference given by calcite and fluorite to replace red feldspar rather than to replace tourmaline, is striking.

Macroscopically the tourmaline is almost black while under the microscope it is strongly pleochroic; ω = bluish-green, ϵ = pale-brown. Its refractive indices for sodium light at room temperature (24°C) are $\omega = 1.668 \pm .001$ and $\epsilon = 1.640 \pm .005$. These indices indicate 80 mol. per cent schorlite (Winchell 1933, p. 303) and are in close agreement with those obtained by Strauss (1954 p. 152) for tourmaline from the Zaaiplaats-Groenfontein tinfield, but higher than the highest values ($n\omega = 1.655$, $n\epsilon = 1.629$) for pegmatitic tourmaline from the Quartz Creek pegmatite area, Gunnison County, Colorado (Staatz, Murata and Glass 1955, p. 794)

The tourmaline is partially altered to sericite.

10. Fluor-Apatite.

Prismatic crystals of this mineral were noticed by Wagner (1921, p. 72) in the upper portions of one of the B5 pipes. According to him they were up to one inch in length and of a greenish-gray colour. He claims that they are of very early development although they enclose patches of red feldspar. None of these crystals were noticed in the lower portions of the pipes.

D. Secondary Minerals.

A wide range of secondary minerals was observed by Wagner (1921, p. 66) in the oxidised upper portions of the pipe-like deposits on Stavoren. They are tungstite, cupro-tungstite, scorodite, bismutite, chalcocite, covellite, bornite, native copper, malachite, azurite, cuprite, chalcotrichite, chrysocolla, olivinite, cerussite, martite and limonite.

Of these only bismutite and native copper are reported by Wagner from the "B" group of pipes. Scorodite, chalcocite, malachite, azurite and limonite are reported by him as common in all the deposits in the granophyre whilst the rest were noticed in some of the other pipes on Stavoren but apparently not in the "B" group of pipes.

E. Paragenesis.

The order of crystallisation of the minerals as set out below was derived from the position occupied

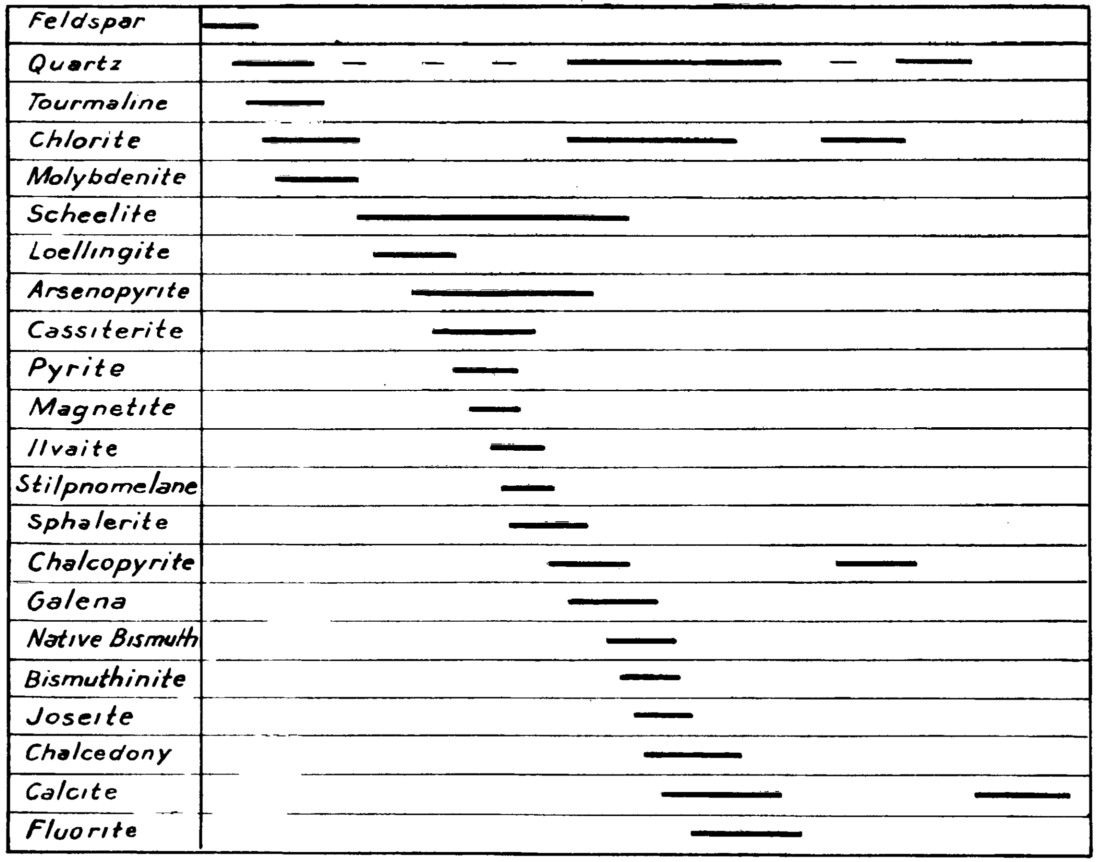

Fig. 8. Paragenetic chart of minerals in the deposits on Stavoren.

by these minerals in the ore-bodies, the interrelationships of the minerals in situ and in hand-specimens, and from a study of the mineral textures as revealed in polished and thin sections under the microscope. The sequence of formation of the minerals is given in condensed form in the paragenetic chart (fig. 8).

The zonal arrangement of the minerals in some of the ore-bodies is considered on the basis that deposition was from the rim inwards, i.e. the late minerals form the core of the ore-bodies whereas the minerals of early formation occupy the outer zones. The relationship is, however, not always as simple as that; the position occupied by thuringite and molybdenite is contrary to this rule. Thuringite usually forms the outermost rim of the ore-bodies although it is clearly younger than the red potash feldspar. Molybdenite, which also crystallised later than the feldspar, occurs with the thuringite. These phenomena are apparently due to selective replacement.

The opening event in the formation of the ore-bodies was the development of the red feldspar. After the formation of the feldspar and before the crystallisation of any ore-mineral, quartz crystallised. This quartz occurs as well-developed prismatic crystals.

The crystallisation of the quartz was succeeded by the deposition of metalliferous minerals such as molybdenite, scheelite, loellingite, arsenopyrite, pyrite, cassiterite, sphalerite, chalcopyrite and galena.

The zonal arrangement of these minerals suggests a sequence in order of age of molybdenite-scheelite-arsenopyrite-cassiterite-chalcopyrite but the paragenetic relationship as revealed by microscopic study of the mineral textures is less conclusive.

Plate XI figure 1 shows arsenopyrite filling a fracture in scheelite whereas Wagner (1921, plate XXIV) shows scheelite moulded on to arsenopyrite. The former which is presumably the more reliable texture clearly suggests that scheelite crystallised before arsenopyrite. The contact of cassiterite with scheelite and arsenopyrite is usually of such a nature that the relationship of cassiterite to these two minerals could not be established with certainty. The contact is either smooth and regular suggesting a simultaneous crystallisation for cassiterite and the other two minerals, or it is occupied by later gangue-minerals. In some thin sections (plate XI fig. 2) cassiterite was found moulded on to scheelite whereas in others Wagner (1921, p. 112) observed scheelite moulded on to cassiterite.

It thus appears as if the general sequence of deposition was apparently scheelite-arsenopyrite-cassiterite, but that there was considerable overlapping.

Molybdenite occurs sparingly in the portions of the pipes examined by the author and was never encountered in contact with any of the other ore-minerals. The fact that it usually occurs in, and replaces thuringite, probably indicates an early formation for this mineral.

Loellingite is replaced by arsenopyrite and is thus an earlier mineral than the arsenopyrite. The fact that it is more fractured than the arsenopyrite probably also suggests that it is older than the arsenopyrite, assuming of course that their resistance to fragmentation is approximately the same.

Pyrite crystallised earlier than the first generation chalcopyrite by which it is replaced. Its relationship to the other ore-minerals, except of magnetite and ilvaite, could not be established. In figure 8 cassiterite has been placed earlier in the sequence than pyrite and magnetite but it could just as well be later.

The occurrence of magnetite and ilvaite in the interstices between pyrite grains, and in fractures in these grains, provides sufficient evidence that pyrite crystallised prior to these minerals. Magnetite is replaced by ilvaite and thus precedes this mineral.

The exolution-intergrowth of sphalerite and chalcopyrite and the replacement of the former by the latter (plate II fig. 2) indicates that chalcopyrite is later than sphalerite.

Galena was encountered in one specimen only. Polished sections show that here galena replaces sphalerite but appears to be contemporaneous with early chalcopyrite.

The latest arrivals among the ore-minerals are the bismuth compounds and second generation chalcopyrite

The only contaminating minerals in the available specimens of bismuth minerals are arsenopyrite, chalcopyrite and galena. The arsenopyrite is enclosed and corroded by the bismuth minerals and chalcopyrite and galena are replaced by them. The sequence of deposition of the bismuth minerals is native bismuth-bismuthinite-joseite.

The second generation chalcopyrite appears to be the last ore-mineral deposited in the ore-bodies. It occupies microscopic fractures in fluorite (plate III fig. 1) and one hand-specimen was collected which shows chalcopyrite crystals moulded on to calcite.

Reverting to the gangue-minerals the formation of the thuringite flakes precedes that of the fine-grained chlorite. The former crystallised before scheelite whereas the latter succeeded cassiterite.

Tourmaline appears to be earlier than the ore-minerals but later than the red feldspar which is replaced by it.

Before the crystallisation of second generation quartz, which is later than first generation chalcopyrite, stilpnomelane was deposited as encrustations on the crystals of early quartz, and also in fractures in arsenopyrite.

The crystallisation of second generation quartz was apparently accompanied by that of chalcedony but was succeeded by that of fluorite and first generation calcite.

The last formed gangue-minerals are third generation quartz, a light-green chlorite, and second generation calcite. The quartz occurs as veins cutting the older minerals, and also as encrustations on fluorite and first generation calcite. The chlorite occupies the cleavage planes of this calcite. The second generation calcite is the latest arrival and occurs in fractures and fissures which cut through the ore-bodies.

The paragenesis can be represented as having taken place in the following stages :

(1) Formation of feldspar zones and crystallisation of early quartz.

(2) Main stage of metallisation during which the following minerals crystallised in the order: tourmaline, thuringite, molybdenite, scheelite, loellingite, arsenopyrite, cassiterite, pyrite, magnetite, ilvaite, stilpnomelane, chlorite, sphalerite, chalcopyrite and galena.

(3) Deposition of bismuth minerals, quartz, chalcedony, early calcite, fluorite and late chalcopyrite.

(4) Deposition of late chlorite and third generation quartz, and development of fissures in which the late calcite is deposited.

The paragenesis as set out above shows an agreement with the paragenesis of the minerals in the pipes of Eastern Australia. Blanchard (1947, p. 265) published data on some pipe deposits of Eastern Australia and claims that in these pipes the depositional sequence is molybdenite - wolfram - cassiterite. He discusses the order of arrival of these minerals in some detail and mentions numerous publications in which wolfram has been listed as following cassiterite, and molybdenite as following wolfram. He points, however, to a few authors such as Dunn (1938, p. 209), Ke-Chin Hsu (1934, p. 431), and Ahlfeld (1945, p. 394), who reported wolfram as preceding cassiterite. One of them Ke-Chin Hsu, basing his conclusions upon microscopic evidence, reports a molybdenite - wolfram - cassiterite sequence.

To summarise Blanchard points out that at Cornwall, Zeehan, Erzgiberge and various other localities cassiterite preceded wolfram whereas in the deposits of Burma, China, Bolivia and Eastern Australia the sequence is reversed and he concludes (p. 291) "The only conclusion which at present seems justified is that in the deposition of molybdenite, wolfram and cassiterite, nature employs controls of a broader range and greater degree of flexibility than those with which man has sought for explanation".

In a recent memoir on tin deposits associated with the Bushveld Igneous Complex in the Potgietersrus District, Strauss (1954, p. 161) concludes that in the Zaaiplaats and Groenfontein deposits the crystallisation of the wolframite was evidently complete before that of cassiterite commenced, but that the paragenetic relationship between the cassiterite and scheelite is difficult to establish and suggests that "apparently the crystallisation of scheelite commenced before and continued after that of cassiterite". Von Backström (1950 pp. 44 - 46) decides that in the tungsten-tin deposits near Upington arsenopyrite is earlier than both scheelite and cassiterite and that cassiterite precedes scheelite. He does not express his opinion on the position occupied by the molybdenite of the deposits. Strauss, as Blanchard, is of opinion that molybdenite crystallised before the tungsten minerals and cassiterite. The early crystallisation of molybdenite is also supported by Söhnge (1950 p. 939).

The abovementioned conclusions of Strauss fit the Stavoren deposits perfectly and it thus appears that Blanchard could add the deposits related to the Bushveld Igneous Complex to those where wolfram precedes cassiterite.

F. Classification of the deposits.

The classification of the deposits at Stavoren according to temperature of formation raises some interesting points. Most cassiterite deposits are considered by Lindgren (1933, p. 643) as of hypothermal origin. Those at Stavoren are, however, characterised by the rarity of high temperature minerals such as tourmaline, apatite, etc., and the sulphides accompanying the cassiterite mineralisation are typically those of the intermediate or mesothermal stage.

The hypothesis that the cassiterite mineralisation at Stavoren is of mesothermal origin is supported by the findings of Strauss (1954). In the deposits of the Potgietersrus tin-fields examined by him, tourmaline is prominent and it was always considered that those deposits were formed at a higher temperature than the tourmaline-poor ones at Stavoren. Strauss, however, concludes (p. 164) that the cassiterite is mostly separated from the high temperature minerals such as tourmaline, and occurs in a typical mesothermal assemblage of minerals.

The abundance of adularia in the Stavoren deposits raises another interesting point. Here adularia is replaced by tourmaline and thus appears to be of hypothermal origin whereas, according to Lindgren (1933, p. 446), adularia is one of the most widespread and characteristic gangue-minerals of epithermal deposits. He, however, groups (p. 566) the adularia-bearing veins of the Premier Mine, British Columbia with the mesothermal deposits. Parker (1923, p. 298) on the other hand places the adularia of the Alpine veins as preceding tourmaline and apatite. Hypothermal adularia also occurs in the molybdenite deposits of Shakon, Alaska (Buddington 1930, p. 200).

The tin deposits under discussion are most likely of composite origin. The formation of the feldspar zones and the crystallisation of early quartz appear to be as of hypothermal origin, following Lindgren's classification, whereas the cassiterite and accompanying sulphides and gangue-minerals are mesothermal.

The study of liquid inclusions in order to determine the temperature of formation of minerals has received considerable attention in recent years. The methods which are in general use are based on the assumption that at the time of its formation each vacuole was completely filled with a single fluid phase, and that the volume of the liquid decreased with a drop in temperature. Two methods of study have been employed to determine the temperature at which the vacuoles are completely filled with the liquid. In the first and older method fragments of the mineral are heated on a heating-stage and the filling temperature recorded. In the second method, called the decrepitation method, the filling temperature is determined by the effects of temperature-pressure relations in the inclusions upon the enclosing mineral. This method is based upon the principle that at the filling temperature, pressure suddenly becomes so great that heated chips of the mineral containing the inclusions will fly apart. For the purpose of detecting the bursts a suitable pick-up is attached to the container in which the chips are heated. The theory relative to each of the methods has been thoroughly described by Ingerson (1947, p. 375), Scott (1948, p. 637), and Bailey and Cameron (1951, p. 626).

The decrepitation method was applied to some of the minerals from Stavoren. The temperatures at which bursts, which were considered to be due to primary inclusions, were detected, are listed in table 24. Except for calcite and fluorite the bursts occur at temperatures well above 300°C which is the upper limit for mesothermal deposits (Lindgren 1933, p. 529).

TABLE 24, Decrepitation temperature of minerals.

Mineral	Temperature °C.
First generation quartz.	360
Scheelite	360
Loellingite	375
Arsenopyrite	360
Second generation quartz	330
First generation calcite	170
Fluorite	170
Third generation quartz	330

The decrepitation temperature of calcite and fluorite is much lower than that of third generation quartz which definitely crystallised later than the calcite and fluorite. This indicates, if the method of determination is reliable, a rise in temperature subsequent to the formation of calcite and fluorite.

Apparently sound criticisms and cautions regarding the results given by liquid inclusions as geologic thermometer have, however, been suggested by various investigators such as Kennedy (1950, p. 533), Bailey and Cameron (1951, p. 626), and Skinner (1953, p. 541). It is thus felt that the data listed in table 24 can not be considered seriously as indicative of the formation temperature of the minerals involved.

VIII. THE INDIVIDUAL PIPES.

The following brief description of the various pipes will serve to illustrate the variation in their form and composition. The data concerning the upper portions of the pipes (above the first level) were obtained from Wagner's memoir (1921).

B5 East Pipe.

"At the surface there was exposed a pipe-shaped body of feldspar-rich pegmatite carrying fluorspar but no ore-minerals. At a depth of 6 feet cassiterite and scheelite made an appearance, but it was only at a depth of 30 feet that the pipe became profitable, bulging out into a large body of ore rich in copper pyrites. At a depth of 40 feet it narrowed down until a depth of 60 feet was attained, when it once more bulged out. The lower enlargement, however, was somewhat smaller than the upper one. Below it to a depth of 80 feet the pipe, which is oval in transverse section, measured 6 feet by 30 feet. The principal ore-mineral in this lower section is scheelite, chalcopyrite having given out, and cassiterite being present in very small quantity only" (page 123).

On the first level of the mine the pipe still measures about 6 feet by 30 feet and contains both zonal and breccia ore-bodies. A few large ore-bodies, with diameter ranging from about 6 inches to a few feet, and numerous small ones scattered at random through the albitised granophyre, constitute the western part of the pipe, whereas the eastern part

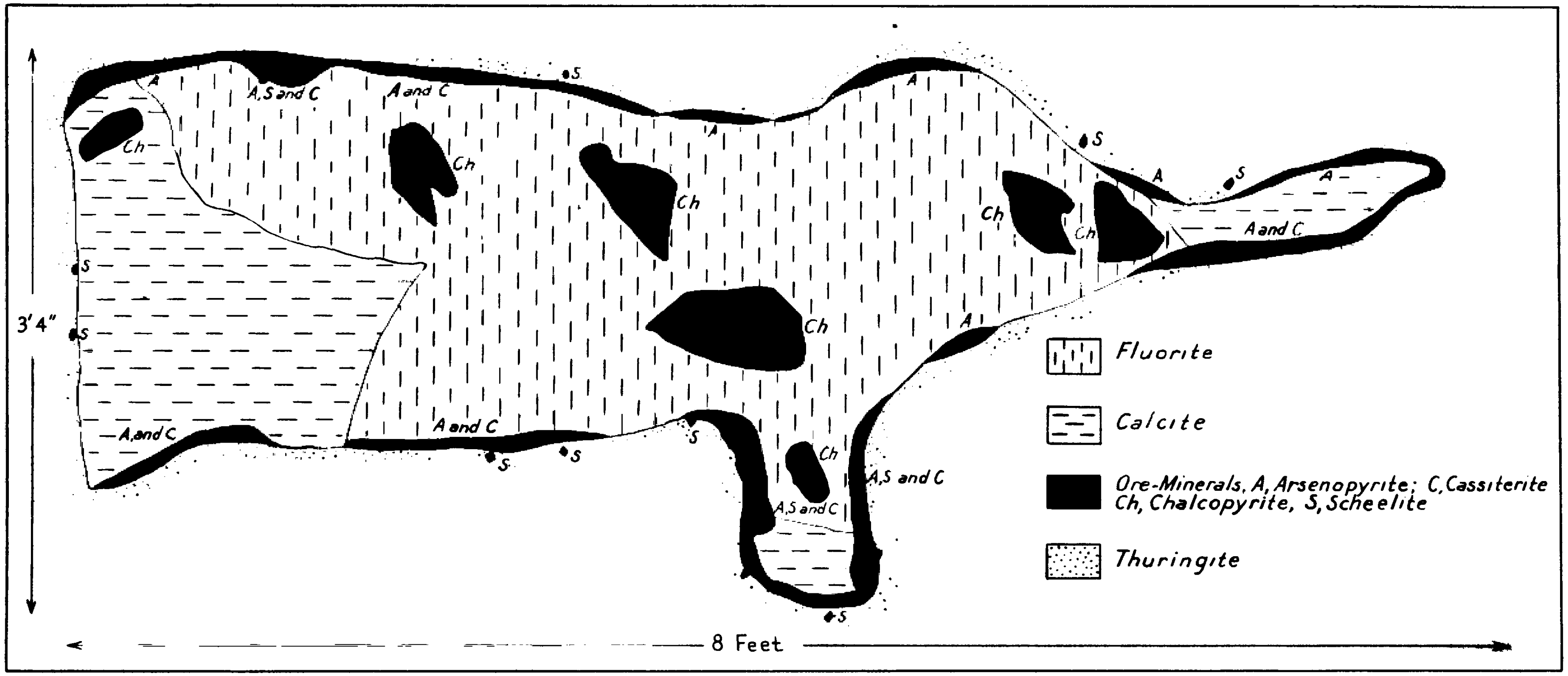

Figure 9. *Plan of a zonal ore-body of the B5 East pipe as exposed in the drive on first level.*

is composed of fragments of slightly to highly altered granophyre cemented by gangue- and ore-minerals.

The largest of the zonal ore-bodies in the western part measures about 8 feet by 3 feet (fig. 9). It has a central part composed of calcite and fluorite in which large patches of late chalcopyrite occur. Around this follows a discontinuous ore-zone composed of arsenopyrite, early chalcopyrite, cassiterite, scheelite and quartz. Here, as in all the other ore-bodies of this type, cassiterite occurs along the inner contact of the zone whereas scheelite is scattered along the outer margin. A narrow and poorly developed thuringite zone borders the ore-body. The zonal arrangement and the mineral content in the small ore-bodies, accompanying this large one, are the same in each one. They are also characterised by the absence of the feldspar zone.

The gangue-minerals cementing the fragments in the eastern part of the pipe are mainly quartz and chalcedony, accompanied by some calcite, fluorite, red feldspar, and chlorite. In contrast to the western part cassiterite is here the most abundant ore-mineral and does not only occur in the cementing material between the fragments, but also as impregnations in the highly altered fragments. Large crystals (1 - 2 inches in diameter) of scheelite, some of which are completely surrounded by cassiterite, are fairly abundant. Arsenopyrite and chalcopyrite are present in small quantity only.

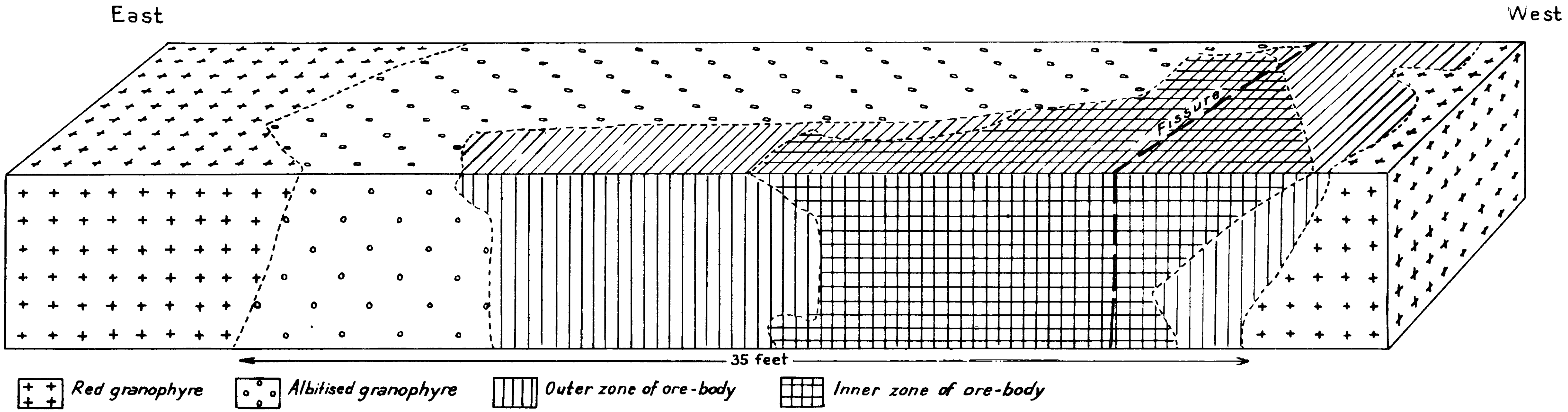

Fig. 10. *The B5 East pipe as exposed on the north wall and in the hanging-wall of the drive on the second level.*

The difference in mineral content of the zonal and the breccia ore-bodies is obvious in this exposure of one and the same pipe, viz.,

Zonal Ore-bodies.	Breccia Ore-bodies.
1. Cassiterite subordinate.	1. Cassiterite most abundant ore-mineral.
2. Scheelite subordinate.	2. Scheelite abundant.
3. Arsenopyrite and chalcopyrite abundant.	3. Arsenopyrite and chalcopyrite subordinate.
4. Calcite and fluorite most abundant gangue-minerals	4. Quartz and chalcedony most abundant gangue-minerals.

The most striking exposure made by present mining operations is that of this pipe on the second level. Here the pipe measures about 40 feet along the strike of the drive, is exposed on both walls and in the hanging, is rich in ore-minerals, and is most interesting in composition.

