The Tin-Bearing Pegmatites of the Erongo Area, South-West Africa.

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[Plate VI.]

Introduction.

In South-West Africa an extensive tract of country situated in the north-western portion of Damaraland and of which the Erongo mountains form the dominant morphological feature is generally referred to as the "Erongo Tinfields." Cassiterite was first discovered here in the north-western portion of the Omaruru division in the year 1909. In the following year considerable deposits, mainly of an eluvial nature, were found on the farm Ameib, about 18 miles north-west of Karibib, and situated immediately below the imposing southern escarpment of the Erongo mountains amid an unrivalled wealth of magnificent granite scenery. Owing to the promising nature of these fields, extensive prospecting operations were carried on, and to-day the tin-bearing area has been shown to extend from south-east of Karibib to beyond the Brandberg and Ugab as far as the southern portion of the Koakoveld, a distance of approximately 140 miles. The exact limits of the fields have, however, not yet been defined.

Within the area so far investigated the tin-bearing pegmatites are found to occur along three well-defined main belts. The orientation of these belts is determined by the general and local strike of the ancient sediments and the contacts of the intruded old granites. Beginning in the north-west what may be referred to as the *Northern Belt* begins with profuse development of pegmatites around Uis, and from here continues westwards over a distance of about 25 miles to Ploeger's claims south of the Brandberg. The exact distance of its further extension westwards towards the sea is unknown.

The Great Central Belt along the Omaruru River commences on the lower course of this river west of Neineis and then continues over Nobgams, Humdegams, Tsomtsaub, Paukwab, the Thelma Mine and Kohero as far east as the western slopes of the Kompaneno mountains, north-west of Omaruru township, a total distance of about 60 miles. This belt comprises some of the most important tin-occurrences of the whole fields.

The Great Southern Belt commences in the west a short distance north of Ebony, and then continues past Sandamab, between Usakos and the Great Spitzkopje, to the south-western corner of the Erongo, fringes the foot of its southern escarpment, crosses the Khan River a few miles north of Karibib, and then continues along the banks of this river as a continuous belt as far as Otjimboyo and Otjakatjongo, 30 miles east of Karibib. The total length of this belt is approximately 80 miles. Near the south-western corner of the Erongo this great belt sends off a subsidiary branch along the slopes of the western escarpment of these mountains, while another subsidiary belt leaves the main belt near the confluence of the Khan and Etiro rivers and undergoes its main development on Erongo-Kanona below the T.P. Erongo.

It was the investigation of these tin-deposits, from which during the past ten years there have been produced 2,100 tons of concentrates of an average content of over 70 per cent. SnO_2, which formed the main objective of the geological survey of this area. The following paper is mainly intended as a brief summary of the results obtained and the conclusions arrived at.

Before entering on the discussion of the tin-bearing pegmatites a short table of the general geology of the area will be given in order to show the relationship of the pegmatites to the great variety of intruded granites. For further details concerning the general geology reference should be made to the previous paper on this area.[1]

TABLE OF THE GENERAL GEOLOGY.

Sediments:—	
Surface Deposits	Windblown sand. Rock debris accumulated under arid conditions. Gravel and boulder terraces of the Namib Kalahari Limestone.
Sediments of the Erongo, Brandberg and Otjongundu Plateau	Shales and mudstones. Felspathic sandstones. Arkoses, grits and conglomerates.
Schist Formation	Mica schists. Marbles and amphibolites. Quartzites and mica schists.
Igneous Rocks.	
The Erongo Granite.	
Igneous rocks of the Erongo Succession	Porphyry tuff. Dykes and flows of acid porphyrites and quartz porphyry. Dykes of diorite porphyrite and granite porphyry. Stocks of diorite and granodiorite. Basic tuffs. Dykes and flows of augite porphyrite. Dykes and flows of melaphyre, frequently amygdaloidal. Dykes of ophitic diabase and dolerite.
Old Granites	Pegmatitic granite. Aplitic granite. Non-porphyritic Salem granite. Red Salem granite. Salem granite. Gneiss-granite.

[1] "The Geology of North-Western Damaraland in South-West Africa," Gevers and Frommurze, *Trans. Geol. Soc. S.A.*, Vol. XXXII, 1929.

TECTONICS.

The ancient sediments of the Schist Formation and of the Fundamental Complex in general have everywhere been intensely folded. The general strike of the sediments is N.E.-S.W., but this greatly varies locally. The folding has taken place on very complex lines and exhibits the powerful influence of multilateral stresses. Dome-like structures are as a result very common. The southern limbs of structural elements almost invariably possess a steeper dip than the northern. Actual overfolding is very common and invariably directed from the south-east or south to the north-west or north. The main lateral stress therefore came from the south-east and south.

The intrusion of the old granites has generally taken place on conformable lines. The contacts are predominantly concordant and the bodies of granite in the area under discussion generally phacolithic in nature. Very frequently the granites fill synclinal structures or form the cores of anticlines and dome-structures. The strips of sediments, usually schists separating granite massifs, are frequently very narrow, and their strike determines the strike and alignment of the various tin-bearing belts.