Whereas in the other exposures of the pipes, the phenomenon that numerous ore-bodies are scattered at random through the albitised granophyre is more or less the rule, in this intersection only one large breccia ore-body was encountered. It occupies the bulk of the pipe and exhibits a general increase, in alteration and replacement of the granophyre fragments, towards the centre.

Figure 10 is a block diagram showing the pipe as exposed on the north wall and in the hanging-wall of the drive. The red granophyre is the normal type except for impregnations of chalcopyrite and molybdenite in the vicinity of the pipe. The granophyre has been albitised only at the upper contact of the ore-body which here plunges steeply towards the east. The footwall of the ore-body is in direct contact with apparently unaltered red granophyre. This fact probably suggests that the alteration of the granophyre was brought about by solutions ascending from the ore-body. It further seems as if the agents that caused the alteration has attacked the granophyre at numerous isolated points having as a result a variegated rock varying from red, slightly altered granophyre, to a gray albite-rich rock. At some points the change from the red to the gray rock is transitional whereas at others sharp contacts exist.

The ore-body itself can be described as composed of two zones which will be referred to as the outer and the inner zones. The outer zone is built up of large fragments of partially to highly altered granophyre with gangue- and ore-minerals occupying the spaces in between. Thuringite is fairly abundant and usually occurs along the contacts of the fragments. Quartz calcite and fluorite are more or less equal in abundance and chalcedony and red feldspar subordinate. Scheelite, occurring as irregularly shaped crystals ranging in size from small microscopic specks to 1½ inches in diameter, is the predominating ore-mineral. Chalcopyrite is second in abundance whilst arsenopyrite and cassiterite are scarcely present.

In the inner zone replacement and alteration are much more prominent so that very little of the original granophyre fragments remains. The bulk of this zone consists of gangue- and ore-minerals and some irregularly replaced remnants of highly chloritised fragments. Quartz of different generations and calcite are the most common gangue-minerals, whereas feldspar and thuringite are scarce. Cassiterite crystals, up to half-an-inch in diameter, are very abundant and occur as inclusions in the later gangue-minerals and as impregnations in the highly chloritised fragment remnants. Large massive patches and irregular crystals of scheelite are also fairly abundant. Arsenopyrite and chalcopyrite are present in small quantities only; the former is the most abundant near the contact with the outer zone.

The exposure of the B5 East pipe on the third level is much less impressive than that on the other levels. The area covered by the gray albitised granophyre still measures about 20 feet by 8 feet but it is poorly mineralised. The ore-bodies are widely spaced, irregular stringers and small pockets composed mainly of gangue-minerals. Of the ore-minerals chalcopyrite, most of which impregnates the rock in direct contact with the ore-bodies, seems to predominate. Scheelite, some of which occurs as perfect pyramidal crystals enclosed in the gangue-minerals, is second in abundance, whereas cassiterite and arsenopyrite is present in relatively small quantities only.

B5a and B5b Pipes.

When mining operations were suspended at about 1919

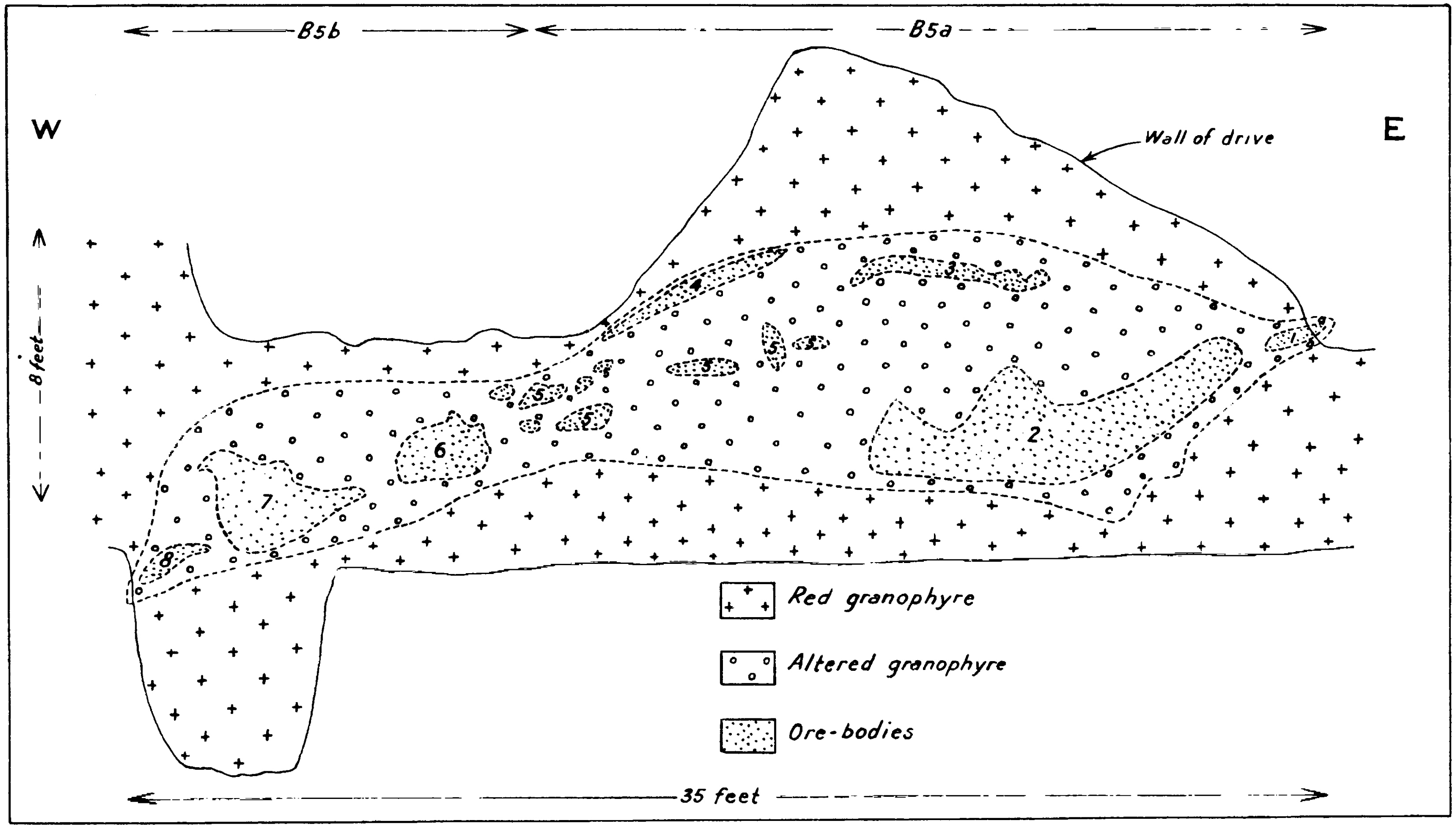

Fig. 11 The distribution of the ore-bodies in the composite B5a and B5b pipe as exposed in the hanging-wall of the drive on the first level.

the B5a pipe was explored to a depth of approximately 30 feet. Wagner (1921) does not give any information about this occurrence and when the writer visited the mine in 1952 the original pit was partly filled in.

The B5d pipe, situated about 25 feet from B5a, was marked by an inconspicuous outcrop of red feldspar, quartz, and cassiterite. On being opened up, in Wagner's time, this pipe was found to be practically vertical and the ore-body surrounded by a thin zone of thuringite. From a depth of 10 to 27 feet the pipe matter was heavily charged with chlorite and barren of ore-minerals. At this point the B5b and B5c pipes were probably in contact with each other so that by following a bulge of the B5b pipe towards the west, mining operations struck the B5c pipe.

On the first level the B5a and B5b pipes have merged into one large pipe measuring approximately 35 feet in an east-west direction and about 13 feet across. The form of the pipe in plan and the distribution of the ore-bodies through it suggest the merging of two pipes. The form is roughly elliptical in plan, and the central part is narrower than the slightly bulged ends (see figure 11). The eastern bulge represents the B5a pipe and the western bulge the B5b pipe.
The bulk of this composite pipe consists of albitised granophyre through which numerous ore-bodies, varying widely in size and form, are scattered at random.
Except for numerous small ones the bulged ends harbour relatively large ore-bodies, whereas in the central part there are only a few small ones. Of all these

only one, a breccia ore-body, is highly stanniferous. The others are all zoned and have arsenopyrite and chalcopyrite as the principal ore-minerals.

Owing to the fact that the composition of the ore-bodies and the distribution of the minerals composing them differ somewhat, each of the principal ore-bodies of the merged portions of pipes B5a and B5b on the first level are described separately. (For numbers of ore-bodies see fig. 11).

No. 1 ore-body is largely exposed on the side wall of the drive. It is composed mainly of arsenopyrite and chalcopyrite accompanied by relatively small quantities of gangue-minerals. In contrast to most other ore-bodies it is not bordered by a pure thuringite zone, but by a zone of thuringite-enriched albitised granophyre.

No. 2 ore-body, measuring about 12 feet by 3 feet, is the largest of the ore-bodies in this exposure. It is zonally built and has a core of calcite and fluorite in which occur large patches of late chalcopyrite. A discontinuous ore-zone surrounds the interior. This zone is separated from the albitised granophyre by a thin rim of thuringite and a few occasional remnants of red feldspar. The principal ore-minerals are again arsenopyrite and chalcopyrite, but in this ore-body they are accompanied by some cassiterite, scheelite, galena, and microscopic amounts of sphalerite. This is the only ore-body in which galena is present.

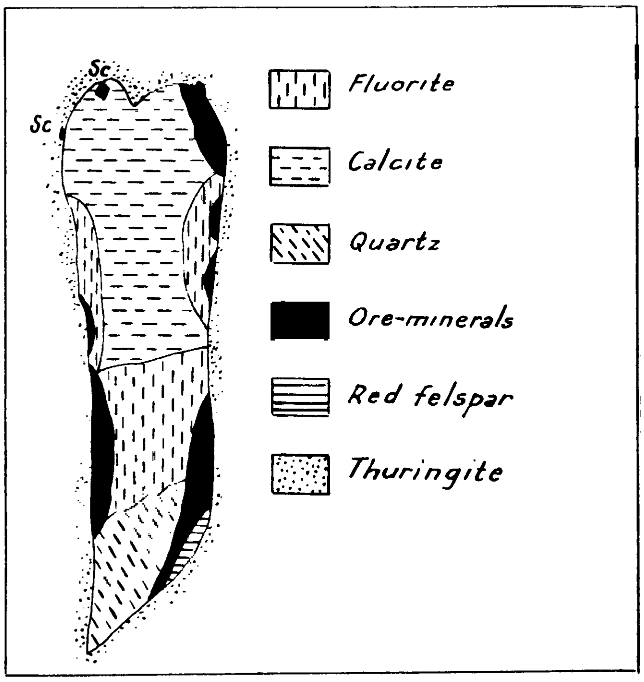

Fig. 12 Sketch of N°8 ore-body, B5b pipe on the first level

No. 3 ore-body measures about 6 feet in length and 12 inches across. It has a core of calcite followed outwards by a discontinuous arsenopyrite-rich ore-zone, and finally by a thuringite zone.

No. 4 ore-body differs from the others in being highly stanniferous and of the breccia type. Cassiterite, the predominating ore-mineral, is not only associated with the other minerals in the spaces between the fragments but is also present as impregnations in the altered fragments. Arsenopyrite and chalcopyrite occur mainly near the contact of the ore-body with the altered host-rock. This is also true of calcite and fluorite. Quartz is the principal cementing material and also the most abundant gangue-mineral. A vug lined with quartz crystals of the third generation has replaced some of the calcite.

No. 5 ore-bodies are a series of small pockets composed mainly of chalcopyrite.

The interior of the No. 6 ore-body consists essentially of fluorite, a little calcite, and a few patches of late chalcopyrite. The ore-zone consists mainly of chalcopyrite replacing and enclosing arsenopyrite. The red feldspar zone is discontinuous, and the thuringite zone well developed.

No. 7 ore-body differs from No. 6 in that it contains less arsenopyrite and more scheelite.

As can be seen from the accompanying sketch (fig. 12) about 90 per cent of the No. 8 ore-body is composed of quartz, fluorite and calcite around which

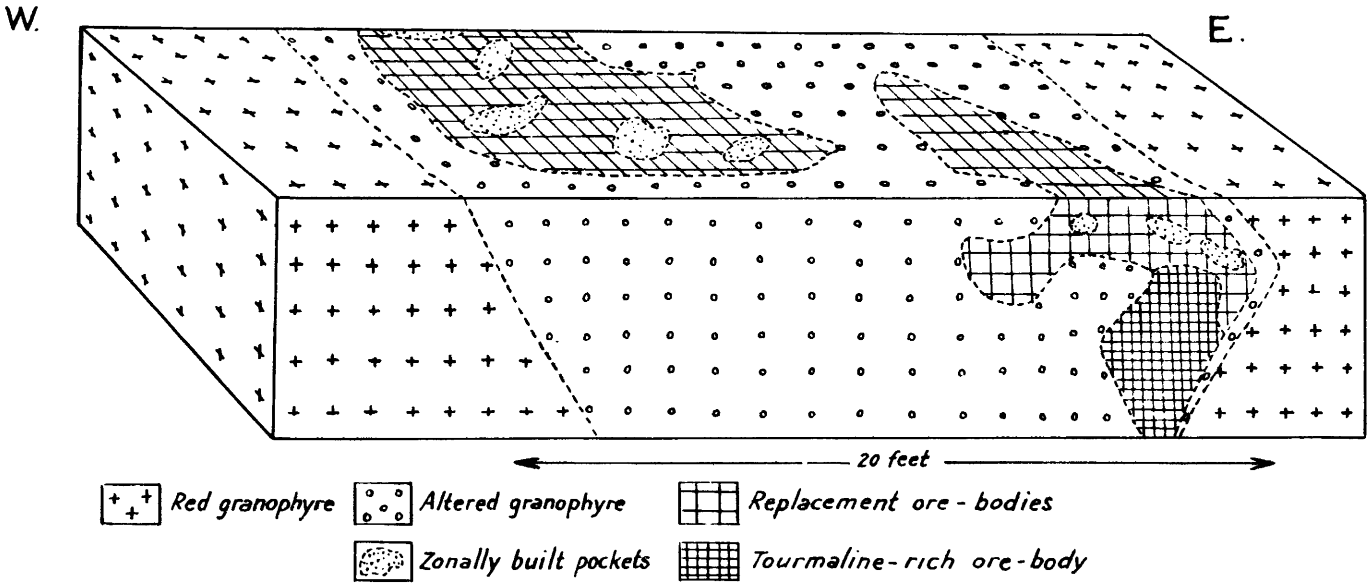

Fig. 13. The B5a pipe as exposed on the south wall and in the hanging-wall of the drive on the second level.

occurs a discontinuous zone of arsenopyrite, chalcopyrite and scheelite. In some areas scheelite alone occupies the position of the ore-zone. The thuringite zone is fairly continuous.

According to the features of the eight ore-bodies summarised in table 25, the various zones are characteristically present in most of the ore-bodies, excluding the feldspar zone which is very erratic and often absent.

On the second level the B5a pipe is separated from the B5b pipe by approximately 20 feet of apparently unaltered red granophyre. The former, measuring about 18 feet along the strike of the drive, harbours two large ore-bodies of the replacement type. These ore-bodies consist of a greenish, highly chloritised rock through which are scattered numerous replacement veinlets, pockets, blebs, and crystals of ore- and gangue-minerals. Some of the largest pockets show a zonal arrangement of minerals; the largest one measures about 2 feet by 2½ feet. In contrast to the exposure on the first level, cassiterite is here very abundant. Arsenopyrite and scheelite are present in fair quantities, and chalcopyrite is subordinate.

Adjoining one of these replacement ore-bodies occurs an ore-body differing from all the other in this mine in that it carries tourmaline (fig. 13). The principal constituents are tourmaline, calcite, quartz, and remnants of the red feldspar; a purplish fluorite, scheelite, and cassiterite are subordinate.

TABLE 25.

SUMMARY OF VARIATIONS IN COMPOSITION OF DIFFERENT ORE-BODIES IN THE B5a AND B5b PIPES ON THE FIRST LEVEL*

No. of Ore-body.	CORE.	ORE-ZONE	FELDSPAR ZONE.	THURINGITE ZONE.
1.	None exposed.	Arsenopyrite and chalcopyrite	None.	Thin, impure.
2.	Fluorite, little calcite, much late chalcopyrite.	Much arsenopyrite and chalcopyrite, a little cassiterite, scheelite and galena.	Occasional remnants.	Thin, continuous.
3.	Calcite.	Arsenopyrite.	None.	Thin, continuous.
4.	Breccia ore-body rich in cassiterite and quartz.			
5.	None.	Chalcopyrite.	None.	Very poor.
6.	Mainly fluorite and a little calcite and late chalcopyrite.	Chalcopyrite and arsenopyrite.	Discontinuous	Wide, continuous.
7.	Mainly fluorite and a little calcite and late chalcopyrite.	Chalcopyrite, arsenopyrite, and scheelite.	Discontinuous.	Thin, continuous.
8.	Calcite, fluorite and quartz.	Arsenopyrite, a little scheelite and chalcopyrite.	None.	Thin, continuous.

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*Cassiterite, as any of the other minerals, is not mentioned in this table if present in small quantities.

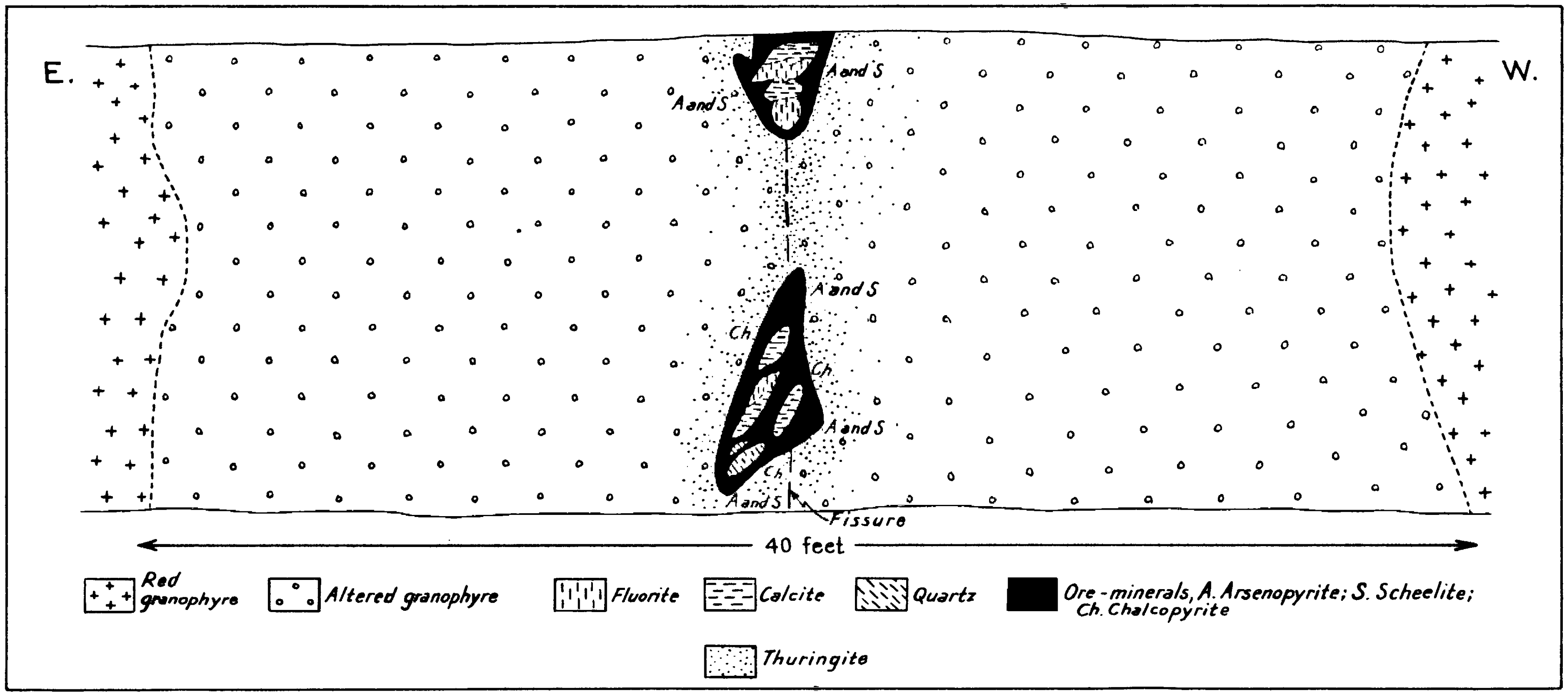


Fig 14 *The B5b pipe as exposed on the south wall of the drive on the second level.*

Recent mining operations on the second level intersected only the northern part of the B5b pipe, thus exposing a wide aureole of gray albitised granophyre. Owing to partial replacement by thuringite the gray rock takes on a dark colour towards the centre of the pipe where a thin rim of thuringite borders two ore-bodies and occupies a fissure connecting the ore-bodies (fig. 14).

The thuringite-enriched rock carries a little chalcopyrite, occasional blebs of scheelite and arsenopyrite, and very rarely specks of molybdenite. The scheelite blebs are bordered by a thin zone consisting of thuringite only.

The two small ore-bodies that are exposed are both of the zonal type and are barren in cassiterite. The upper one has a core of calcite and fluorite, both enclosing crystals of first generation quartz. In the lower ore-body much of the core of fluorite, calcite, and quartz, has been replaced by late chalcopyrite. Here the ore-zone is composed of arsenopyrite, chalcopyrite, quartz, and scheelite. In both ore-bodies red feldspar is absent and the thuringite zone distinct.

On the third level the B5a pipe measures about 13 feet, and the B5b pipe about 10 feet, along the strike of the drive. In the former the altered granophyre harbours only a few small ore-bodies some of which consist entirely of arsenopyrite, chalcopyrite, and a prominent thuringite zone. Others contain in addition some other gangue-minerals in which scheelite crystals are enclosed, but very little cassiterite is present.

On the third level the B5b pipe is somewhat more impressive than the B5a one, in that the small ore-bodies are more numerous and stanniferous. The largest of these measures 18 inches by 6 inches, and has a core of calcite, fluorite, and quartz. In places the discontinuous ore-zone is entirely composed of arsenopyrite; elsewhere small crystals, either of cassiterite or of scheelite, predominate. Inclusions of scheelite in the gangue-minerals are more abundant than on the other levels. In contrast to the B5a pipe the thuringite rim around the ore-bodies are poorly developed.

B5c Pipe.

This must have been the most promising of the "B" group of pipes on Stavoren. In Wagner's time (1921) the workings on this pipe were the deepest on Stavoren, having attained a vertical depth of about 185 feet. During present development the pipe was removed to a depth of about 200 feet with the result that at the time of the author's visit to the mine only the outer portions of the pipe were left on the first and second levels. Wagner (1921, p. 123) describes this pipe in considerable detail.

At a depth of 32 feet the pipe expanded into a large body of stanniferous chloritic rock below which occurred an ore-body, rich in red feldspar, containing a huge vug lined with crystals of cassiterite, arsenopyrite, and scheelite. Beyond this the pipe was fairly well-defined, dipping with a steep angle towards the west.

Cassiterite was the main ore-mineral in the upper portions of the pipe whereas, from a depth of 95 feet down to about 170 feet, scheelite and arsenopyrite predominate, cassiterite being present in small quantities only.

The ore-bodies in the scheelite-rich portions have been of the zonal and replacement types. Wagner (1921, p. 125) writes: "The section of the pipe carrying scheelite-ore showed a border of raven-mica (thuringite) sharply defined from the surrounding granophyre, and succeeded inward by a more or less continuous zone of red pegmatitic feldspar. This in turn was succeeded by the ore-zone, the interior of the pipe (ore-body) being occupied by calcite-quartz breccias already described, or by massive fluorspar and calcite, or finally by large vugs lined with crystals of quartz, calcite, and chlorite". The portions of the pipe still remaining on the first level consist of irregularly outlined pockets and stringers of ore- and gangue-minerals scattered through a green chlorite mass which is separated from the red granophyre by gray albitised granophyre.

In the lowest portion of the pipe actually exposed in Wagner's time, the scheelite-ore was again replaced by cupriferous tin ore. "This (meaning the cupriferous tin ore) is composed of irregular patches of chalcopyrite and pyrite enclosing well-formed pyramidal crystals of dark-brown cassiterite up to half-an-inch across, in a matrix of quartz, calcite, green fluorspar, and chlorite" (Wagner 1921, p. 127).

On the second level cassiterite and arsenopyrite are abundant but very little scheelite is noticeable.

On the third level the drive cuts through this pipe exposing it on both walls and in the hanging. Here the pipe measures about 30 feet in an east-west direction and 5 feet across. On the whole ore-minerals are very poorly represented. Those present are, in order of abundance, chalcopyrite, scheelite, arsenopyrite and cassiterite.

In the same way as all the other pipes exposed on this level this one consists mainly of albitised granophyre containing numerous small ore-bodies scattered through it. The two largest of these have a diameter of 18 inches; both are of the zonal type. The core of the one is composed mainly of calcite enclosing fragments of altered granophyre and prismatic quartz crystals measuring up to 5 inches in length. In the other one fluorite occupies the core. The ore-zone is poorly developed in both and is composed of chalcopyrite, scheelite, arsenopyrite, and cassiterite. The red feldspar zone is absent, leaving the ore-zone in direct contact with a narrow but continuous rim of thuringite. Although most of the other ore-bodies can also be grouped with the zonal type there are at least a few that more closely resemble the breccia type.

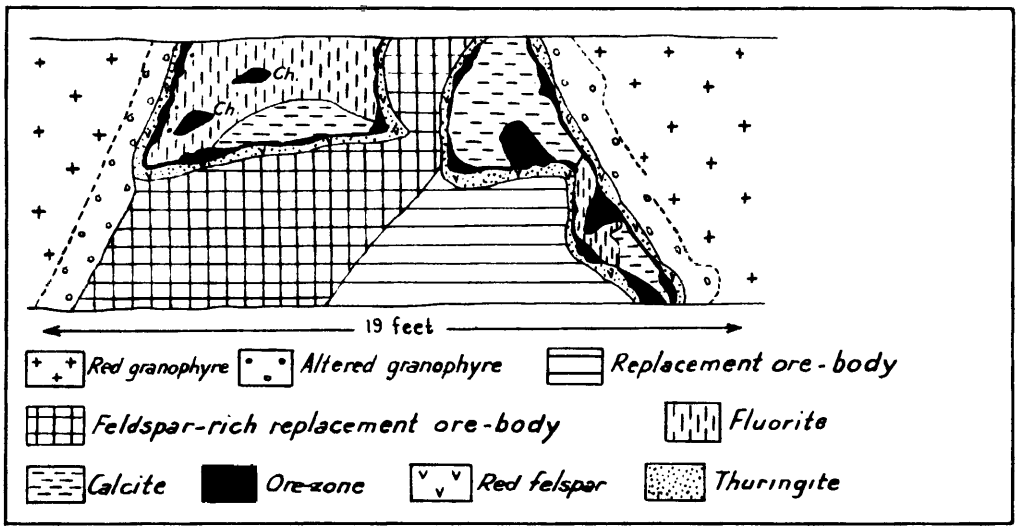


Fig. 15 The B5d pipe as exposed on the south wall of the drive on the second level of the mine.

B5d Pipe.

The evidence for the existence of a pipe between the B5c and B6a pipes is very poor on the first level and no such outcrop has been reported by Wagner. Wessels on an unpublished map, however, shows a prospecting pit, 5 feet deep, about half way between the B5c and B6a pipes.

On the first level ore-bearing albitised granophyre occurs next to the fissure connecting the B5c and B6a pipes, but no clearly outlined pipe could be located.

On the second level there occurs a strongly mineralised exposure between those of the B5c and B6a pipes. This may be a branch of the latter from which it is separated by only about 10 feet of red granophyre. The writer, however, prefers to refer to this exposure as B5d.

It occurs in the south wall of the drive and measures 12 feet at the hanging and 18 feet at the foot-wall of the drive. Except for a narrow aureole of albitised granophyre this pipe is mineralised throughout, being very rich in cassiterite and scheelite. It contains two zonal ore-bodies separated from one another by a replacement type of ore-body (see fig. 15).

The ore-zone, composed of arsenopyrite, scheelite, cassiterite, quartz and chloritic matter, and the thuringite zone are fairly continuous in both zonal ore-bodies. The former varies much in width. The feldspar zone is discontinuous.

Scheelite usually occurs as large massive patches and small crystals along the outer portions of the ore-zone; in places it is completely isolated by a rim of thuringite. Cassiterite on the other hand occurs along the inner portions; very little is, however, in contact with fluorite whereas large crystals occur on the calcite contact. Some of these are enclosed in the calcite.

A portion of the replacement ore-body accommodates remnants of red feldspar whilst in the other portion this mineral is absent. The principal ore-minerals in this ore-body are scheelite, arsenopyrite, and cassiterite. The gangue-minerals are quartz, calcite, and fluorite.

B6a Pipe.

In the upper portion of this pipe cassiterite was the principal ore-mineral and scheelite was absent. The thuringite bordering the ore-bodies was heavily charged with molybdenite which occurred as small flakes and scales scattered through the thuringite, and also in compact masses. In Wagner's time the pipe was worked to a depth of 60 feet and several tons of molybdenite were recovered. The interiors of the ore-bodies down to this level were largely occupied by calcite some of which was replaced by later quartz.

On the first level the pipe is mineralised throughout, the minerals occurring in irregularly-shaped bodies scattered all over the pipe-zone. The type of

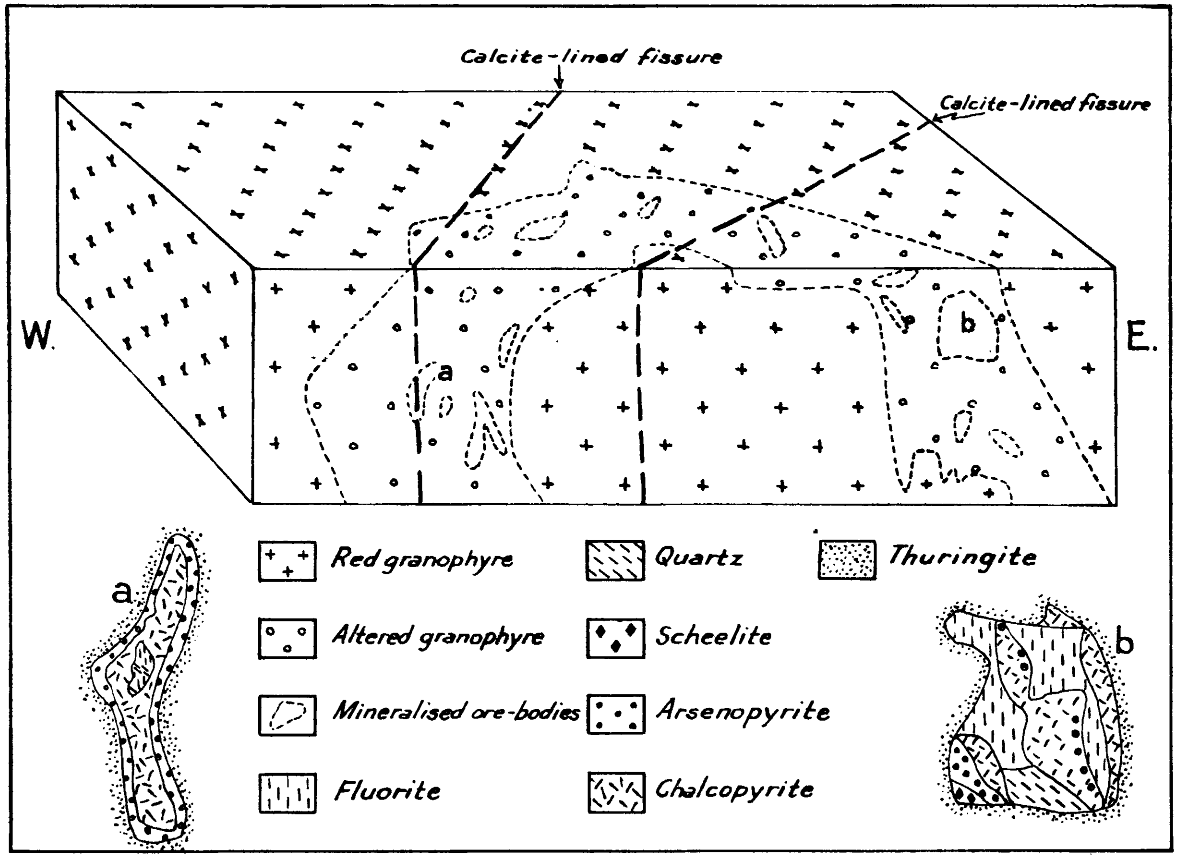


Fig. 16. The B6a pipe as exposed on the south wall and in the hanging-wall of the drive on the second level.

mineralisation is very much the same as that of the other pipes on the third level except that here the ore-bodies are much more closely spaced and are very rich in ore-minerals. In contrast to the upper portions the ore-minerals are, in order of abundance, arsenopyrite, cassiterite, and scheelite. Molybdenite has more or less disappeared being present only as microscopic flakes in the thuringite zone.

Scheelite occurs in fairly well-developed crystals, the largest having a diameter of about 2 inches. Cassiterite is present mostly as massive patches and stringers, often bordering scheelite crystals or being moulded on to the crystals. Arsenopyrite occurs in massive patches. The gangue-minerals are red feldspar, quartz, thuringite, calcite and fluorite and they are present in more or less equal quantities.

This exposure differs from all the others in the mine in that it accommodates the dark-red calcite. At first sight this mineral can easily be mistaken for red feldspar but if more closely examined a darker red colour and a distinct cleavage becomes obvious.

On the second level the B6a pipe, measuring about 20 feet by 5 feet, is slightly bent in an east-west direction so that two exposures are made on the south wall of the drive (see fig. 16). This would probably have been mistaken for two branches of a pipe if the drive had been a few feet to the south so that the outline of the pipe was not exposed in the hanging-wall.

The pipe here is very poor in ore-bodies. The few that are present are of the zonal type, all with a well-defined thuringite zone which in places is composed of relatively large flakes. The most abundant ore-mineral is chalcopyrite which replaced the older ore- and gangue-minerals to such an extent that it constitutes the largest part of the ore-bodies. In some ore-bodies (fig. 16a) a zone of arsenopyrite, which is the second most abundant of the ore-minerals, is continuous right round whereas in others it is scarce. Scheelite is present in small quantities but no cassiterite was noticed.

Figure 16 illustrates that a calcite-lined fissure cuts through the pipe and the ore-bodies; a phenomenon which clearly suggests that the fissure is younger than both.

<u>B6b and B6c Pipes</u>.

On the surface these two pipes are about 70 feet apart. Old mining operations explored B6b to a depth of 7 feet and B6c to a depth of about 20 feet. Nothing has been reported about the material removed but the fact that the pipes were not explored to a greater depth is probably enough proof that the mineralisation was poor.

On the first level the two pipes are connected and still poorly mineralised. The few ore-bodies scattered through the albitised granophyre are of the zonal type. Of the minerals forming the core of these ore-bodies fluorite is the most abundant, calcite is second in abundance and quartz is scarce. The fluorite encloses some fragments of the red feldspar. The ore-bodies are further characterised by much red feldspar. Some are composed almost entirely of this mineral. Thuringite does not only border the ore-bodies but has gained access to the interior of some of them being deposited along the inner contact of the feldspar zone. Of the ore-minerals chalcopyrite predominates and cassiterite, scheelite, and arsenopyrite are present in small quantities only.

On the second level the two pipes are separated from each other by approximately 20 feet of apparently unaltered granophyre. Here the B6b pipe differs from the exposure on the first level in that no chalcopyrite is present and arsenopyrite is abundant. The entire exposure of the B6c pipe is composed of a breccia built up of large fragments of granophyre in a matrix of quartz, chalcedony, and calcite. Some of the fragments are only slightly altered and still red in colour whereas others are highly chloritised and green. The matrix carries some cassiterite, arsenopyrite and scheelite. Most of the cassiterite occurs as impregnations in the chloritised fragments.

In places the interstices between the fragments are occupied by vugs measuring up to 2 feet in diameter. These vugs are lined with quartz crystals some of which are coated by a thin film of iron oxide leaving the impression that it is ferruginous quartz.

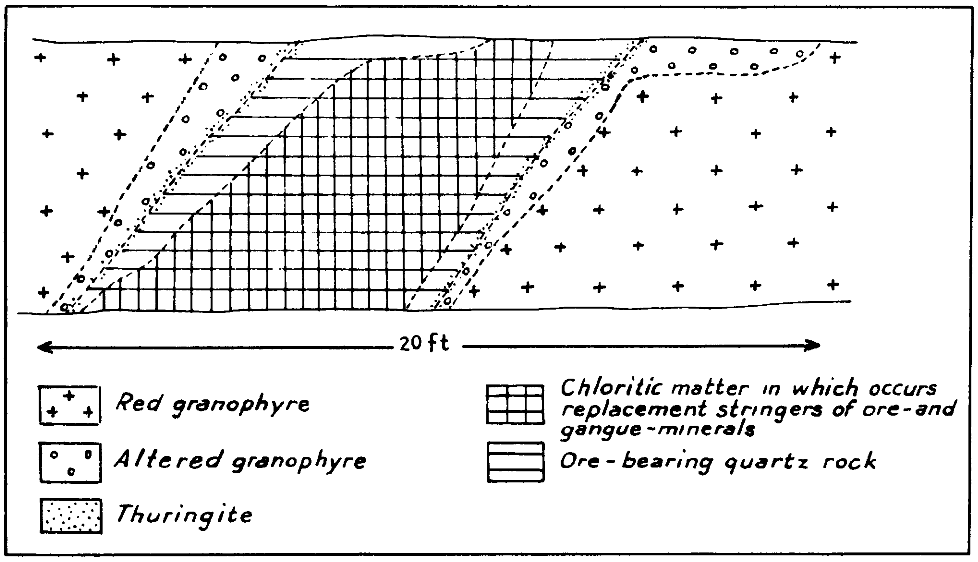


Fig. 17 B6d pipe as exposed on the south wall of the drive on the second level.

<u>B6d Pipe</u>.

In his description of the "B7 - Seelig group of pipes" Wagner only mentions the existence of a small pipe 10 yards east of the Seelig pipe and points out that it yielded arsenical tin ore composed of coarse crystals of cassiterite and arsenopyrite in a matrix of quartz and calcite.

The locality where this pipe is expected to be on the first level is, as is indicated on the plan (folder 1) a few feet to the north of the drive and therefore not exposed.

On the south wall of the second level drive the pipe measures about 15 feet along the strike. It has, as is shown in figure 17, a central portion of chloritised granophyre which is partially replaced by ore- and gangue-minerals. Around this occurs an ore-bearing quartz-chlorite rock in which occurs remnants of red feldspar. This is again bordered by gray albitised granophyre which finally grades into the normal red granophyre. Small quantities of thuringite occur between the albitised rock and the ore-bearing material but this mineral is on the whole poorly represented.

The exposure is probably that of a breccia ore-body. The central part represents a large fragment partially replaced by veinlets and patches of gangue- and ore-minerals. The quartz-rich ore-bearing zone is typical of the material that usually occupies the interstices between the fragments in the breccia ore-bodies.

Cassiterite and scheelite are both fairly abundant whereas arsenopyrite is present in relatively small amounts and chalcopyrite is absent. Of the gangue-minerals second generation quartz predominates. The less abundant calcite and fluorite are more or less confined to the replacement stringers in the large fragment.

Seelig and B7 Pipes.

These two pipes are discussed together for they provide another example of the merging of two pipes. They outcrop about 50 feet from each other but are connected on the first level where a large area of albitised granophyre, measuring about 70 feet by 20 feet, is exposed. On the second level the intersections are of such a nature that it is not possible to arrive at a definite conclusion as to whether the pipes are connected or not. All the other pipes that are composite on the first level are apart on the second level and this presumably also holds good for the Seelig and B7 pipes.

The outcrop of the Seelig pipe was a feldspar-rich one carrying a good deal of chlorite but no ore-minerals. A large body carrying much cassiterite and scheelite was intersected at a depth of 30 feet and another one at about 60 feet. The latter yielded magnificent speciments of cassiterite embedded in coarse white calcite. One of these, No. 3407 in the collection of the Geological Survey Museum, "consists of a solid mass of blackish-brown cassiterite 5 inches across in a matrix of coarsely crystalline white calcite, through which are scattered long prismatic crystals of quartz coated with chlorite (i.e. stilpnomelane) and small patches of red feldspar. The cassiterite mass is made up of differently orientated interlocking crystals and encloses irregular patches of scheelite" (Wagner 1921, p. 128).

The B7 is a small pipe originally worked to a depth of 60 feet for cassiterite and scheelite. In addition it yielded a small quantity of bismuthinite, native bismuth and joseite.

The large area of albitised granophyre representing the Seelig and B7 pipes on the first level, is poorly mineralised. Except for a few small eyes, only three ore-bodies with diameters exceeding 6 inches and two with diameters exceeding 3 feet are exposed. These ore-bodies are all of the zonal type; the core is composed of fluorite and calcite enclosing quartz crystals, and the ore-zone carries arsenopyrite, scheelite, and cassiterite.

In places the gray albitised rock takes on a darker colour due to replacement by thuringite. These parts usually carry small amounts of ore-minerals of which chalcopyrite and pyrite are the most abundant.

Numerous small fissures lined with calcite and striking northwest-southeast, traverse the gray rock. These fissures cut through, and are clearly younger than, the ore-bodies.

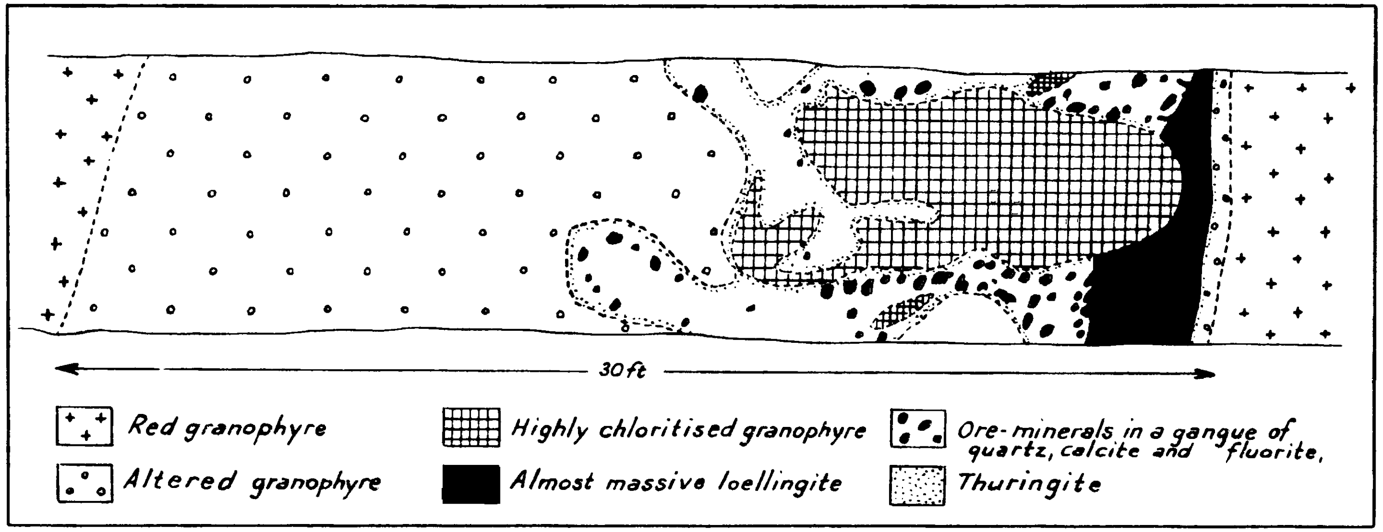


Fig. 18 Seelig pipe as exposed on the south-wall of the drive on the second level.

The exposures of the Seelig and B7 pipes on the second level are of special interest in that they are the only ones in which loellingite was detected.

Here the drive intersects only the northern portion of the Seelig pipe thus exposing only a part of a large ore-body and a wide zone of albitised granophyre (figure 18). The ore-body has a central part of highly chloritised granophyre which is irregularly replaced and completely isolated from the albitised rock by ore- and gangue-nimerals. Along its western contact a thin zone of thuringite separates massive loellingite from the gray rock. To the east this massive loellingite is replaced by quartz and fluorite, both enclosing arsenopyrite, cassiterite, scheelite and loellingite. The eastern half of the chlorite mass is surrounded by quartz and calcite, both enclosing quartz crystals and ore-minerals. It should be mentioned that inclusions of the ore-minerals in the gangue are more abundant near the contact of the gangue with the altered material than in the central parts of the gangue. These contacts are usually lined with thuringite.

Only a small portion of the B7 pipe is exposed on the second level and that in the face of a short crosscut leading from the drive to the south. In this exposure which measures about 4 feet by 4 feet, a few ore-bodies are scattered through gray albitised rock which is traversed by numerous stringers of thuringite. These ore-bodies carry essentially loellingite, quartz, and scheelite. Occasional patches of fluorite, calcite and red feldspar are also present but no cassiterite was visible. The ore-bodies are all bordered by a thin rim of thuringite.

Quarry Pipe.

This pipe is situated about 45 feet to the west of B7 pipe. In Wagner's time it was mined to a depth of 98 feet yielding high-grade tin and scheelite ore. In the upper portions there were patches of cupriferous tin ore composed of cassiterite, chalcopyrite and pyrite. The interior of the ore-bodies was for the largest part occupied by coarsely crystalline, white calcite.

The second and third level drives were not carried far enough to the west to intersect this pipe.

B8 Pipe.

None of the present workings were carried far enough to the west to intersect this pipe. In Wagner's time it was removed to a depth of about 30 to 40 feet and he describes it in considerable detail. (p. 130).

According to Wagner a great deal of high-grade tin ore has been recovered from a "succession" of feldspar-rich ore-bodies. These ore-bodies were mostly of the zonal type and were only occasionally bordered by a thuringite zone. The ore-zones consist of cassiterite, scheelite, arsenopyrite, quartz, and chlorite and the interior of the ore-bodies were generally occupied by green fluorite or by a mixture of fluorite and calcite, or by the latter alone.

Occasionally patches of late generation chalcopyrite were found in the calcite and fluorite. Fine-grained masses of chlorite were more abundant in this pipe than in any of the others on Stavoren.

Other pipe-like exposures.

Except for the pipes described so far there occur a few mineralised exposures that should be mentioned.

The western 50 feet of the drive on the first level is in gray albitised granophyre. This rock is slightly mineralised, the visible ore-minerals being chalcopyrite and pyrite and with the aid of a ultra-violet lamp small specks of scheelite were detected. This area of albitised rock coincides with the numerous small prospecting pits between the quarry and B8 pipes on the surface.

The granophyre in the 150 feet east of the B5 East pipe is altered and mineralised in some localities next to the fissure which cuts through some of the pipes on the first level. The mineralisation in these exposures is similar to that of the other pipes. No outcrops of pipes in that vicinity could be detected and unfortunately the second level drive was stopped after cutting through the B5 East pipe so that any pipe to the east of it is not exposed. On the third level, however, pipe-like matter was intersected to the east of B5 East, and the section (folder 1E) shows that these exposures link up fairly well with those on the first level.

The Eastern Group of Pipes.

During recent exploration the Eastern Group of pipes were exposed only on the first level of the mine (see folder 2). These exposures are all poor in ore-minerals and they show very little variation as far as the composition and the internal structure of the pipes are concerned. They are all characterised by the abundance of red potash feldspar (adularia), which occurs as irregular stringers in the pipe material of altered granophyre, and by the scarcity of ore-minerals and the typical zonal and breccia ore-bodies.

Chalcopyrite is the most abundant ore-mineral and was detected in quantity in the B4 and B1c pipes only. Arsenopyrite is second in abundance, scheelite and cassiterite are present in very small quantity only, and none of the other ore-minerals was noticed.

IX. THE ORIGIN OF THE PIPES AND THE ASSOCIATED ORE-BODIES.

(A) Mode of formation.

Some of the deposits on Stavoren, such as the "71 Yards Fissure" appear to be typical fissure-lodes according to the account of it by Wagner (1921, p. 143) but the "L" group of deposits are pipe-like bodies which, on the surface and on the first level of the mine, do occur along clearly defined fissures but on the lower levels they are not localised along any visible fracture or any intersection of a fracture system. As a matter of fact the joints of the granophyre appear almost invariably to have developed subsequent to the formation of the pipes; they usually cut through the pipes and the ore-bodies. Even the clearly defined fissures along which the pipes occur in the upper parts of the mine seem to have developed subsequent to the formation of the pipes.

The linear arrangement of the pipes is presumably due to their development along potential zones of weakness which, subsequent to the formation of the pipes, developed into fissures creating the impression that the deposits are genetically related to the fissures.

There thus appears to exist a close analogy with the cassiterite-bearing pipes which occur in the granite in the Zaaiplaats area (Strauss 1954) and with the molybdenum pipes in granite of Eastern Australia (Blanchared 1947, p. 270). Both these authors conclude that the formation of these pipes are independent of the joints in the granite.

The pipe-like deposits in the granophyre at Stavoren are bodies of albitised granophyre in which the ore occurs in disconnected shoots or ore-bodies erratically disposed. In this respect the pipes differ remarkably from those in the granite of the Zaaiplaats area. According to Strauss (1954, p. 64) the most characteristic structure of the latter is an outer casing of quartz and tourmaline (luxullianite) inside which is a core of granite in various stages of alteration and studded with crystals of cassiterite.

The "E" group of deposits differs further from those in the granite in so far that at Stavoren cavity-filling appears to have been the predominating process during deposition of the minerals, whereas, according to Strauss, the pipes in the Zaaiplaats area are replacement deposits.✓

The metasomatic alteration of the granophyre and the replacement of earlier minerals by later ones clearly suggest that replacement played an important role during the formation of the pipes but that cavity filling predominated during the formation of the ore-bodies is indicated by some criteria that are characteristic of cavity-filled deposits:

Crustification, such as exhibited by the zonal ore-bodies distinguish cavity-filled deposits and are absent from replacement deposits (Bateman 1942, p. 109).

Although special attention was paid to the presence of double terminated quartz crystals during the investigation of the ore-bodies underground, none could be found. The crystal in thephoto (plate IX fig. 1) is almost certainly exceptional. The absence of such crystals is characteristic of cavity-filled deposits in which crystals have grown in open spaces from the wall. The interior of the cavities were probably at one stage lined with crystals of quartz and the ore-minerals and later gangue-minerals were deposited subsequently.

The numerous vugs also indicate the existence of cavities. Some of them formed subsequent to the ore deposition by solution of calcite. Others, however, are lined with early minerals, such as the red potash feldspar, and are thus pre-mineralisation vugs.

The origin of the cavities is, however, an enigma. Wagner (1921, p. 119) suggests that they might be contraction or shrinkage cavities and points (p. 23) to similar cavities in granite. Wagner does not clearly state whether the cavities are caused by shrinkage during cooling of the granite or whether he uses the term in the same sense as Irving (1911, p. 667) does. The latter noted cavities at Leadville, Colorado, and in siliceous gold ores of the Black Hills, and considered them as shrinkage cavities due to replacement. This, of course, is in disagreement with the law of equal volumes according to which replacement in rigid rocks is not attended by change in volume.

A more acceptable explanation for the origin of the cavities is probably that they are solution cavities, a theory based on an explanation offered by Locke (1926, p. 431) for the origin of breccia pipes. He suggests that such pipes may have formed by the solution of rock along trunk channels by rising solutions during an early stage of their activity. This was followed by a collapse and brecciation of the rock thus left unsupported.

In the Stavoren type of deposit these solutions have presumably attacked the rock at numerous isolated points thus converting the wall-rock into albitite and forming cavities in which the ore- and gangue-minerals were subsequently deposited to form zonal ore-bodies. Where the rock collapsed prior to the crystallisation of the minerals, breccia ore-bodies resulted. The brecciation may have resulted from the collapse of unsupported rock or from the explosive release of pressure during coalescence of two cavities in which the internal pressure differed greatly. The latter is an explanation offered by Strauss (1954 p. 141) for the origin of breccias in the Zaaiplaats deposits.

The replacement ore-bodies may originally have been breccia ore-bodies in which the fragments have been chloritised and replaced to such an extent that their fragmental nature is not recognisable any more.

(B) Metasomatic alteration of the granophyre.

(1) Albitisation.

In passing from the apparently normal granophyre to the albitite a series of interesting steps can be traced, viz.:

i. A change in the colour of the potash feldspar and consequently of the rock as a whole.

ii. A change in the composition of the feldspar.

iii. First a slight increase and thereafter a marked decrease in quartz.

iv. A change in the texture of the rock.

The change in colour of the potash feldspar is from red to slightly grayish. Under the microscope the gray feldspar is almost colourless but contains numerous inclusions of black dustlike particles. Not only the newly formed albite but also the remaining potash feldspar take on this colour.

It seems as if the temperature that existed during the mineralisation could have had an influence on the red colour of the feldspars. Anderson (1915) made a study of aventurine feldspar and found that after heating a cleavage piece with numerous hematite lamellae for 25 hours at 1050°C the feldspar becomes white and full of very fine dust. It appears, however, to be fairly certain that the temperature prevailing during the formation of the Stavoren type of ore deposit or the alteration of the granophyre,did not exceed 575°C which is a much lower temperature than that applied by Anderson. This lower temperature may probably prove sufficient to cause the change in colour if the time factor is taken in consideration.

In addition to the change in colour the alteration of the feldspar resulted in the formation of albite. Both, the potash and the plagioclase feldspar, are albitised. In this secondary albite the twinning lamellae are usually not persistent through the grains but are short and broad. This type of texture was described by Becke (1906) who considered it to have originated by the replacement of orthoclase by albite. Anderson (1937, p. 62) observed similar textures in the albitised Pellisier granite of Northern Inyo Range, California-Nevada, and used the term "chess-board" texture to describe it. The term is derived from the fact that the appearance of the albite grains resembles that of a chess-board.

In the early stages of replacement the albitised rock is characterised by the abundance of perthite that has formed by replacement of potash feldspar at numerous isolated points along the cleavage planes. In later stages the patches of albite coalesce to such an extent that the original feldspar becomes completely replaced. It is this development of albite from numerous isolated points that gives rise to the formation of the chess-board texture. In some instances the potash feldspar was attacked from one side resulting in a feldspar grain of which one portion is albite and the other potash feldspar (see plate XII). In such cases the twinning lamellae are continuous through the albite portion.

The process of albitisation was succeeded by one of desilication. In the altered specimens collected from near the contact with the normal red granophyre quartz is, as is confirmed by the volumetric proportions of the component minerals (table 26), even more abundant than in the red granophyre itself, but in specimens taken from near the contact with the ore-bodies very little quartz could be traced in thin sections.

Although the intergrowth of quartz and feldspar is still prominent in the quartz-rich albitised granophyre the texture is no longer that of the typical granophyre. It differs from the typical granophyric texture in that the small wedge-shaped quartz individuals of the micropegmatite seem to have coagulated, during replacement, and to have formed large quartz grains which are more or less oval-shaped; and the feldspar component of the intergrowths is albite and antiperthite. This difference in texture is illustrated in plate XIII figures 1 and 2. In both textures the orientation of the quartz is such that all the quartz individuals intergrown with one and the same feldspar grain, extinguish simultaneously.

TABLE 26. <u>Volumetric proportions of the component minerals in the granophyre and the altered products</u>.

	1.	2.	3 [ii]
Quartz[i]	30.8	44.3	3.5
Feldspar	58.6	43.7	79.5
Rest	10.6	12	17

[i] The quartz intergrown with feldspar is included.

[ii] Almost any radiation from normal granophyre to albitite exists and therefore only the most extreme volumetric proportions are given. Each analysis is the average of 4 thin sections.

1. Granophyre.
2. Quartz-rich albitised granophyre.
3. Albitite.

2. Chloritisation.

The process of chloritisation succeeds that of albitisation. It initiates with the development of thuringite which, in places, shows a gradual increase at the expense of the secondary albite resulting in the thuringite zone which usually commenced along the contacts of adjacent albite grains; less common is replacement along cleavage planes in the feldspar.

The main period of chloritisation is post-cassiterite and in an advanced degree yields a fine-grained greenish mass composed mainly of chlorite.

Except for the development of thin thuringite zones around the ore-bodies this alteration is confined to the fragments in the breccia ore-bodies and to highly stanniferous replacement ore-bodies.

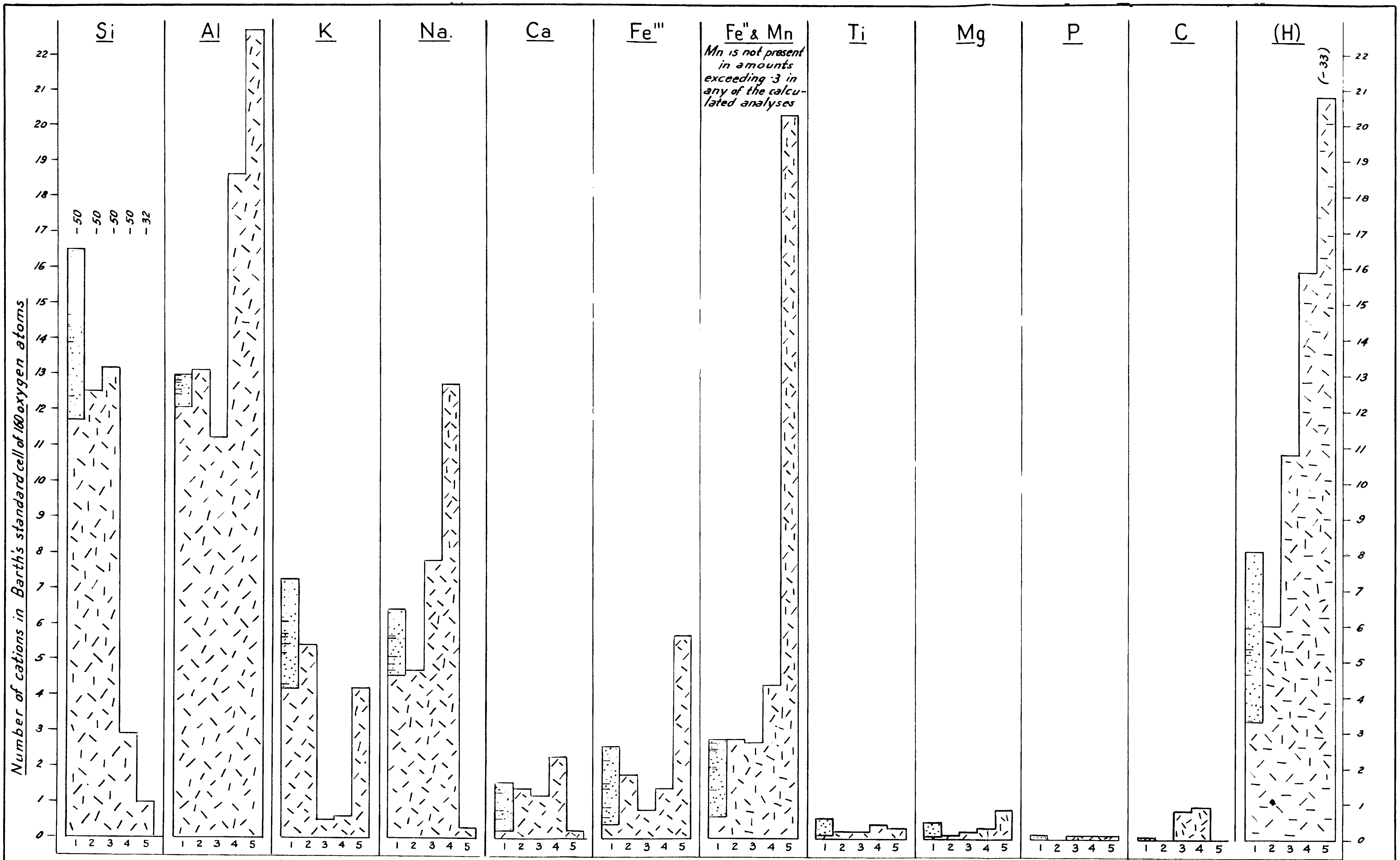
The degree of chloritisation is related to the cassiterite mineralisation; the higher the cassiterite content of the ore-bodies, the intenser the chloritisation.

3. Chemical changes resulting from albitisation and chloritisation.

In order to establish the nature of the chemical changes brought about by the metasomatic alteration of the granophyre the writer had analyses made of the altered rock-types. These analyses, together with an existing analysis of granophyre, are listed in table 27, their C.I.P.W. Norms in table 28, and their Niggli Values in table 29. For the rough calculation of the mineralogical composition of albitite (table 28 column 3a) the approximate weight percentage of thuringite in the rock was determined from its modal composition; a figure of 15 per cent was thus obtained. The composition of 15 per cent by weight of thuringite, calculated according to the analysis of the mineral (table 19 column 2) was subtracted from that of the albitite (table 27 column 3) and the norm for the remaining constituents calculated as usual.

According to the rule of equal volumes metasomatic replacement takes place volume by volume. The weight analyses as such are therefore inadequate to determine the chemical changes during metasomatism. Barth (1948, p. 50) points out that in most rocks oxygen makes up about 92 per cent by volume with the result that the number of oxygen ions is of the utmost importance for the volume relations in rocks. He therefore introduced a method of calculation in which the volume relations are automatically satisfied by recalculating the rock analysis to a standard cell of 160 oxygen atoms. For this calculation he uses the total available oxygen.

To determine the variation in the chemical composition of the Bushveld granophyre, seven chemical analyses of this rock-type, from various parts of the Bushveld Igneous Complex, were obtained from the literature and recalculated to the Barth's standard cell. The variation in the standard cell composition of Bushveld granophyre is given diagrammatically in figure 19 column 1, and the variation in the norm of their standard cell in figure 20 column 1. From these diagrams it is clear that the chemical composition of



Mn is not present in amounts exceeding ·3 in any of the calculated analyses

Fig.19 *Comparison of the standard cell content of:*

(1) *Bushveld granophyre-dotted part indicates the variation in seven different analyses of this rock-type and a horizontal mark the value of each individual analyses.*
(2) *Typical hornblende granophyre from Stavoren.*
(3) *Quartz-rich albitised granophyre from Stavoren.*
(4) *Albitite from Stavoren and* (5) *Chloritised rock from Stavoren.*

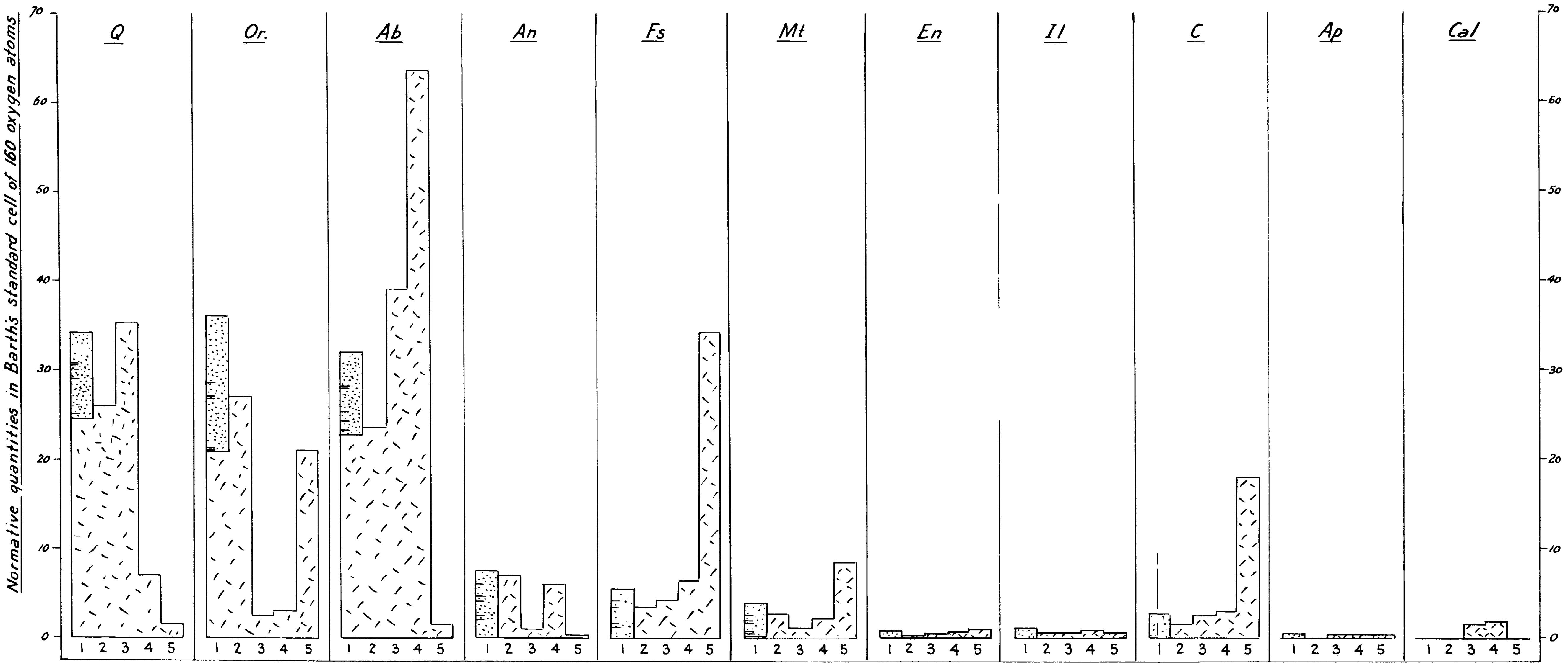


Fig. 20. Comparison of the norm of the standard cell of :- (1) Bushveld granophyre - the dotted part indicates the variation in seven different analyses of this rock-type and a horizontal mark the value of each individual analysis. (2) Typical hornblende granophyre from Stavoren. (3) Quartz-rich albitised granophyre from Stavoren. (4) Albitite from Stavoren and (5) Chloritised rock from Stavoren.

the hornblende granophyre from Stavoren (column 2 in figures 19 and 20) is in good agreement with that of this rock-type from other parts of the Bushveld Igneous Complex.

A study of the results obtained from the standard cell calculations (see figure 19 and table 30) confirms the deductions drawn from the microscopic investigation. In passing from the granophyre to the quartz-rich albitised granophyre there is a large increase in sodium and a decrease in potassium, as is demanded by the replacement of potash feldspar by albite. The replacement of the albite-oligoclase of the granophyre by albite is not so obvious from the cation content of the standard cells but the norms (figure 20 and table 31) clearly indicate a decrease in anorthite in the quartz-rich albitised granophyre and that the calcium in the quartz-rich rock is mainly present as calcite. The fact that quartz is more abundant in the albitised rock is also obvious in the norms. Ferric iron is subtracted and probably released and leached during the discolouration of the red feldspar. MnO was not determined separately for the granophyre and was probably taken as FeO so that the decrease in ferrous iron, in passing from the granophyre to quartz-rich albitised granophyre, is not only negligibly small but is also apparent rather than real. The decrease in Al is mainly due to the addition of quartz at the expense of aluminium-bearing minerals such as feldspars.

Na ⊕
K ⊖

TABLE 27. Analyses of granophyre and altered products.

	1	2	3	4
SiO2	70.40	74.21	59.83	34.19
Al_2O_3	12.50	11.11	17.81	19.89
CaO	1.45	1.32	2.36	0.20
MgO	0.05	0.14	0.19	0.56
Fe_2O_3	2.75	1.21	2.10	7.90
FeO	3.75	3.59	5.68	24.81
MnO	n.d.	0.17	0.19	0.41
TiO_2	0.35	0.36	0.49	0.38
P_2O_5	n.d.	0.08	0.11	0.05
K_2O	4.78	0.42	0.48	3.40
Na_2O	2.73	4.70	7.40	0.18
H_2O+	1.02	1.83	2.63	8.25
H_2O-		0.07	0.06	0.11
CO_2	-	0.67	0.77	nil
F	-	0.03	0.04	0.03
Total	99.78	99.91	100.14	100.36
S.G.	2.66	2.68	2.71	

1. Typical hornblende granophyre - Stavoren. Analyst, Dr. J. Moir (Wagner 1921, p. 28).

2. Quartz-rich albitised granophyre - B5 East pipe, second level, Stavoren. Analyst, P.R.B. Heymann. Division of Chemical Services, Pretoria. Sample No. JGDS 49.

3. Desilicified albitised granophyre (albitite) - B6a pipe, second level, Stavoren. Analyst, P.R.B. Heymann, Division of Chemical Services, Pretoria. Sample No. JGDS 25.

4. Chloritised granophyre - B5 East pipe, second level, Stavoren. Analyst, P.R.B. Heymann, Division of Chemical Services, Pretoria. Sample No. JGDS 56.

TABLE 28. C.I.P.W. Norms of granophyre and altered products.

	1	2	3	3a[1]	4
Quartz	31.26	42.04	8.50	10.0	1.26
Orthoclase	28.21	2.50	2.83	2.3	20.09
Albite	23.07	39.74	62.60	67.0 (Ab93	1.52
Anorthite	7.22	1.54	5.84	An7)	0.42
Hypersthene	4.26	5.67	8.52	-	40.57
Thuringite	-	-	-	15.0	-
Magnetite	3.98	1.74	3.08	2.0	11.46
Ilmenite	0.66	0.68	1.15	.8	0.73
Corundum	0.20	2.36	2.98		15.75
Apatite	-	0.2	0.27	0.8	0.16
Calcite	-	1.52	1.75	2.0	-
Fluorite	-	0.12	0.14	0.1	0.12
Water	1.02	1.90	2.69	-	8.36
Total	99.88	100.01	100.35	100.0	100.44

Numbers 1, 2, 3 and 4 refer to samples in table 27.

[1] Approximate mineralogical composition of albite, calculated from the chemical analysis 3 and the mineralogical composition.

TABLE 29. Niggli Values of granophyre and altered products.

	1	2	3	4
si	354.2	435.5	219.4	81.11
al	37.03	38.39	38.45	27 80
fm	26.53	25.04	24.86	66.13
c	7.83	8.29	9.28	0.51
alk	28.61	28.28	27.41	5.56
ti	1.34	1.59	1.69	0.07
p	-	0.21	0.18	0.01
h	17.10	37.16	32.87	66.12
co_2	-	5.32	3.85	-
mg	0.02	0.06	0.05	0.04
k	0.53	0.06	0.04	0.93

Numbers 1, 2, 3 and 4 refer to samples in table 27.

TABLE 30. Analyses of granophyre and altered products recalculated to Barth's standard cell of 160 Oxygen atoms.

	1	2	3	4
Si	62.50	63.2	52.9	33.0
Al	13.1	11.2	18.6	22.7
Ca	1.4	1.2	2.3	0.2
Mg	0.1	0.2	0.3	0.8
Fe'''	1.8	0.8	1.4	5.7
Fe''	2.8	2.6	4.2	20.0
Mn	-	0.1	0.1	0.3
Ti	0.2	0.2	0.4	0.3
P	-	0.1	0.1	0.1
K	5.4	0.5	0.[illegible]	4.2

Table 30 continued.

	1	2	3	4
Na	4.7	7.8	12.7	0.3
C	-	0.8	0.9	-
H	6.0	10.8	15.9	53.8
Total	98.0	99.5	110.4	141.4
less H	92.0	88.7	94.5	87.6
	320.2	320.6		

Numbers 1 - 4 refer to samples in table 27.

TABLE 31. <u>Norm of the standard cell of granophyre and altered products</u>.

Q	26.2	35.6	7.1	1.5
Or	27.0	2.5	3.0	21.0
Ab	23.5	39.0	63.5	1.5
An	7.0	1.0	6.0	0.2
En	0.2	0.4	0.6	1.6
Fs	3.4	4.2	6.4	34.3
Mt	2.7	1.2	2.1	8.5
Il	0.4	0.4	0.8	0.6
C	1.6	2.5	2.9	18.1
Ap	-	0.3	0.3	0.3
Cal	-	1.6	1.8	-
Total	92.0	88.7	94.5	87.6

Numbers 1 - 4 refer to samples in table 27.

TABLE 32. Additions and subtractions.

	Granophyre passes into quartz-rich albitised granophyre by				Quartz-rich albitised granophyre passes into albitite by				Albitite passes into chlorite rock by			
	Adding		subtracting		adding		subtracting		adding		subtracting	
Ions	No.	val.	No.	val.	No.	val.	No.	val.	No.	val.	No.	val.
Si	0.7	2.8					10.3	41.2			19.9	79.6
Al			1.9	5.7	7.4	22.2			4.1	12.3		
Ca			0.2	0.4	1.1	2.2					2.1	4.2
Mg	0.1	0.2			0.1	0.2			0.5	1.0		
Fe'''			1.0	3.0	0.6	1.8			4.3	12.9		
Fe''			0.2	0.4	1.6	3.2			15.8	31.6		
Mn	0.1	0.2							0.2	0.4		
Ti					0.2	0.8					0.1	0.4
P	0.1	0.5										
K			4.9	4.9	0.1	0.1			3.6	3.6		
Na	3.1	3.1			4.9	4.9					12.4	12.4
C	0.8	3.2			0.1	0.4					0.9	3.6
H	4.8	4.8			5.1	5.1			37.9	37.9		
Total	9.7	14.8	8.2	14.4	21.2	40.9	10.3	41.2	66.4	99.7	35.4	100.2

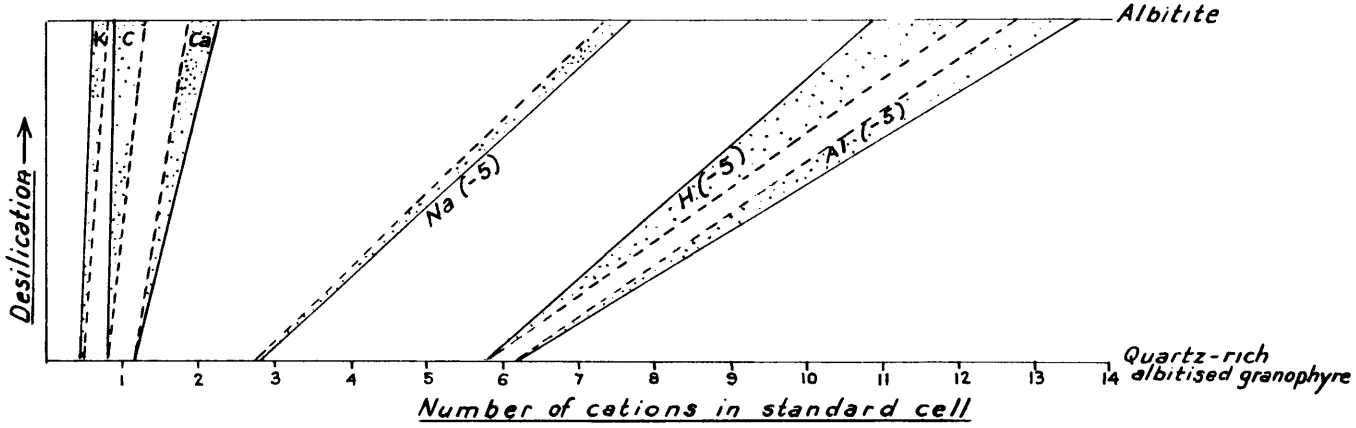


Fig. 21 Additions in number of cations when quartz-rich albitised granophyre passes into albitite. Dotted lines ... proportional additions per unit desilication. Full lines..... actual additions.

The alteration of quartz-rich albitised granophyre to albitite was mainly but not purely a process of desilication. Figure 21 indicates that the increase in Al, Ca and Na is larger, and that in K, C and H smaller, than what is required for a proportional increase as demanded by a pure process of desilication. This graph was compiled from the cation values in table 30 columns 2 and 3. The proportional additions were obtained by recalculating the cation values of the quartz-rich albitised granophyre in terms of a Si content of 52.9 and a total cation content of 110.4 (the Si and cation content of the albitite).

Chemically the process of chloritisation differs greatly from that of albitisation. During chloritisation of albitite sodium, calcium and silicon were largely subtracted whereas ferrous and ferricions, potassium and aluminium were added in large quantities (compare table 32). The addition of iron indicates that the chlorite which formed is an iron-rich one.

The altered material is not homogeneous but varies considerably within a few inches. The analyses should therefore not be regarded as representing the final products of the various processes of alteration.

The granophyre passes into quartz-rich albitised granophyre by adding and subtracting more or less equal amounts of ions (see table 32). In the process of desilication and chloritisation the total ions added is about twice that subtracted. In all these processes the total charge of the ions added and those subtracted are more or less the same in agreement indicating that the electrostatic equilibrium is maintained during these processes of metasomatism. The difference in the amounts of ions added and subtracted but agreement in the total charge of these ions is due to the fact that tetravalent ions of Si count among those subtracted, whereas inter alia, monovalent ions are added.

Spectrographic analyses reveal slight variations in some of the minor elements. B, Li, Ga and Mo tend to be more abundant in the albitised and chloritised rocks than in the granophyre. Sn and W show no variation from granophyre to albitised rock but are more abundant in the chloritised products. Traces of Cr occur in the granophyre and albitised rocks.

Chemically and mineralogically the alteration products of the granophyre differ remarkably from greisen which is a characteristic metasomatic product of granitic rocks in contact with hypothermal tin veins. The association of cassiterite with albite is, however, by no means uncommon and led Barsukov (1953, pp. 1065 - 1068) to the conclusion that in hydrothermal solutions tin is transported as $Na_2Sn(OH,F)_6$ which on hydration passes into $Sn(OH)_4$ and eventually into SnO_2.

(C) <u>The source and nature of the metasomatising agents and the ore-solutions</u>.

The genetic relation between quartz-bearing rocks, such as granites, and tin deposits was realized at an early date by Daubree and de Beaumont (Lindgren 1933, p. 650). This conclusion has been adopted by almost all geologists who have studied such deposits.

Brown (1948), however, proposes a revolutionary hypothesis as alternative to the hydrothermal theory and as regards the relation of types of intrusives to types of ore he concludes (p. 73) "granites constitute more than 95 per cent of all visible intrusives according to Daly, and are associated with more than 95 per cent of all lode ores according to Emmons. The occurrence of ores is, therefore, related more closely to the relative abundance of rock-types than to differences between these types". A genetic association between granitic rocks and tin deposits is, however, not only supported by the world-wide association of tin deposits with granites but also by the fact that the average tin-content of granites is in the vicinity of 56 - 80 grams per ton whereas in gabbro the average is only 8 grams per ton (Rankama and Sahama 1950, p. 732).

The tin deposits of the Transvaal were until recently considered genetically related to the intrusion of the main mass of Bushveld granite. In the Zaaiplaats tin-mining area, about 50 miles northwest of Stavoren, splendid exposures enabled Strauss and Truter to make a detail study of the Bushveld granite. They conclude (Strauss and Truter 1944, p. 48; also Strauss 1954, p. 23) that there are Bushveld granites of three different ages, each with its own variational or derivative facies. In chronological order they are; (1) Main granite which includes coarse-grained, gray, leucocratic and mesotype granites, granophyric granite, granophyre, and contact microgranite; (2) Foot-hills granite; and (3) Bobbejaankop granite and its roof facies the Lease microgranite and pegmatite. According to these authors (Strauss and Truter 1944, p. 74 and Strauss 1954, p. 23) all the tin deposits in the Bushveld Igneous Complex are genetically related to the Bobbejaankop granite and its roof facies, the Lease microgranite.

Not much evidence bearing on the conclusions of Strauss and Truter could be gathered on Stavoren. The scarcity of typical high temperature minerals in the Stavoren deposits, and (as will be discussed subsequently) the type of wall-rock alteration favour, however, an epigenetic origin for these deposits. The author thus postulates the existence of Bobbejaankop granite at depth in the Stavoren area. The mineralising solutions presumably migrated from arches in the roof of this granite upwards along potential zones of weakness and subsequently gave rise to the formation of ore-bodies in the granophyre.

There still exists considerable uncertainty in regard to the nature of the transporting agent of tin The frequent association of cassiterite with halogen- and boron-bearing minerals led early investigators to the theory that tin was transported in the form of volatile compounds consisting of tin, halogens and boron. It was, however, thereafter realized that there are many tin deposits where evidence of associated halogen- and boron-bearing minerals is lacking. The hydrothermal theory developed afterwards, holds that mineral deposits are formed by the deposition from aqueous solutions, either acid or alkaline. As an alternative to the hydrothermal theory Brown (1948) proposes his metallurgical theory according to which ore is vaporised chiefly as simple mineral substances.

Whatever the nature of the transporting agent it appears to be quite clear that its composition changed considerably during upward migration from the source magma into the overlying rocks. If derived from the same or similar source magma, as is postulated, one would at least expect that the ore-solutions and metasomatising agents that formed the pipes on Stavoren were originally similar in composition to those responsible for the Zaaiplaats deposits. The ore assemblage of the two tin-bearing areas is roughly similar but the alteration product of the granophyre at Stavoren differs markedly from that of the granites in the Zaaiplaats area. In the latter area the granitic rocks are silicified, tourmalinised, and sericitised, whereas, at Stavoren the granophyre is albitised, desilicified, and chloritised.

Strauss illustrates(1954, p. 145) that in the Zaaiplaats area silification and tourmalinisation commenced in deep-seated portions of the pipes where the temperature was too high for ore-deposition. He furthermore points out that the deposition of cassiterite was preceded by tourmalinisation and succeeded by sericitisation. Similarly at Stavoren albitisation preceded, and the main period of chloritisation succeeded, cassiterite crystallisation. Gevers and Frommurze (1929, p. 142) also conclude that in the tin-bearing pegmatites of the Erongo area in

South-West Africa, albitisation preceded and sericitisation succeeded cassiterite deposition. Von Backström (1950, p.44) on the other hand inferred that sericite largely preceded metallisation in the tungsten-tin deposits near Upington. Similarly Söhnge (1950 p. 939) listed sericite as preceding the ore-minerals in the Nababeep near West Tungsten-mine in the northwestern Cape Province.

In order to elucidate the difference in metasomatic alteration at Zaaiplaats and at Stavoren it seems advisable to distinguish between pre-cassiterite and post-cassiterite alteration, and to assume the paragenetic sequence set out by Strauss. Furthermore it must be kept in mind that in the Zaaiplaats area the pipes occur mainly in the Bobbejaankop and overlying Main granite, whereas, at Stavoren they occur in a stratigraphically higher horizon than the Main granite.

The author offers the following hypothesis: During its upward migration from the source magma the ore-solutions reacted with the granitic rocks along the channel-ways and converted the rocks into silicified and tourmalinised granites. This alteration would be accompanied by strong leaching of potassium and sodium from the wall-rocks. In the Zaaiplaats area the physical conditions were such that ore-deposition commenced at, or shortly above horizons where the process of tourmalinisation was active. This is not far away from the source magma; consequently the sodium and potassium content of the solutions was such that only relatively small quantities of soda and potash feldspar could form. The formation of these feldspars are actually recorded by Strauss. In the Stavoren area, on the other hand, the physical conditions were such that the ore-solutions migrated upwards into the granophyre. Consequently during the migration of these solutions through the underlying granitic rocks tourmalinisation, silicification and concomitant leaching of alkali presumably took place. Eventually the alkalinity of the solutions was high enough to return alkali to the wall rock higher up the passage. This commenced with albitisation and desilication of the granophyre. During these processes potassium and silicon were leached from the granophyre and were eventually incorporated in the formation of red potash feldspar (adularia) and quartz, both being characteristic gangue-minerals in the ore-bodies at Stavoren.

Turning to the post-cassiterite alteration we find that the sericite from the Zaaiplaats area differs chemically mainly from the Stavoren chlorite in containing more silica, potash and alumina, and much less ferric and ferrous iron (table 33).

TABLE 33. Chemical analyses of chlorite and sericite.

	1	2	3
SiO_2	50.74	22.4	34.19
Al_2O_3	28.79	16.85	19.89
CaO	0.73	1.26	0.20
MgO	0.96	0.90	0.56
Fe_2O_3	3.12	10.15	7.90

Table 33 continued.

	1	2	3
FeO	0.93	35.93	24.81
MnO	0.05	0.51	0.41
TiO_2	n.d.	0.41	0.38
P_2O_5	0.12	n.d.	0.05
K_2O	8.19	0.57	3.40
Na_2O	0.38	0.31	0.18
H_2O-	5.22	9.50	8.25
H_2O-		1.17	0.11
CO_2	tr.	-	nil
F	0.18	-	0.03
Total	99.61	100.00	100.36

1. Yellow-green sericite, Groenfontein 871. Analyst; C.J. Liebenberg, Division of Chemical Services, Pretoria (Strauss 1954 p.165).

2. Thuringite, Stavoren (see table 18 analysis 2).

3. Chloritised granophyre, Stavoren (see table 27 analysis 4).

It can therefore be argued that at Stavoren there was a deficiency in potassium in the albitised rocks with the result that chlorite, and not sericite, formed. In conflict to this argument, however, is the fact that even the potash feldspar of the ore-bodies was chloritised and not sericitised. It can be inferred, in favour of the contention of Von Backström (1950, p. 44), that sericitisation precedes the crystallisation of the potash feldspar but, even then the potassium which was finally incorporated in the potash feldspar, must have been available in the ore-solutions. It appears that the formation of chlorite instead of sericite was rather due to excess iron in the ore-solutions. In the deposits of the Zaaiplaats area hematite crystallised prior to the formation of sericite, whereas, during the formation of the Stavoren deposits conditions were probably unfavourable for hematite deposition, perhaps owing to a deficiency in oxygen. Consequently the iron was still available in the ore-solutions at a late stage and was incorporated in an iron-rich chlorite.

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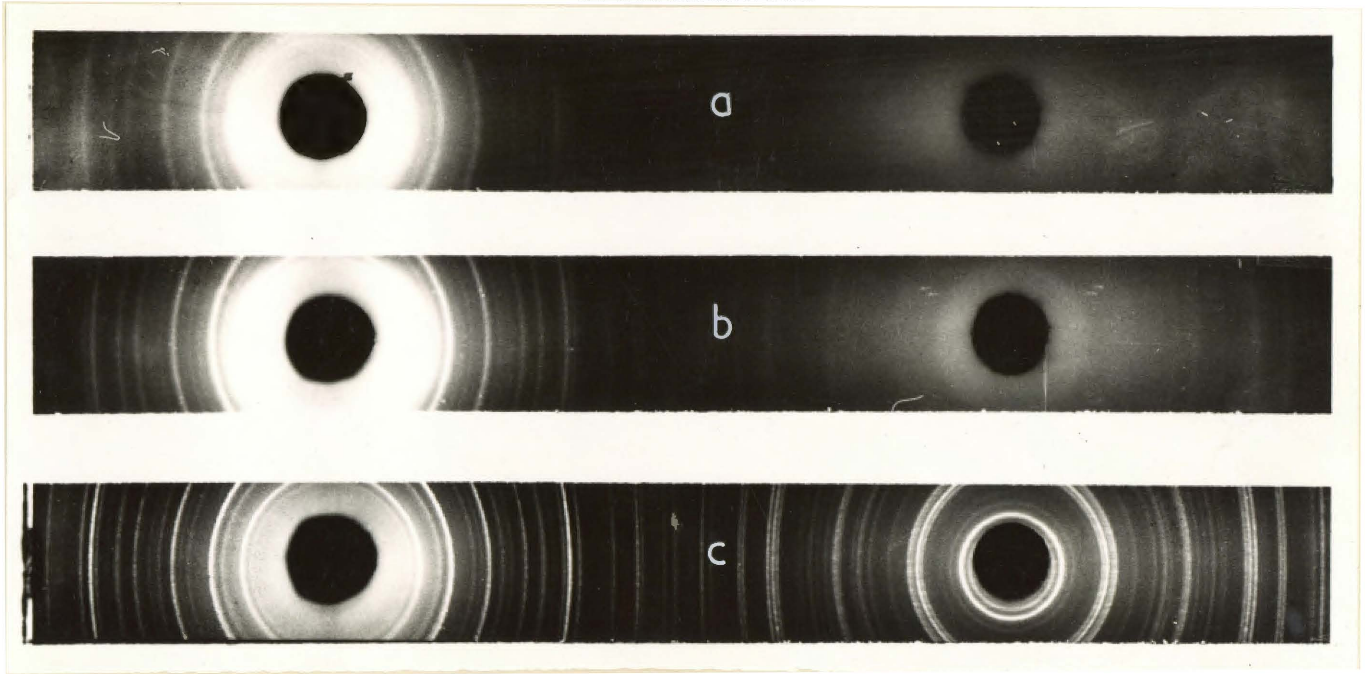
PLATE I.



X-ray diffraction patterns of malacon and zircon.
Cobalt radiation. Camera radius = 57.3 mm.

(a) Malacon, macroscopic crystal, Hittero, Norway. (Geol. Surv. Museum collection No. 394).

(b) Malacon, ex Bushveld granophyre, Stavoren 470, Potgietersrus District.

(c) Zircon, ex quartzite, Stavoren 470, Potgietersrus District.

PLATE 11.

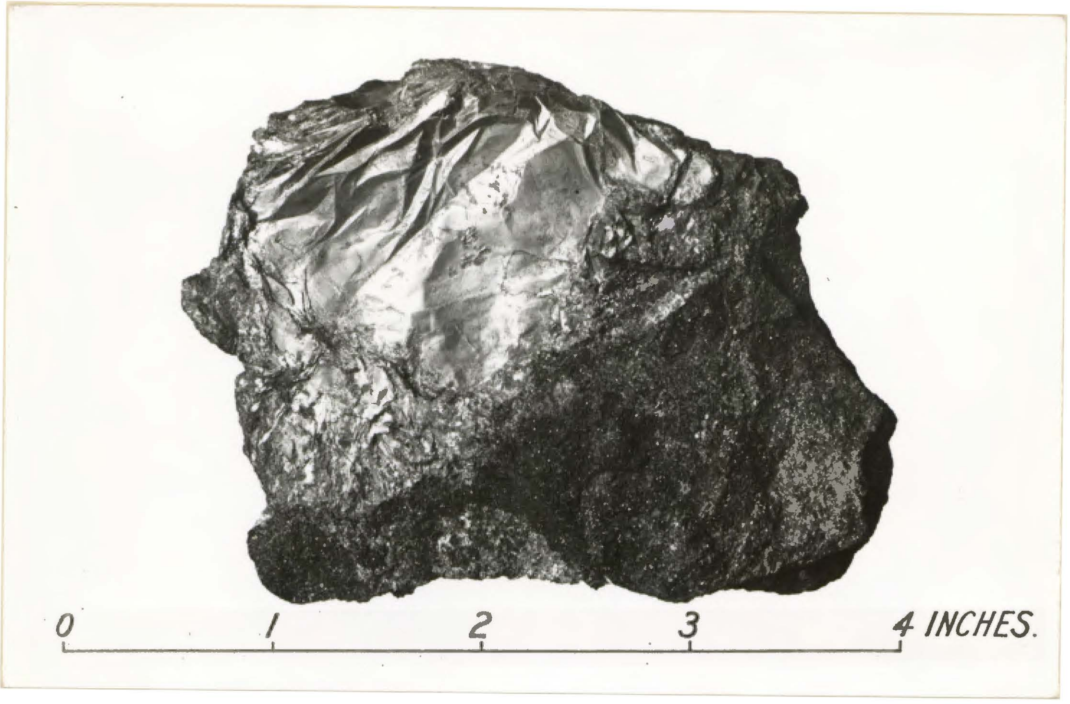


Fig. 1 Joseite from the B7 pipe on Stavoren. The lower portion of the specimen is composed mainly of small flakes of thuringite. Reprinted from Wagner (1921, plate XVI). Sample No. 3503 in the Museum of the Union Geological Survey.

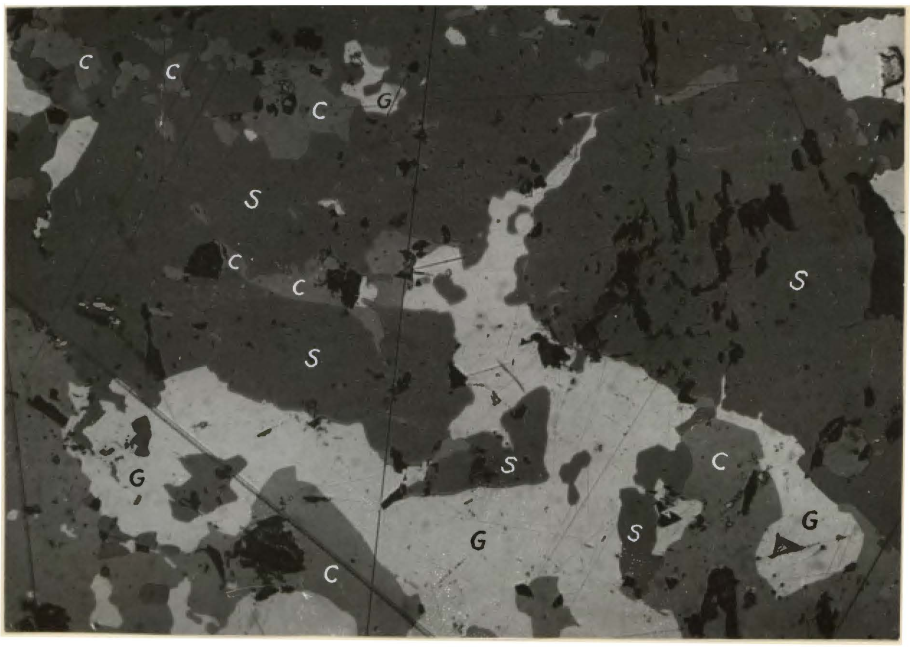


Fig. 2 Galena, G, (grayish-white) and chalcopyrite, C, (light-gray) replacing sphalerite, S, (dark-gray). Reflected light using Wratten filters D No. 35 and H No. 45.
Magnification X130. Photo by S.A. Hiemstra.
Polished section No. 736.

PLATE 111.

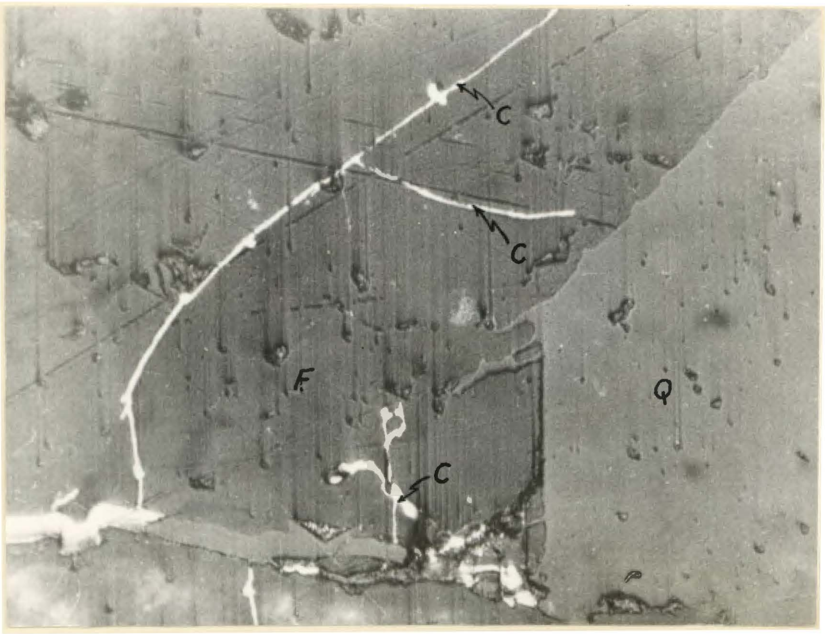


Fig. 1 Chalcopyrite, C, along a microscopically fine fracture in fluorite, F,. Q = quartz. Reflected light. Magnification X245.

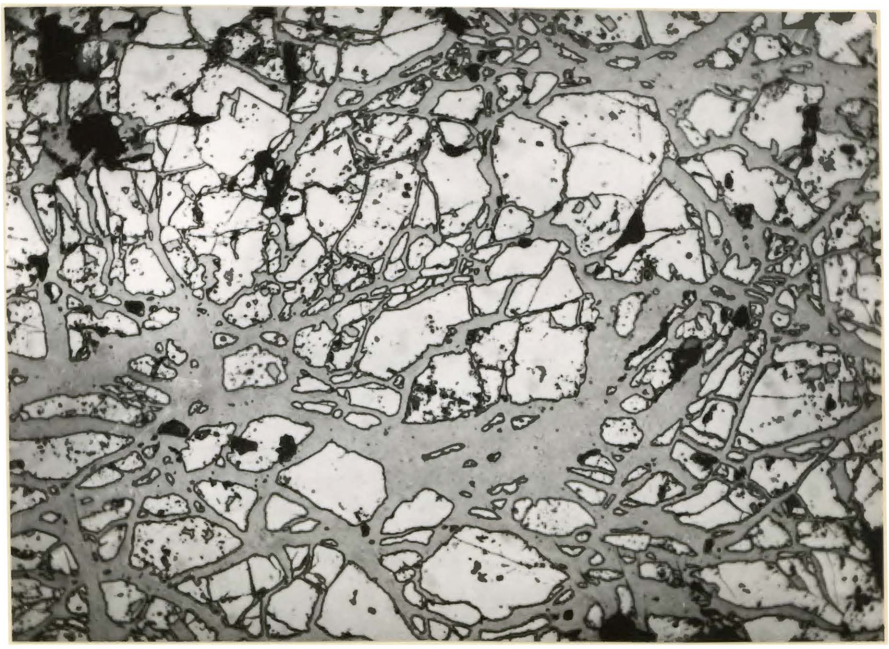


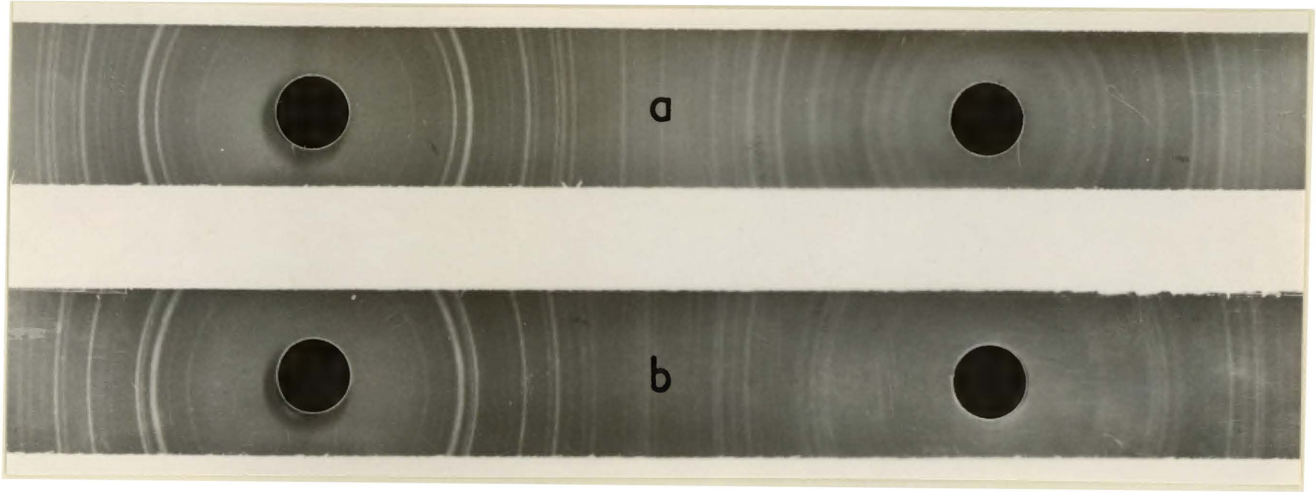
Fig. 2 Chalcopyrite (gray) replacing pyrite (grayish-white). Reflected light.
Magnification X130.
Photo by S.A. Hiemstra.
Polished section No. 736.

PLATE IV.

Fig. 1 Fractured lenticular crystals of loellingite (white) with quartz (dark) filling the fractures and the interstices between the crystals. Reflected light.
Magnification X 12.
Polished section No. 737.

Fig. 2 Quartz (white) replacing arsenopyrite (black).
Transmitted light. Magnification X175.
Thin section No. 18038.

PLATE V.



X-ray diffraction patterns. Cobalt radiation. Camera radius = 57.3 mm.

(a) Arsenopyrite, Stavoren.
(b) Loellingite, Stavoren.

PLATE VI.

Fig. 1 Quartz filling fractures in brecciated, twinned cassiterite crystal. A-A' is the twinning plane. Transmitted light. Magnification X56. Thin section No. 18039.

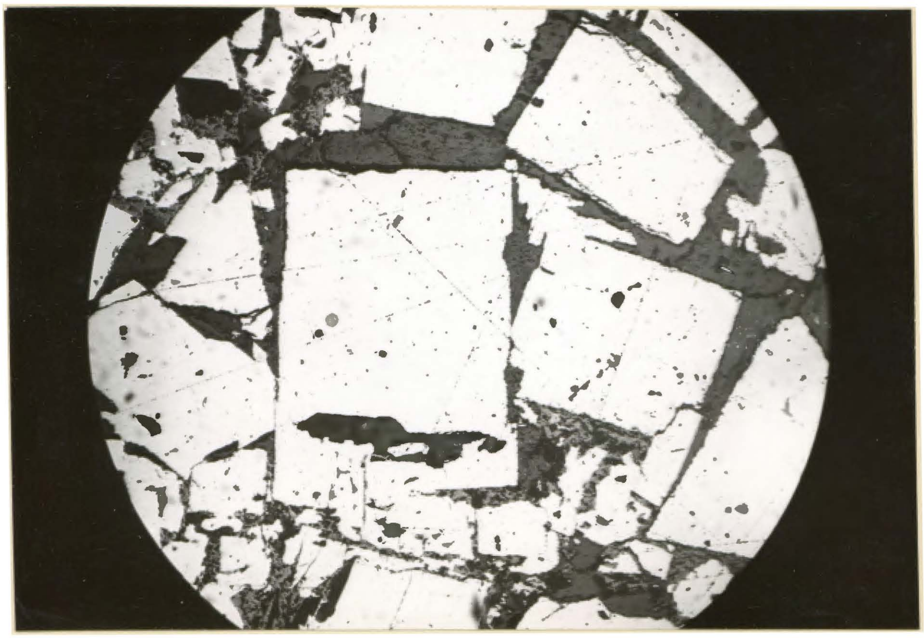


Fig. 2 Ilvaite (gray) filling the interstices between idiomorphic grains of pyrite. Magnification X 35.

PLATE VII.

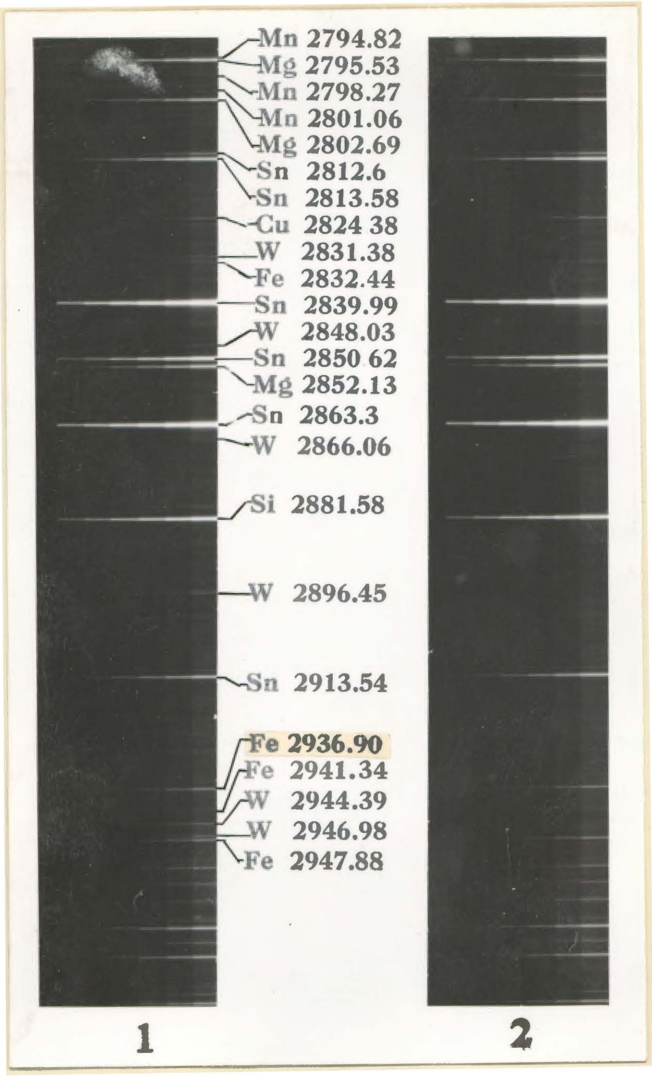


Fig. 1 Part of a spectrum showing that W is present in detectable quantity only in the dark-coloured cassiterite (spectrum 1) whereas Mn and Cu are more abundant in the light-coloured cassiterite (spectrum 2).

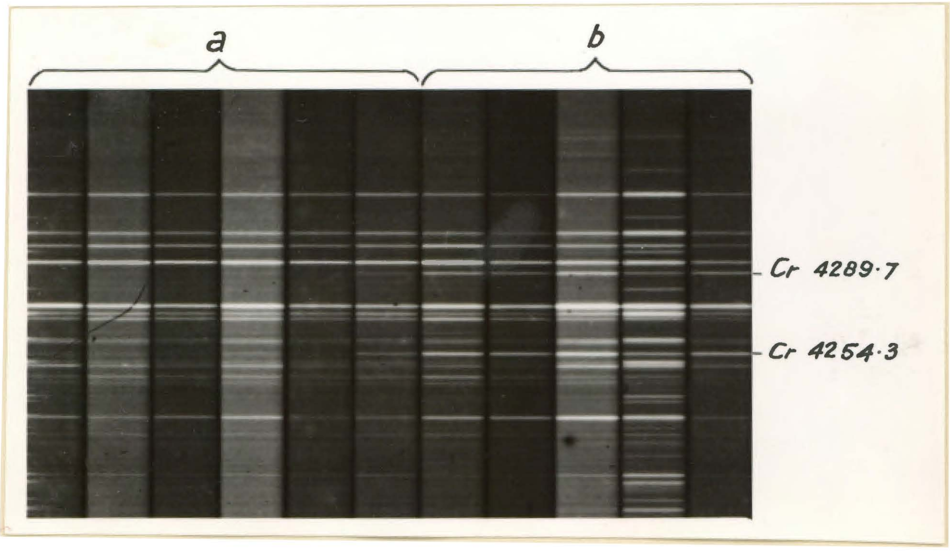


Fig. 2 Part of a spectrum to show that Cr is more abundant in cassiterite from the first level of the mine.

(a) Samples from the second level.
(b) Samples from the first level.

PLATE VIII.

Fig. 1 Combs of second generation quartz moulded on to a crystal of first generation quartz. The original outline (A-A') of the quartz crystal is marked by inclusions.
Crossed nicols. Magnification X175.
Thin section No. 18038.

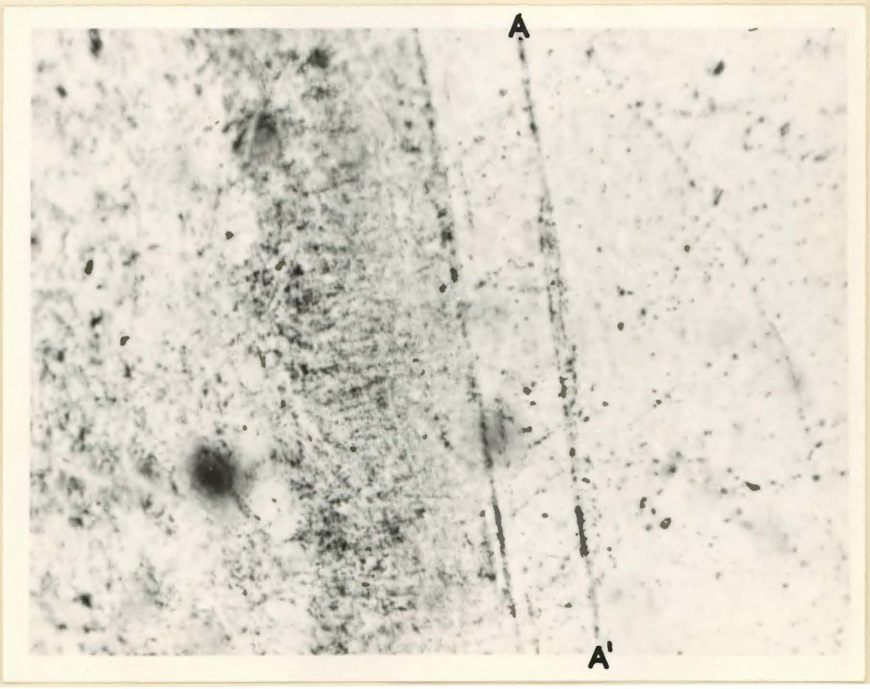


Fig. 2 Same as fig. 1 but without analyser. The comb quartz is marked by numerous inclusions.

PLATE IX.

Fig. 1 Brecciated scheelite-cassiterite ore from the B5b pipe. In the centre is a crystal of first generation quartz from which second generation quartz has grown outwards, and at the bottom irregular grains of scheelite (black) acted as nuclei around which second generation quartz grew. Reprint of plate XXl, fig. 2 in Wagner (1921).

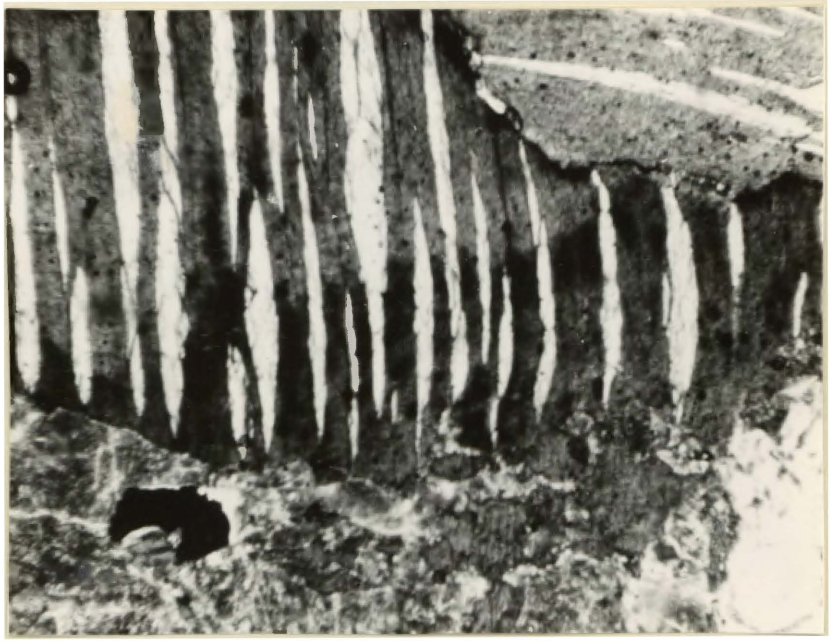
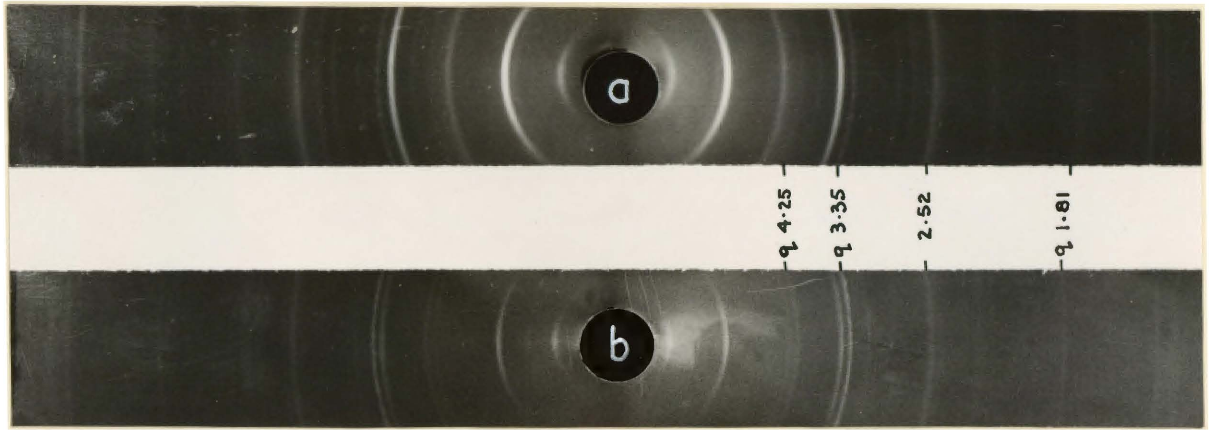


Fig. 2 Quartz lenses (white lerticular) in thuringite. Thin section No. 18040. Magnification X56.

PLATE X.



X-ray diffraction patterns (front reflections only) of thuringite from Stavoren. Co radiation. Camera radius = 114.59 mm.
Marked lines; q = quartz.

(a) Untreated mineral.
(b) Mineral heated to 500°C.

PLATE XI.

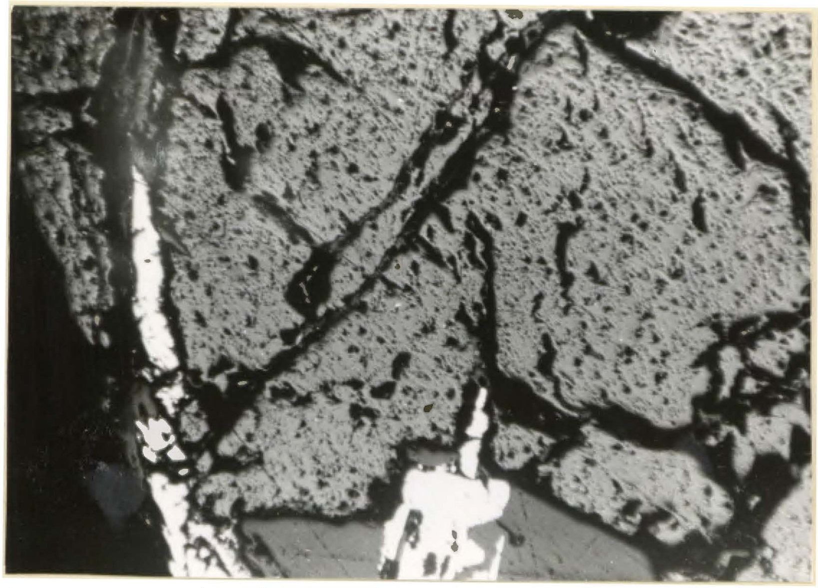


Fig. 1 Arsenopyrite (white) filling fractures in scheelite (gray with pitted surface).
Reflected light. Magnification X45.
Photograph by G.M. Koen.
Polished section No. 738.

Fig. 2 Cassiterite, C, moulded on to scheelite, S.
Magnification X120.
Reprinted from Wagner (1921, plate XXIV, fig. 1).

PLATE XII.

Fig. 1 A single grain of potash feldspar (right half) of red granophyre replaced by albite (left half). The light-coloured spots in the potash feldspar are due to discolouration. Thin section No. 18016. Magnification X175.

Fig. 2 Same as figure 1 but with nicols crossed. Magnification X175.

PLATE XIII.

Figure 1. Typical granophyric texture. Crossed nicols. Thin section No. 18032. Magnification X175.

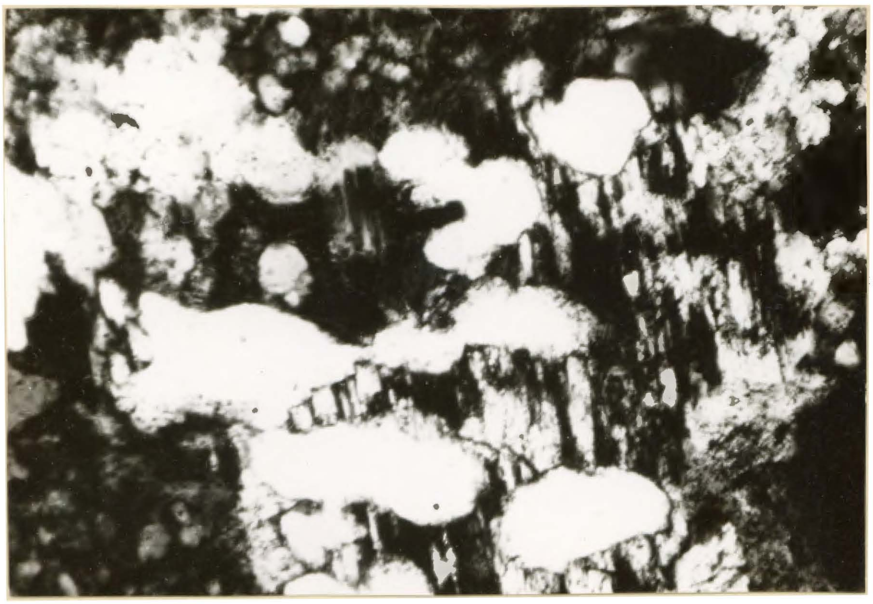
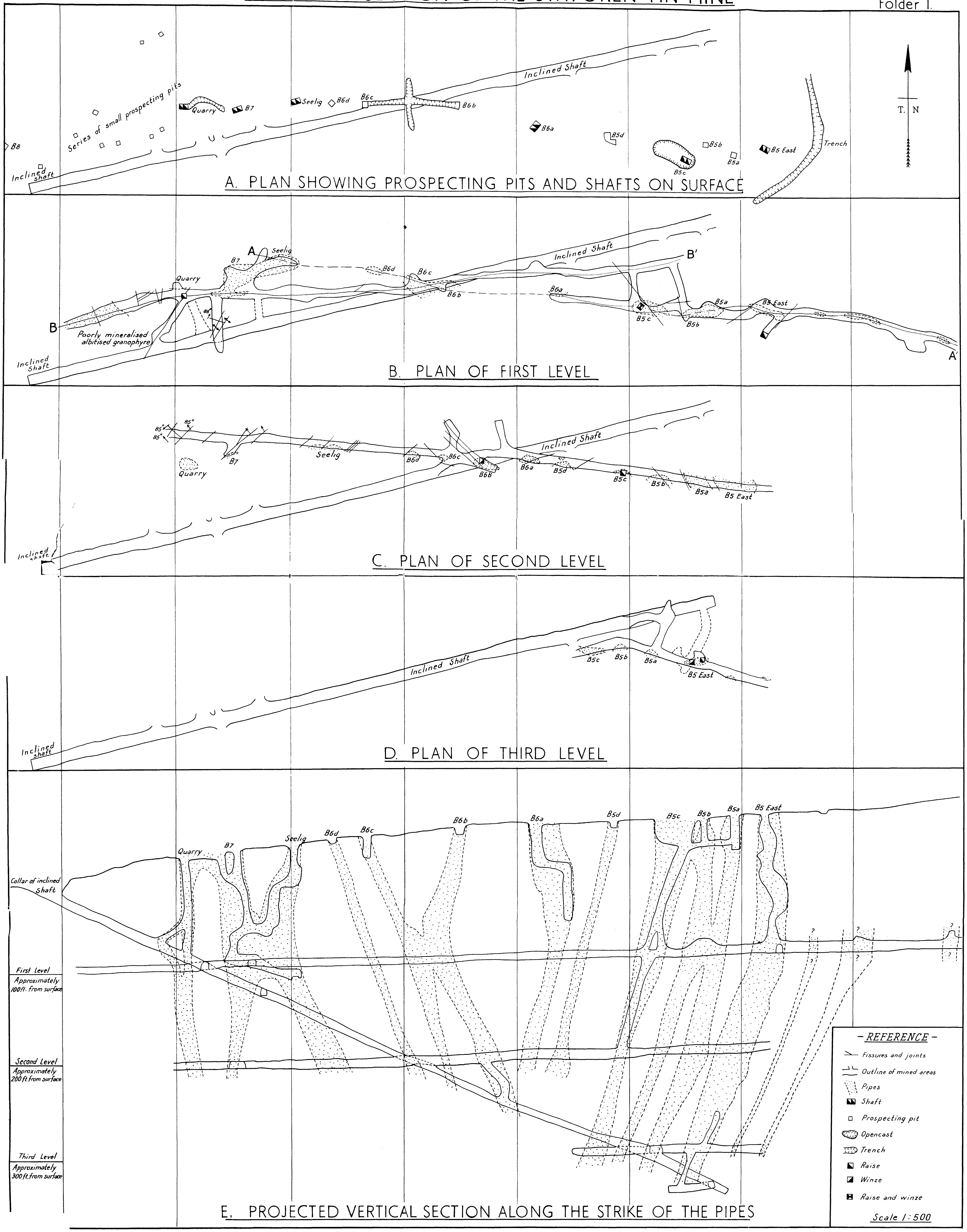


Figure 2. Intergrowth of oval-shaped quartz grains and replacement antiperthite in slightly albitised rock. Crossed nicols.
Thin section No. 18023. Magnification X175.

— PLANS AND SECTI AVOREN TIN-MINE

Folder I.



A. PLAN SHOWING PROSPECTING PITS AND SHAFTS ON SURFACE

B. PLAN OF FIRST LEVEL

C. PLAN OF SECOND LEVEL

D. PLAN OF THIRD LEVEL

E. PROJECTED VERTICAL SECTION ALONG THE STRIKE OF THE PIPES

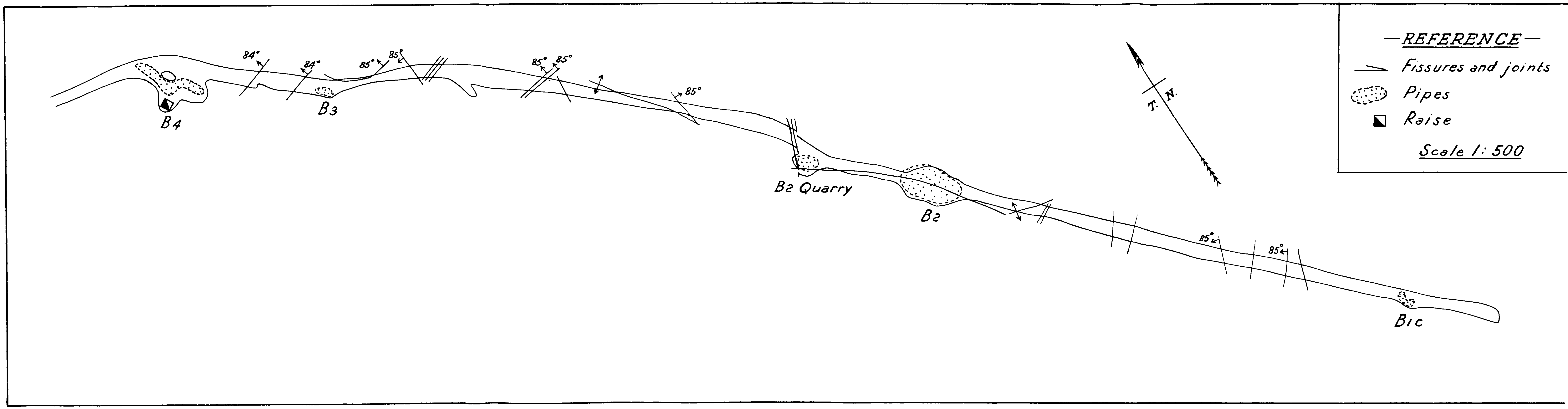
PART II

TYSONITE FROM MUTUE FIDES.

182,2

— STAVOREN TIN-MINE.— Plan of the Eastern Portion of the Drive on the First Level.

Folder 2.



CONTENTS.

ABSTRACT.

Tysonite from the tin deposits on Mutue Fides 422 has the following optical properties: $n\epsilon_D = 1.608 \pm .002$, $n\omega_D = 1.614 \pm .002$; $n\omega_D - n\epsilon_D = .006$; $n\omega_F - n\omega_C = .011$; and $S.G.^{24}_{4} = 5.995 \pm .005$. Microscopically polysynthetic twinning with the first order pyramid $(10\bar{1}2)$ as composition and twinning-plane is prominent, and $0001 \wedge 10\bar{1}2 = 45^\circ 36'$.

X-ray powder diffraction data are given: $a = 4.122 \pm .005$ A, $c = 7.304 \pm .005$ A, $c/a = 1.772$. The mineral alters to bastnaesite and the chemical analysis suggests also partial oxidation. The chemical analysis, specific gravity, refractive indices and X-ray data of the bastnaesite agree with those of this mineral from other localities. Other minerals associated with the tysonite are fluorite, hellandite?, and quartz.

It is also suggested that fluocerite and tysonite are two different minerals, and that the former is an oxidation product of the latter.

INTRODUCTION.

The fluoride of the rare earth metals, $(Ce,La,Di)F_3$, an exceedingly rare mineral, was first described by Berzelius in 1818. Originally the mineral was called fluocerite by Haidinger. This mineral was obtained from a a pegmatite at Finbo and Broddbo in Dalarne, Sweden, and was subsequently found in the same group of pegmatites at Österby in Dalarne, Sweden (Geijer 1921 p. 19). A fluoride of Ce, La, and Di, from granite pegmatite in the Pike's Peak region in Colorado, was described in 1880 by

Allen and Comstock (1880 p. 390) who called it tysonite.

Geijer (1920 p. 9) encountered microscopical grains of fluocerite in the Bastnäs mine at Riddarhyttan. In a subsequent publication (Geijer 1921 p. 19) he points out that fluocerite and tysonite are one and the same mineral with the formula $(Ce,La,Di)F_3$, and on a basis of priority prefers the name fluocerite.

In 1945 fluocerite was discovered in a pegmatite at Mpuye Hill near Mubende in the Protectorate of Uganda (Roberts 1945 p. 37 and 1946 p. 31). This mineral was analysed by Bennett who calculated its formula as $(Ce,La,Di)_2O_{0.4}F_{5.2}$ (Roberts 1946 p. 32).

The present author agrees with Geijer that the fluocerite from Broddbo and the tysonite from Colorado is one and the same mineral species but the study of the data listed in table 1 reveals that the specimens from Österby and Uganda differ from the optically uniaxial negative material from Broddbo and Colorado in being positive and in having a lower specific gravity. Furthermore the material from Colorado is a fluoride with the formula RF_3 (R = rare earth metals) whereas the minerals from Österby and Uganda appear to be oxyfluorides with formulae respectively $R_2O_1F_4$ and $R_2O_{0.4}F_{5.2}$. Owing to an incomplete analysis the exact composition of the Broddbo material (table 1 column 1) is somewhat in doubt but it is at once apparent that the analysis is almost identical to the original analysis of Colorado tysonite (table 1 column 2). Accordingly there is hardly any reason to doubt that the Broddbo material, as is indicated by its optical character, is the same mineral species as that from Colorado, namely tysonite.

TABLE 1. Compilation of chemical analyses, and optical and physical properties of tysonite and fluocerite.

	1	2	3	4	5
Ce_2O_3	82.64	82.64	42.89	46.03	41.58
La_2O_3 group			39.31	36.00	39.26
Y_2O_3 group	1.12			3.96	0.13
F	(28.05)	(29.98)	28.71	19.49	24.46
CaO			0.18		0.42
CO_2			0.53		0.98
H_2O				1.78	0.71
Rem.			0.41	1.50	3.08
	111.81	112.62	112.03	108.76	110.62
-F=O	11.81	12.62	12.08	8.21	10.30
Total	100.00	100.00	99.95	100.55	100.32
$n\omega$	1.618[ii]	1.613[ii]	1.613[ii]	1.615	1.6185[iv]
$n\epsilon$	1.611[ii]	1.607[ii]	1.607[ii]		
$n\omega - n\epsilon$	.007	.006	.006		
$n\epsilon - n\omega$				.002[iii]	low[iv]
S.G.	5.93[i]	6.14[i]	6.14[i]	5.7[iii]	5.8[iv]
Optical character	–	–	–	+	+

i. Palache, Berman and Frondel (1951 p. 49).

ii. Geijer (1921 pp. 20 and 21).

iii. Hintze (1915 pp. 2567 and 2568).

iv. Roberts (1945 p. 37).

1. Fluocerite (tysonite), Broddbo. Analyst, Berzelius (Geijer 1921 p. 19). Fluorine calculated from R_2O_3+F-(F=O)=100.

2. Tysonite, Colorado, mean of two analyses by Allen and Comstock (Geijer 1921 p. 19). Fluorine calculated as for 1.

3. Tysonite, Colorado. Analyst Hillebrand (Amer. J. Sci., 1899, 7, p. 52). Rem. is Fe_2O_3 0. 11 and Na_2O 0.30.

4. Fluocerite, Österby. Average of four analyses (Geijer 1921 p. 19).

5. Fluocerite, Uganda. Analyst, W.H. Bennett. Rem. is ThO_2 1.88, SiO_2 0.12, Al_2O_3 0.48, Fe_2O_3 0.32, TiO_2 0.01 and MgO 0.27 (Roberts 1946 p. 32).

It is, therefore, suggested that the name tysonite is retained for the uniaxial negative fluoride (Colorado type), and fluocerite applied to the uniaxial positive material which appears to be an oxyfluoride (Österby type). These names are used in this sense in the textbooks on mineralogy which were published prior to Geijer's work (Dana 1914 pp. 166 and 175; Hintze 1915 pp. 2559 and 2567) and they are also used in the same sense in this paper.

The mineral from Mutue Fides which is described here is regarded as tysonite; its chemical analysis is not convincing but its optical and physical properties, and its X-ray data are in agreement with those of tysonite.

The occurrence of fluocerite (tysonite) in the tin-fields of the Potgietersrus District of Transvaal, is known since 1921 as is indicated by a record of a chemical analysis of fluocerite (tysonite) from the Springbok Flats (Hall 1938 p. 307). The exact source of the analysed sample is not reported but it most probably come from the Mutue Fides tin-deposits. From this locality the mineral came to the notice of Prof. J. Willemse of the University of Pretoria in 1942. At that time he was doing field-work in that area as a member of the staff of the Union Geological Survey. He sent the mineral in for identification and it was identified as fluocerite in the Union Geological Survey Laboratory by Dr. B. Wasserstein (verbal communication). Subsequently Strauss (1954 pp. 84, 98 and 116) reported this mineral from the Zaaiplaats and Groenvlei tin-mines, some 60 miles north-northeast of Mutue Fides.

The crystal structure of fluorides of the tysonite type was first investigated by Oftedal (1929 p. 272) by means of Laue and powder photographs. He determined the cell constants for tysonite as c=7.280 kX, a=4.112 kX and c/a=1.771, but regards this as a "pseudocell", the "real cell" being a tripple hexagonal cell with dimensions c=7.280 kX, a=7.124 kX, and c/a=1.022. The structure was reinvestigated by Schlyter (1952^{ii} p. 73) in 1952. He found no reflections in Weissenberg rotation photographs that would necessitate a larger cell than Oftedal's "pseudocell". In a parallel study (Schlyter 1952^{i} p. 61) he shows that tripositive ions of radii close to that of La^{3+}, namely Ce^{3+}, Pr^{3+}, Nd^{3+}, Y^{3+}, etc., gave fluorides of of the tysonite type and that the ratio c/a is practically constant (=1.772) for all these fluorides. This ratio is in agreement with the axial ratio a:c = 1:1.7736 which was arrived at by Flink (1910 p. 30) from measurements on tysonite from Broddbo.

The unit cell and orientation of Schlyter is accepted throughout in this study.

SOURCE AND DESCRIPTION OF MATERIAL.

The sample investigated was kindly contributed by Prof. Willemse of the University of Pretoria. He collect ed the material from the tin deposits on the farm Mutue Fides 422 in the Potgietersrus District of Transvaal. The farm is situated in the Springbok Flats approximately 40 miles southeast of Potgietersrus. The deposits are of hydrothermal origin and occur in, and are related genetically to, granite of the Bushveld Igneous Complex.

The sample, measuring about 2 x 1½ inches, consists of massive tysonite penetrated by veinlets of bastnaesite and fluorite. Microscopically quartz and hellandite? was also observed.

PHYSICAL AND OPTICAL PROPERTIES.

In hand-specimen the tysonite is dull, yellowish-brown, changing to reddish-brown due to alteration to bastnaesite. In transmitted light it is almost colourless.

Macroscopically cleavage is hardly visible but thin sections show two sets of cleavage: the one parallel to the basal pinacoid (0001) and the other to the first order prism $(10\bar{1}0)$.

No pycnometers of suitable size were available for specific gravity determinations but sufficient accuracy could be obtained by using the apparatus and method described by Hiemstra (1955 p. 276). Air bubbles adhering to the particles were removed by heating the container with the particles and about ¾ of its volume of water under diminished pressure. A close check was kept on the temperature of the distilled water during the determination, and the results were corrected for the density of pure water at 4°C.

The average of three determinations on different portions of material is S.G.$^{24}_{4}$ = 5.943 ± .005. This value is in agreement with that of the Broddbo material (table 2) but, owing to the partial alteration to bastnaesite and probably also to an oxide or oxyfluoride, certainly does not represent the true specific gravity of the tysonite. From a thin section of material similar in colour to that used for specific gravity determination, the amount of alteration product was roughly estimated at 5 per cent by volume. The corrected value for tysonite is S.G.$^{24}_{4}$= 5.995 ± .005, assuming the specific gravity of the alteration product to be 4.97 (S.G. of bastnaesite).

TABLE 2. Physical and optical properties of tysonite.

	Mutue Fides	Colorado	Broddbo
S.G.	5.995 ± .005	6.14[i]	5.93[i]
$n\epsilon_D$	1.608 ± .002	1.607[ii]	1.611[iii]
$n\omega'_D$	1.614 ± .002	1.613[ii]	1.618[iii]
$n\omega_D - n\epsilon_D$	.006	.006	.007
$n\omega_F - n\omega_C$	.011		

i. Palache, Berman and Frondel (1951 p. 49).
ii. As quoted by Geijer (1921 p. 21). Sodium light.
iii. Geijer (1921 p. 20). Sodium light.

The mineral is uniaxial negative. Its refractive indices were determined according to a single variation method at room temperature (23°C). The indices were matched in monochromatic light with those of immersion liquids. For the determination of $n\epsilon$ the grains were brought to the desired orientation on a universal stage. The results obtained are listed in table 2.

TWINNING.

The latest textbooks on mineralogy (Winchell 1951 p. 31 and Palache, Berman and Frondel 1951 p. 48) do not report any evidence on twinning in fluocerite (tysonite). Koechlin, however, reports "Schalenbildung" on the first order pyramid in tysonite from Pike's Peak, Colorado (Hintze 1915 p. 2561) and Weibull polysynthetic twinning in fluocerite from Österby (Hintze 1915 p. 2568). Polysynthetic twinning is common in the Mutue Fides mineral (see plate 1 fig. 1). A study of thin sections on the Fedoroff Universal Stage reveals the following (see fig. 1):

a. The composition-plane occurs in the same zone as the basal pinacoid (i.e. $\tilde{c}$ direction) and the first order prism (10$\bar{1}$0). Accordingly the composition-plane corresponds to a pyramid of the first order.

b. The interfacial angle between (0001) and the composition-plane is 46°C. This value is the average of a series of determinations some of which were carried out with a set of Fedoroff hemispheres having a refractive index (n = 1.648) above those of the mineral, and others with hemispheres having a refractive index (n = 1.554) below those of the mineral. The variation of the measured interfacial angle due to the different hemispheres used is within the limits of experimental error, and the value of 46° is considered to be correct to ± 1°.

From figure 1 it is also obvious that two adjacent lamella can be brought into similar orientation by revolving the one through 180° about the pole to the composition plane. Consequently the pole to the composition-plane

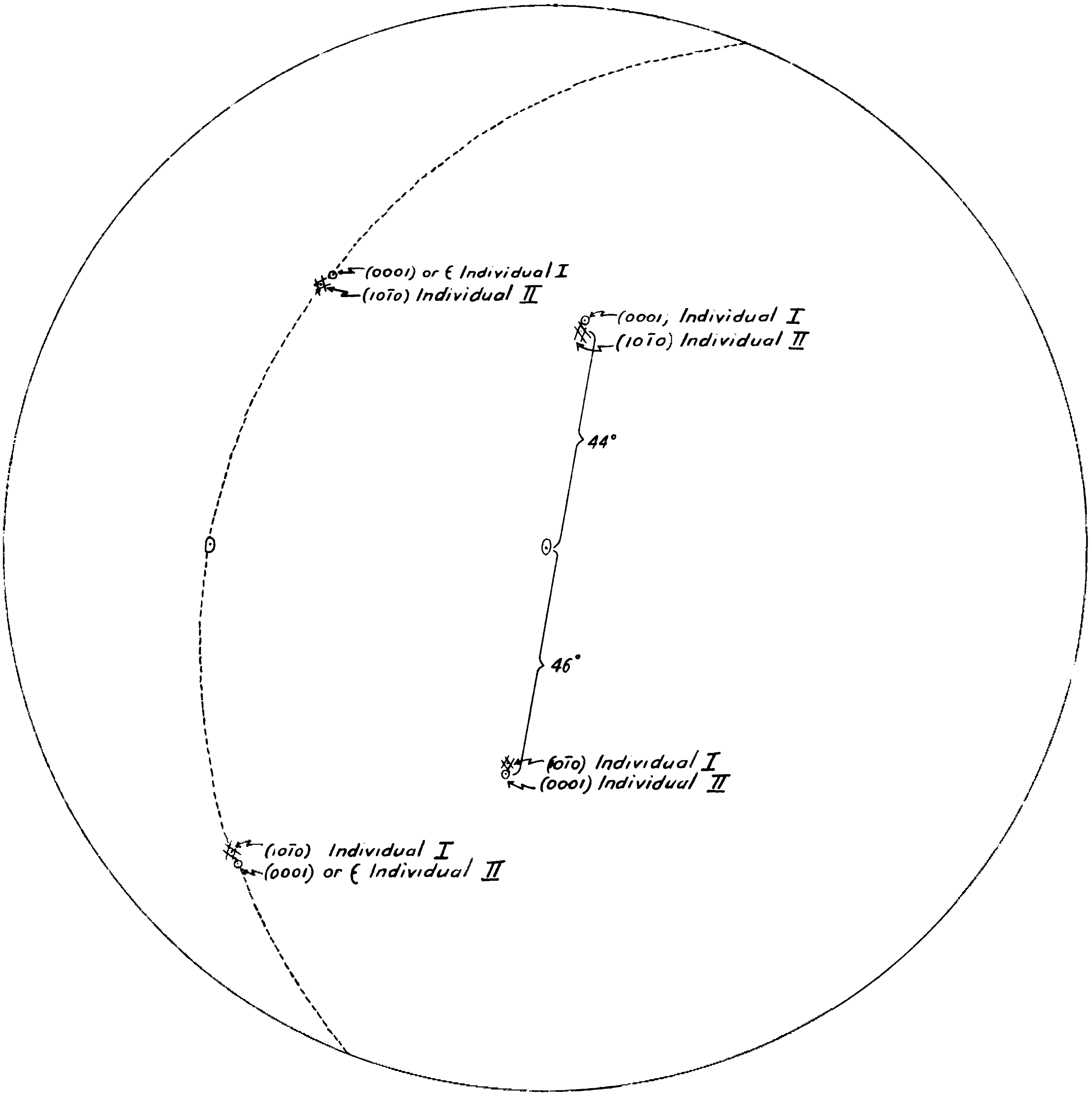


Figure 1. Stereographic projection of polysynthetic twins of tysonite

Red: Original plot Black: Projection on composition-plane
✡ = Pole to cleavage θ = Pole to composition-plane

and the twinning-axis coincide making the composition-plane also the twinning-plane. The Miller indices of the twinning-plane, determined according to the equation: $\tan (0001 \wedge h0\bar{h}l) \times \frac{1}{2}\sqrt{3} = h/l \times c$ (Ford 1932 p. 132), are (1012). The true interfacial angle would be 45°39'.

DETERMINATION OF UNIT-CELL DIMENSIONS.

The X-ray examination of the tysonite was carried out on a Seifert X-ray unit. Powder diffraction photographs were taken with cameras of the Debye-Scherrer type in which the films is mounted according to the method of Straumanis (1949). Unfiltered cobalt-radiation produced at 32 K.V. and 10 ma. was used. The measuring was done and the shrinkage correction determined as described by Wasserstein (1951 p. 106).

The values of θ as listed in table 3 is the average of two photographs. These values were converted to interplanar spacings by using suitable tables. The hkl for each reflection was derived from the indexed $\mathrm{Sin}^2\theta$ values for (i) tysonite from W. Cheyenne Canon, Colorado (Oftedal 1929 p. 273) and (ii) artificial LaF_3 (Schlyter 1952^{ii} p. 74). Both, Schlyter and Oftedal, used copper-radiation and it was therefore necessary to convert their diffraction angles into interplanar spacings so as to allow comparison with the Mutue Fides tysonite. The cell dimensions listed in table 3 were determined from the higher θ values and were corrected for absorption by the extrapolation method according to which the calculated cell dimensions are plotted against $\frac{1}{2}(\mathrm{Cos}^2\theta/\mathrm{Sin}\ \theta.\mathrm{Cos}^2\theta/\theta)$. The unit-cell determinations were facilitated by the fact that the ratio c/a is

TABLE 3. X-ray data of fluocerite.

	1			2		
hkl	Int.(est.)	θ Co rad.	d A	Int.	θ Cu rad.	d A.
101	8	16.34	3.19	s	13.96	3.19
102	½	20.97	2.50	-	-	-
103β	1	23.48		w	20.32	
110	5	25.99	2.04	m	22.01	2.06
103	10	26.55	2.00	s	22.61	2.00
112, 200	5	30.14	1.78	m	25.64	1.78
201	5	31.27	1.73	m	26.43	1.73
203	4	38.60	1.43	s	32.60	1.51
114	3	41.04	1.38	m	34.48	1.36
105	3	41.59	1.35	m+	34.93	1.35
211	2	42.54	1.32	s	35.73	1.32
213β	3	42.70		vw	36.52	
006	-	-	-	vw	39.50	1.21
213	7	49.50	1.177	s	41.04	1.173
106	1	51.21	1.164	w	42.14	1.148
205	7	52.39	1.129	s	43.13	1.127
214	1	55.86	1.08	-	-	-
116	6	58.81	1.046	m+	47.5	1.045
220	1	60.30	1.030	w	48.65	1.026
215 310 222	7	64.77	0.989	s	51.28	0.987
311	6	65.85	0.980	m+	52.03	0.977
313	4	77.29	0.917	-	-	-
216	1	77.84	0.915	-	-	-
203	2	81.76	0.904	-	-	-
a	4.122 ± .005 A			4.120 ± .003 A		
c	7.304 ± .005 A			7.295 ± .007 A		
c/a	1.772			1.771		

1. Tysonite from Mutue Fides. Co radiation. Camera rad. = 114.59 mm.

2. Tysonite from W. Cheyenne Canon, Pike's Peak, Colorado. Cu radiation. Camara radius 57.65 mm. (Oftedal 1929 p. 273) Cell dimensions (Oftedal's "pseudocell") from precision measurements on p. 276. These values have been corrected for wavelengths.

practically constant (1.772) for fluorides of the tysonite type (Schlyter 1952[i] p. 63).

CHEMICAL COMPOSITION.

In contrast to the optical properties of the Mutue Fides mineral the analysis in table 4 column 1 is not in exact agreement with that of tysonite from Colorado and Broddbo (table 1 analyses 1, 2 and 3). It differs in having approximately 2.5 per cent less fluorine and correspondingly more rare earths oxide. Accordingly the analysis corresponds to the formula $R_2O_{0.4}F_{5.2}$ which is in exact agreement with the formula suggested by Bennett for the fluocerite from Uganda. It thus appears that there is chemically no difference between the optically uniaxial negative mineral from Mutue Fides and the uniaxial positive mineral from Uganda. This is apparent rather than real.

The degree of alteration of the Uganda mineral is not given in the literature but the Mutue Fides mineral is partially altered to bastnaesite, the fluocarbonate of the rare earths, and an earthy product. These alteration products made it impossible to obtain pure tysonite for a chemical analysis and the material that was analysed contained at least 5 per cent of this impurity. This conclusion is based on a study of thin sections of material similar to that analysed.

TABLE 4. Chemical analysis of tysonite from Mutue Fides.

	1	2	3
Ce_2O_3	36.31	32.50	35.80
La_2O_3 group	47.50	31.29	34.46
Y_2O_3 group	1.12	12.0	13.22
CaO	nil	6.18	
Fe_2O_3		1.05	1.16
Al_2O_3		0.55	0.61
TiO_2		1.20	1.32
SiO_2		0.33	0.36
CO_2	trace		
F	26.00	24.66	22.55
	110.93	109.76	109.48
-F=O	10.93	10.36	9.48
	100.00	99.40	100.00

Analysis 1 = 87 $(Ce_{0.42}La_{0.56}Y_{0.02})F_3$ (tysonite) +
13 $(Ce_{0.42}La_{0.56}Y_{0.02})_2O_3$

1. Tysonite (partially altered), Mutue Fides 422, Potgietersrus District, Transvaal. Analyst, Abraham Kruger, Division of Chemical Services, Pretoria. HCl used for CO_2 determination. For the interpretation the following atomic weights were used: Ce = 140.13, La = 138.92, Y = 88.92.

2. Fluocerite (tysonite) and fluorite intergrowth from the Springbok Flats, Transvaal. Analysed in 1921 (Hall 1938 p. 307).

3. Analysis 2 after correcting for fluorite and recalculated to 100.

The analysis listed in table 4 is, therefore, not regarded as being the true composition of the tysonite which is believed to correspond to the formula RF_3.

In the analysis, only traces of CO_2 are recorded meaning that only a portion of the alteration product can be bastnaesite. The analyst agreed that the CO_2 content could be as much as 0.5 percent which is approximately equivalent to 2.5 per cent bastnaesite. This leads to the conclusion that the earthy material is probably an oxyfluoride or oxide of the rare earth metals involved (see discussion on the alteration).

The uncertain nature of the earthy alteration product made it impossible to calculate the true composition of the tysonite.

The analysis that was carried out in 1921 on an intergrowth of fluocerite (tysonite) and fluorite from the Springbok Flats in Transvaal is listed in column 2 of table 4. The exact locality of the material submitted for this analysis is unfortunately not known but it is fairly certain that the mineral came from Mutue Fides; this deposit is situated in the Springbok Flats and is the only deposit in that area in which tysonite is known to occur. Moreover a geological report on the Mutue Fides deposits was published in 1921 suggesting that a geological investigation of the deposits was carried out at about the same time as this analysis was made.

This analysis, after correcting for fluorite and neglecting the small amounts of Al_2O_3, TiO_2, Fe_2O_3 and SiO_2, reflects less fluorine than the new analysis of the Mutue Fides material and corresponds to the formula $R_2O_{0.8}F_{4.4}$. The deficiency of fluorine in the corrected analysis can be due to the fact that in making the correction for fluorite impurities, all the CaO was relegated to fluorite (CaF_2) whereas part of it, and even a part of the rare earth metals, may be derived, as the Al_2O_3, TiO_2, etc. from other mineral impurities, such as

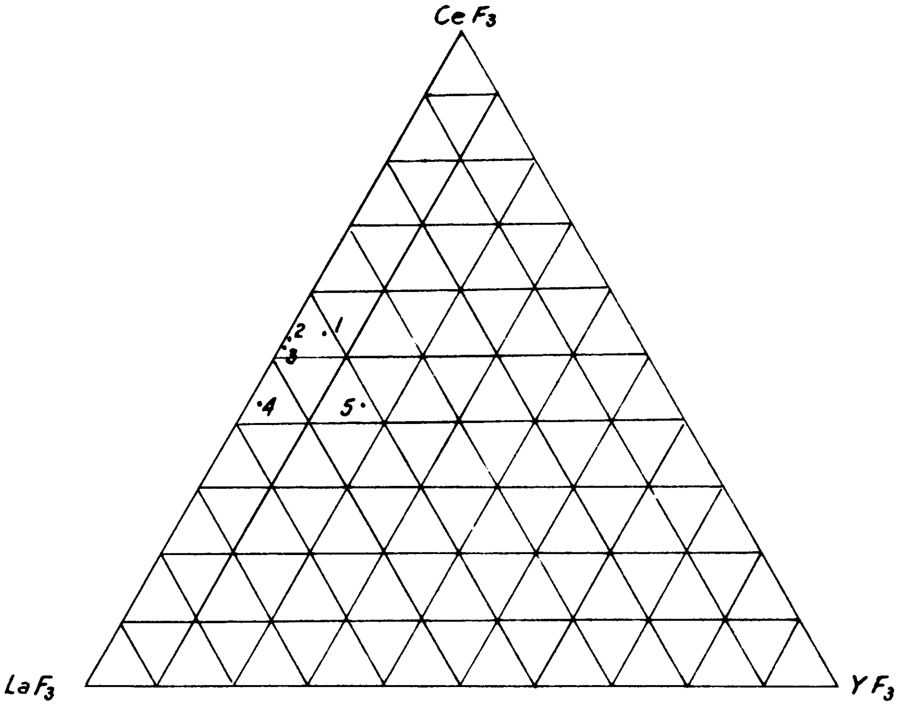


Fig. 2. Variation in the proportion of CeF_3, LaF_3, and YF_3 in tysonite and fluocerite.

1. Fluocerite, Österby (analysis 4 in table 1)
2. Tysonite, Colorado (" 3 " " 1)
3. Fluocerite, Uganda (" 5 " " 1)
4. Tysonite, Mutue Fides (" 1 " " 4)
5. Fluocerite?, Springbok Flats (analysis 3 in table 4)

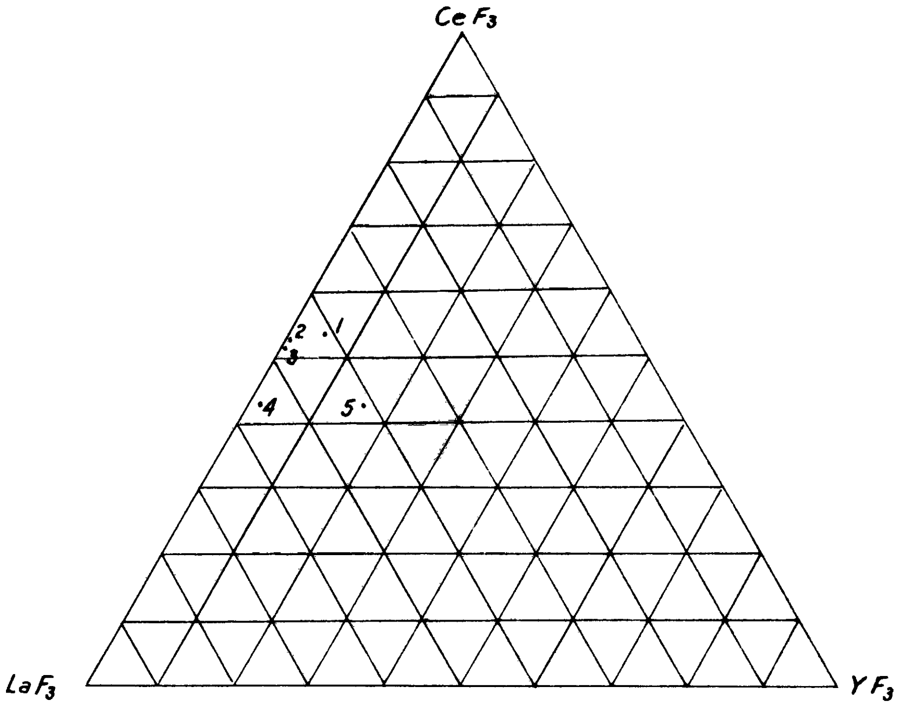


Fig. 2. Variation in the proportion of CeF_3, LaF_3, and YF_3 in tysonite and fluocerite.

1. Fluocerite, Österby (analysis 4 in table 1)
2. Tysonite, Colorado (" 3 " " 1)
3. Fluocerite, Uganda (" 5 " " 1)
4. Tysonite, Mutue Fides (" 1 " " 4)
5. Fluocerite?, Springbok Flats (analysis 3 in table 4)

titano-silicates of Ca and the rare earths. On the other hand it can be an analysis of a true oxyfluoride from another locality than Mutue Fides, or it is also possible that both, the oxyfluoride and the fluoride, occur in the same deposit, the former being an oxidation product of the latter.

A further point of interest in the 1921 analysis is the high percentage of Y_2O_3 (12.0 per cent). This oxide is not reported in the analysis of tysonite from Colorado. That from Broddbo and Mutue Fides contains 1.12 per cent Y_2O_3, the fluocerite from Österby 3.96 per cent and that from Uganda 0.13 per cent.

For comparative purposes the various chemical analyses of fluocerite and tysonite were recalculated in terms of CeF_3, LaF_3 and YF_3. The results are given diagrammatically in figure 2. It is obvious that the relative proportions of CeF_3, LaF_3 and YF_3 are approximately the same in the tysonite from Colorado and the fluocerite from Uganda (analysis 2 and 3 in figure 2). The Österby mineral (analysis 1) has a CeF_3 content more or less similar to that of the minerals from Uganda and Colorado but a lower LaF_3 and correspondingly a higher YF_3 content. The CeF_3 content of the Mutue Fides and the Springbok Flats material (analysis 4 and 5) is almost identical but are much lower than that of the Colorado, Uganda and Österby material, and LaF_3 + YF_3 correspondingly higher.

The cerium content is thus also in favour of the suggestion that the Springbok Flats mineral was collected at Mutue Fides, but the high percentage of yttrium in the Springbok Flats mineral suggests the opposite. The determination of Y_2O_3, however, involves a series of pricipitations so as to obtain the yttrium earths free from the lanthanum earths and the author is of opinion that the abnormal Y_2O_3 content of the Springbok Flats mineral is due to an incomplete separation of Y_2O_3 and La_2O_3.

The substitution of one tripositive rare earth ion by another is also prominent in the analyses of bastnaesite (see figure 3), and the fact that the optical and physical properties of the minerals concerned are not effected markedly is explained by the close similarity in the ionic radii of the tripositive rare earth ions (Ce^{3+} = 1.18kX, La^{3+} = 1.22kX, and Y^{3+} = 1.06kX). Furthermore the atomic weight of La (138.92) and Ce (140.13) is very much the same. That of Y (88.92) is much lower but the only mineral of the group under discussion in which this element appears to be present in quantity, is one of which the optical properties are not known, viz. the mineral from the Springbok Flats (1921 analysis).

Schlyter (1952^i p. 61) shows experimentally that a complete range can exist from CeF_3 to LaE_3 without a change in the crystal structure, and that Y^{3+} can replace La^{3+} up to Y/Y ± La = 0.65, also without a change in the crystal structure.

ALTERATION.

The characteristic replacement of tysonite by bastnaesite and an opaque earthy product is visible in every thin section of the Mutue Fides mineral. Even portions that appear macroscopically unaltered are microscopically seen to be altered. The replacement often proceeds along cleavage cracks and twinning-planes and in an advanced stage of alteration the tysonite occurs as islands in bastnaesite (plate 1 figure 2).

The optical orientation of the bastnaesite replacing the tysonite is usually, but not always, identical to that of the host mineral. In some sections bastnaesite cuts across the twinning lamellae of tysonite without being influenced by the twinning. In such cases the optical orientation of the bastnaesite corresponds to that of one set of lamellae.

This optically orientated pseudomorphs of bastnaesite after tysonite has been described by Oftedal (1931 p. 466) who ascribes the phenomenon to a similarity in the crystal structure of the two minerals.

Hidden suggests that the earthy product contains some lanthanite, $(La,Ce)_2(CO_3)_3.8H_2O$, and Geijer that it is a hydrate of cerium (Geijer 1921 p. 21). Some of this earthy matter from material from Mutue Fides was removed from thin sections for an X-ray examination. The material produced a weaker but exactly similar pattern to that of bastnaesite, without any additional reflection (plate II fig. 1). This weaker pattern may indicate a lower crystallinity for the earthy material and it can thus be argued that the material is bastnaesite in a metamict state but Geiger counter tests and outoradiographs prove that radio-active material is absent in the sample investigated. Furthermore, the sample submitted for a chemical analysis contained at least 5 per cent alteration products but the analysis indicates only traces of CO_2 meaning that only a portion of the alteration product is in fact bastnaesite. This leads to the conclusion that the earthy product consists of bastnaesite, which is responsible for the X-ray pattern, and an oxide or oxyfluoride of the rare earth metals and that the oxidised material does not yield X-ray diffraction lines owing to it being in a cryptocrystalline or even amorphous state.

In thin sections of the most altered portions of the sample investigated, clear colourless bastnaesite is seen to be the principal alteration product whereas the earthy matter predominates in the least altered portions. Furthermore it was noticed that the earthy material occurs along the contact between bastnaesite and tysonite. This led the author to the conclusion that the earthy matter is an intermediate state between tysonite and bastnaesite suggesting that the former is first oxidised and thereafter carbonatised.

The alteration of tysonite is due to the higher affinity of fluorine for calcium than for the rare earth metals, and the formation of bastnaesite is probably brought about by a reaction between tysonite and hydrothermal solutions rich in CO_2, CaO, etc. Accordingly the oxidation of tysonite into fluocerite may result if there is a deficiency of CO_2 and an excess of oxygen. The oxyfluorides from Uganda and Österby are possibly products of oxidation.

MINERALS ASSOCIATED WITH TYSONITE.

Bastnaesite.

In hand-specimen the bastnaesite occurs as veinlets penetrating the tysonite. The colour of this mineral is brown and its lustre greasy. It exhibits a perfect parting on (0001). The lustre on the parting-plane is pearly.

Under the microscope it is seen to replace tysonite (plate 1 fig. 2), the two minerals being optically orientated in parallel position. The largest grains of the bastnaesite are often composed of slightly diverging basal cleavage plates, a phenomenon also noticed by Geijer (1920 p. 11) in bastnaesite from Bastnäs.

The optical and physical properties of the bastnaesite from Mutue Fides agree closely with those of bastnaesite from other localities (table 5) and its X-ray diffraction spacings are almost in exact agreement with those of bastnaesite from W. Cheyenne Canon, Pike's Peak, Colorado (table 6).

TABLE 5. Optical and physical properties of bastnaesite from Mutue Fides and other localities.

	1	2	3	4	5
$n\omega$	1.717	1.716	1.717	1.718	1.716
$n\epsilon$	1.818	1.817	1.818	1.819	1.816
$n\epsilon - n\omega$	.101	.101	.101	.101	.100
S.G.	5.12-5.20		4.948	4.99	4.965±.005

	Locality.	Reference.
1.	Pike's Peak, Colorado.	Glass and Smalley (1945).
2.	Jamestown, Colorado.	Glass and Smalley (1945).
3.	Madagascar.	Glass and Smalley (1945).
4.	Gallinas Mts., New Mexico.	Glass and Smalley (1945).
5.	Mutue Fides. Refractive indices for Na light at 23°C. For the determination of the specific gravity the same method and apparatus as for the determination of the specific gravity of tysonite were used.	

TABLE 6. X-ray powder diffraction spacings of bastnaesite.

1		2	
Int. (est.)	d A	Int.	d A
1	4.73	-	-
8	3.49	6	3.54
9	2.83	9	2.85
½	2.41	2n	2.39
8	2.04	9	2.04
5	2.00	8	2.00
8	1.88	9	1.88
3	1.77	7n	1.76
7	1.66	9	1.66
4	1.56	7	1.56
3	1.47	7	1.47
5	1.43	8	1.44
5	1.34	6	1.34
10	1.30	10	1.29
4	1.28	7	1.27
8	1.178	7n	1.19
-	-	7b	1.17
8	1.153	7	1.15
7	1.067		
7	1.038		
8	1.007		
6	0.988		
8	0.968		
5	0.960		
6	0.947		
7	0.917		

1. Bastnaesite from Mutue Fides. Co radiation.

2. Bastnaesite from W. Cheyenne Canon, Colorado. Cu radiation. Oftedal (1930 pp. 240 and 241). A.S.T.M. cards No. 2-4010.

222/203

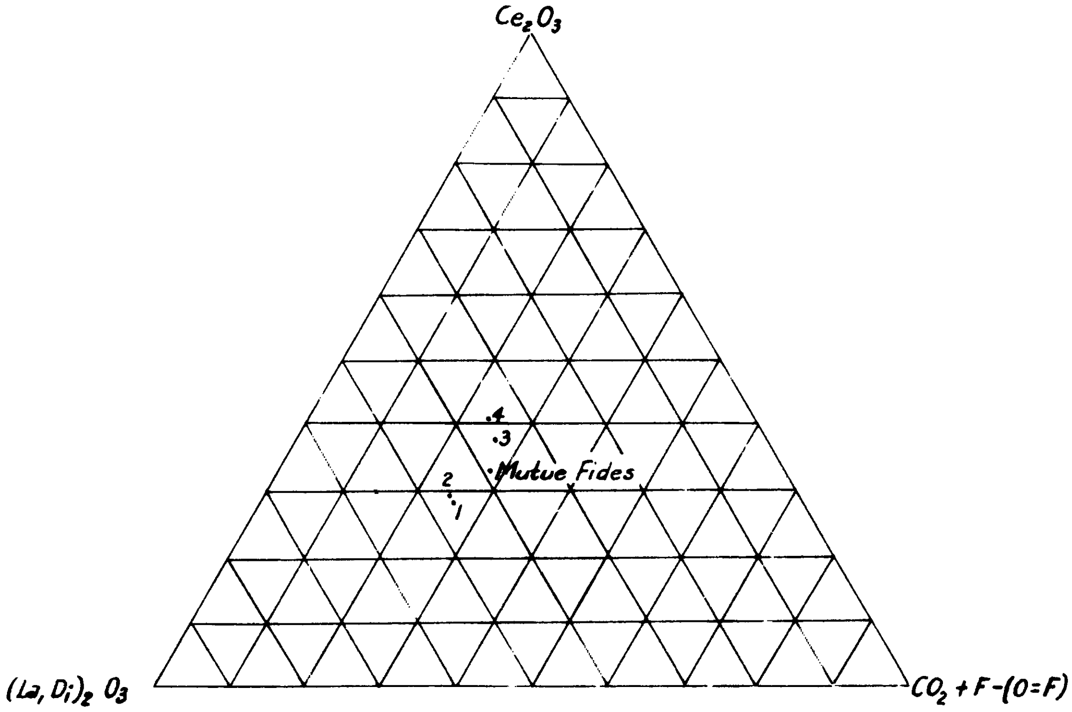
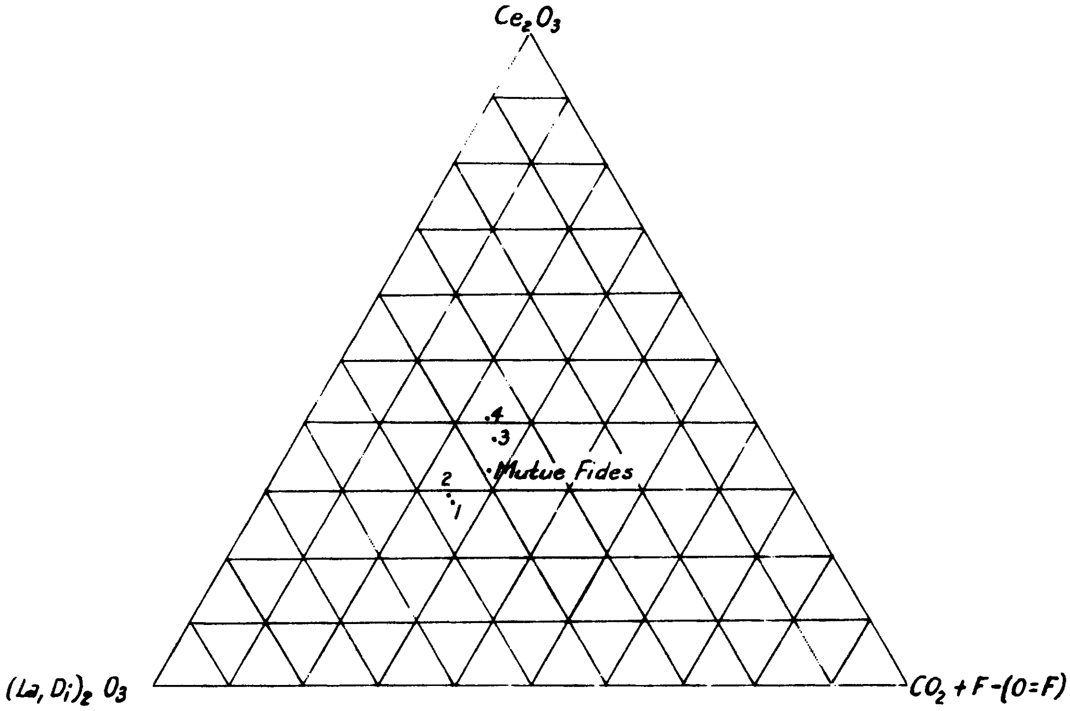


Figure 3. Variations in the chemical composition of bastnaesite

Nº	Locality	Reference
1.	Bastnas, Sweden	Glass and Smalley (1945 p.611 analysis 2)
2.	Bastnas, Sweden	" " " (" " " 3)
3.	Cheyenne Mt, Pike's Peak, Colorado	" " " (" " " 5)
4.	Ambositra, Madagascar.	" " " (" " " 6)



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4.	Ambositra, Madagascar.	" " " (" " " 6)

The chemical analysis of this mineral is listed in table 7. A spectrographic analysis on a portion of the material that was submitted for the chemical analysis, shows, in addition to the elements determined chemically, some Ca and traces of Ge, Mg, Si, and Fe. The remains of 4.91 per cent (table 7 column 1) are, therefore, considered to be mainly CaO derived from fluorite impurities in the bastnaesite. Relegating the CaO to fluorite the sample analysed had the following mineral composition:

Bastnaesite	93.16%
Fluorite	6.84%

The composition of the bastnaesite after deducting for fluorite and recalculating to 100, is shown in column 2 of table 7.

From the work of Glass and Smalley (1945) on bastnaesite it follows that in various chemical analyses of this mineral "The combined percentages of the cerium groups, where the greatest difference might occur, vary from 73.59% to 76.80%, with a difference of 3.21%; CO_2 from 19.11% to 20.20%, with a difference of 1.09%; and F from 5.23% to 7.83%, with a difference of 2.60%" (p. 612). In the analyses compiled by Glass and Smalley the ratio $Ce_2O_3/(La,Di)_2O_3$ varies from 0.622 to 1.116 (fig. 3).

The fluorine content and the ratio $Ce_2O_3/(La,Di)_2O_3$ of the Mutue Fides mineral fall within the limits of variation given by Glass and Smalley but the CO_2 content is 3.4% higher than the highest value given by them for CO_2 and the total percentage of rare earths correspondingly lower. The most probable explanation for this high CO_2 content is that the loss on ignition (method used for CO_2 determination) consisted of CO_2 and some fluorine. The remains of 4.91% should, therefore, in fact be higher in the original analysis (table 7 column 1) thus indicating a higher percentage of fluorite impurities in the analysed sample and accordingly a higher percentage of rare earths in the recalculated analysis of the bastnaesite (table 7 column 2). Another explanation is that the bastnaesite of Mutue Fides might be accompanied by small quantities of synchisite, (Ce,La)(CO_3)F.$CaCO_3$, or parisite, 2(Ce,La) (CO_3)F.$CaCO_3$. This could not be confirmed by a study of thin sections because the colour and birefringence of these three minerals (bastnaesite, synchisite, and parisite) are so much the same that synchisite and parasite can easily be missed when present in small quantities in bastnaesite.

Parisite has been identified by Söhnge (1945 p. 176) in the tin-deposits of Zaaiplaats which are genetically related to that of Mutue Fides. According to Palache, Berman, and Frondel (1951 p. 288) the mineral from Zaaiplaats is in fact synchisite.

TABLE 7. Analysis of bastnaesite.

	1	Interpretation		2
		Fluorite	Bastnaesite	
Ce_2O_3	30.52	-	30.52	32.76
(Sa,Di)$_2O_3$+ Y_2O_3 group	37.20	-	37.20	39.93
F	9.31	3.33	5.98	6.42
CO_2 (ignition loss)	21.98	-	21.98	23.59
H_2O-	nil	-	nil	nil
P_2O_5	nil	-	nil	nil
Rem. = CaO ?	4.91	4.91	-	-
	103.92	8.24	95.68	102.70
-F=O	3.92	1.40	2.52	2.70
	100.00	6.84%	93.16%	100.00

1. Bastnaesite, Mutue Fides 422, Potgietersrus District, Transvaal. Analyst, C.J. Liebenberg, Division of Chemical Services, Pretoria. Analysed in 1944. Remains are considered as CaO derived from fluorite impurities in the analysed sample.
2. 1 corrected for fluorite and recalculated to 100.

Fluorite.

This mineral, as the bastnaesite, occurs as veinlets in tysonite. Microscopically it was found to be more abundant in and near bastnaesite than in tysonite. It appears to be younger than both bastnaesite and tysonite, and occasionally occurs as thin lamellae interbedded with bastnaesite along the basal cleavage planes of the latter (plate II fig. 2).

The colour of the fluorite varies from purplish to greenish and colourless. On account of its association this mineral was first thought to be an yttrian or cerian variety but the following properties indicate a normal fluorite: S.G. $\frac{22}{4}$ = 3.17 ± .01.

n = 1.4351 (Na light at 23°C - Method of minimum deviation).

a_o = 5.4630 ± .0005 A at 25°C.

A spectrographic analysis reveals traces of Fe, Mg, Sr, Al, La, Y?, Ce, and Si. These impurities are, however, common in most fluorites.

Hellandite?

A few minute grains, at places veinlike, of a brownish-red mineral were noticed in thin sections of the tysonite. The largest grain encountered in eight thin sections has a diameter of 0.1 mm. only, and an attempt to lift some of the grains from a thin section for refractive index determination or for X-ray investigation was unsuccessful. The identification is, therefore, only based on the colour, the anisotropic character, the absence of pleochroism, the biaxial (2V large) positive character of the grains, and on the mineral association. The refractive indices are slightly higher than those of tysonite.

Hellandite is a silicate chiefly of calcium, rare earths, aluminium, and iron and was originally reported from a pegmatite near Kragero in Norway (Winchell 1951 p. 518). This mineral was also tentatively identified by Strauss (1954 p. 157) in the tin-bearing breccia lodes on Welgelegen 357, in the Zaaiplaats Tin Mining Area.

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PLATE 1.

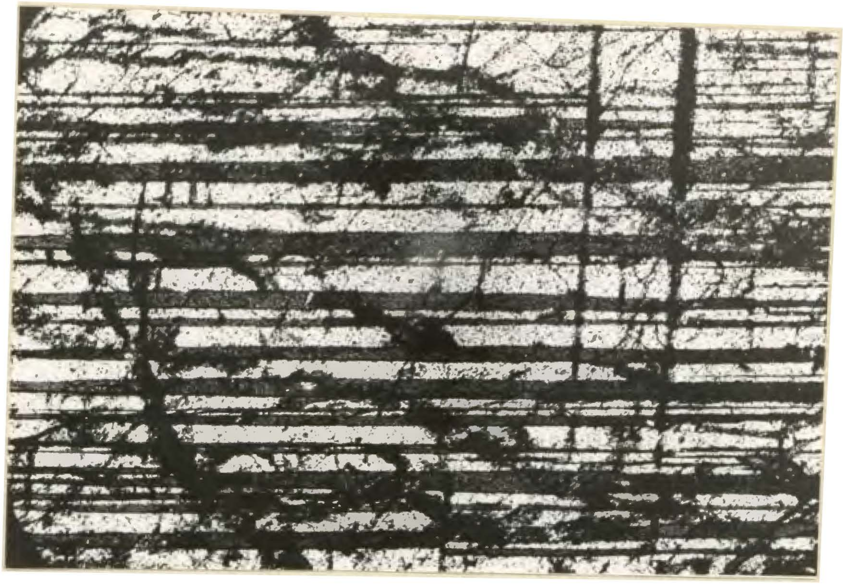

Fig. 1. Polysynthetic twinning in tysonite from Mutue Fides ($10\bar{1}2$ composition-plane - in this case two directions intersect almost at right angles). Crossed nicols. Magnification X42. Thin section No. 20048.

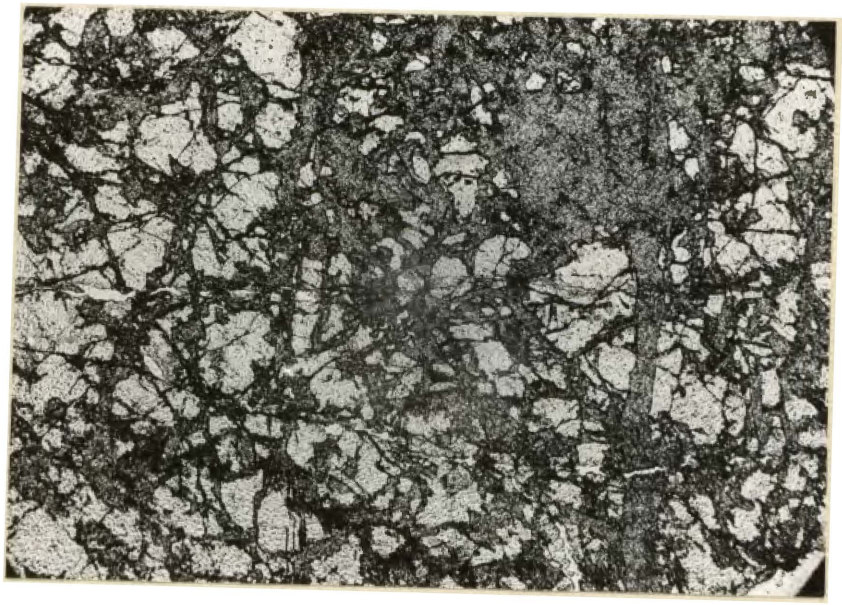

Fig. 2. Remnants of tysonite (light) in bastnaesite (dark). Magnification X42. Thin section No. 20047.

PLATE II.

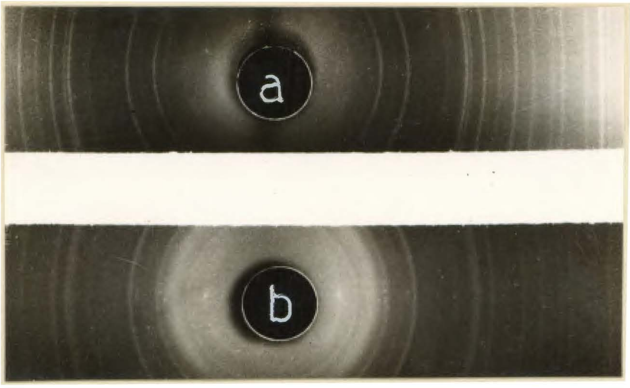

Fig. 1. X-ray diffraction patterns, front reflections only.
Co radiation. Camera radius = 57.3 mm.

a. Bastnaesite.
b. Earthy alteration product of tysonite, Mutue Fides.

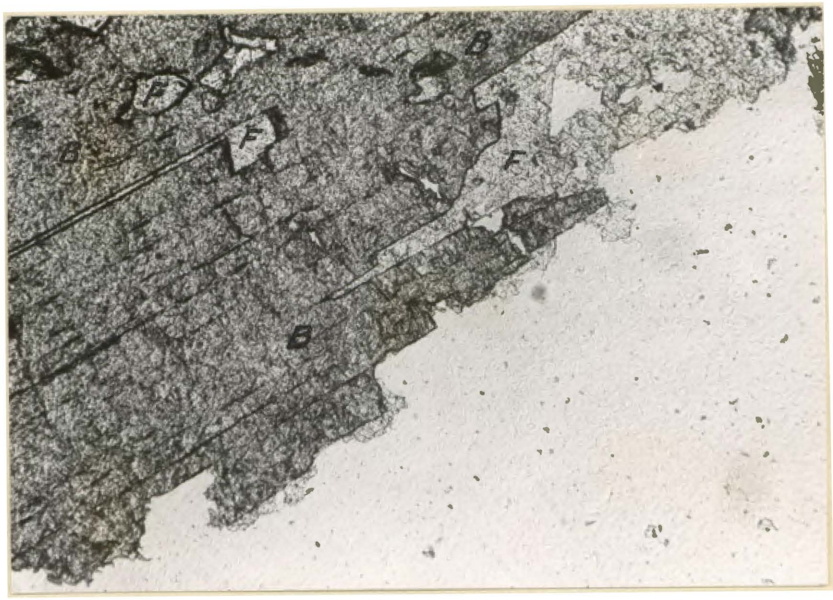

Fig. 2. Fluorite (F) replacing bastnaesite (B), along the basal cleavage planes.
Thin section No. 20048. Magnification X64.
Photograph by S.A. Hiemstra.

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