From this it would appear that the vast crustal invasion which began with the intrusion of the Salem granite, and culminated in the injection of innumerable pegmatites, took place while the folding movements were still in active progress. There have been at least two periods of folding: one still active while the old granites and associated pegmatites were intruded, and a later upheaval subsequent to their intrusion, and to the deposition of the sediments of the unconformably overlying Phyllite formation. A long period of time therefore separates these two periods of intense folding.

The very much more youthful sediments of the Erongo, Brandberg, Otjongundu Plateau, etc., and the Waterberg sediments of Upper Karroo age, with which the former sediments are most probably approximately contemporaneous, have not suffered any appreciable folding beyond faulting and warping on a considerable scale.

THE PEGMATITES.

A great variety of different pegmatites is met with in this part of South-West Africa.[2]

The bulk of these may be divided into two groups: *Tourmaline pegmatites* and *tin-bearing pegmatites*.

Mode of Occurrence and Distribution of the Pegmatites.—As has been stated already, the old granites and associated pegmatites were intruded while the folding of the ancient sediments was in active

[2] Reuning, E.: "Pegmatite und Pegmatitmineralien in S.-W.A.," *Zeitschr. für Krystallogr., etc.*, Vol. LVIII, 1924.

progress. It is also to be expected therefore that the pegmatites exhibit a very definite relationship to the structural plan of the sediments.

While there is a great number of pegmatites in the parent granite bodies themselves, particularly in their marginal portions, they attain their greatest development in the enveloping schists. Usually they are most abundant in the neighbourhood of the granite contact. It is a noteworthy fact that pegmatites are rare in the crystalline limestones so abundantly distributed over the whole tin-bearing area, even when these are in direct contact with the parent granite. The latter also very seldom break through these apparently highly rigid rocks. Within the schists they occur in distinct groups, and the presence of these can usually be ascribed to one or more structural features.

Numerous bodies of granite, phacolithic in nature, occupy positions marked by a very powerful torsion of the schists, the space occupied by the granite having mainly been formed by differential movements along the bedding planes of the sediments. The contact in the inner arc of compression is frequently characterized by a crumpling of the sediments and generally an absence of pegmatites, while the outer arc of tension is very generally accompanied by extensive disruption of the sediments (schists) and a consequent abundance of oriented xenoliths in the marginal portions of the granite. In addition there is generally also a profusion of pegmatites in the region of the outer arc. This feature is very general and grouping of pegmatites is more apparent where the schists exhibit bends. Differential movements along the bedding planes in zones of tension evidently greatly aided the magma in its upward ascent. Where the schists straighten out again, the pegmatites usually become much less abundant and even completely disappear. An intricate net-work of dykes is almost invariably connected with bending movements in the schist frame.

Other factors favouring the intrusion of dykes are connected with the close neighbourhood of two or more granite-bodies separated by a schist frame of only narrow width. Such a strip of schists is then usually intensely invaded by dykes. Also where such a strip of schists is suddenly cut off across its strike by an occasional discordant granite contact, the number of dykes increases considerably. In the latter case all the bedding planes and planes of schistosity lay directly open for attack by the magma, and the ease with which the latter could effect penetration of the schists was as a result materially enhanced.

It is also a noticeable fact that pegmatite dykes are usually very much more abundant at localities where the dip of the schists is steep than at places where this is low, as, for instance, the curving terminal portions of pitching anticlines and domes. Evidently the great weight of the overlying rocks rendered penetration by the magma very much more difficult where the dips were low than in cases where penetration merely entailed the lateral forcing apart of sediments, particularly since in its effort to effect this the magma was greatly aided by differential movements along the steeper bedding planes.

By far the greatest number of dykes are conformable strike-dykes, *i.e.*, parallel to the strike and dip of the schists. In the area immediately south-west and west of the Erongo of the 1,710 pegmatite dykes that were noted and of which directions of strike were measured, 79 per cent. were oriented parallel, 13 per cent. at right angles, and 8 per cent. at diagonal and oblique angles to the strike of the schists.

While the majority of dykes, whether strike, cross or diagonal dykes, in any one area show no differentiation with regard to their respective ages, it is a noteworthy fact, that dykes obviously somewhat later and cutting parallel dykes are usually cross or oblique dykes. This fact indicates that after the first injections the sedimentary frame had already become somewhat consolidated by the folding and presence of the congealed granites and pegmatites and that the lines of smallest resistance and easiest penetration had already been occupied. The later magma was therefore obliged to follow joints and fissures across the strike of the sediments.

The thickness of the pegmatite dykes varies from a few inches to 50 feet and more. Their thickness usually decreases with the distance from the granite-contact. The height within the schist frame to which the pegmatites have been intruded naturally varies greatly.

The shape and behaviour of the individual dykes also vary greatly; some are folded, others undulate in the horizontal plane and jump from bedding plane to bedding plane, both horizontally and vertically. Others possess numerous constrictions and exhibit the pinch-and-swell structure.

The Relationship of Pegmatites and Aplites.—Heldring, in his article on the Tin-Fields of South-West Africa, makes the statement, "that the pegmatite changes into aplite, and this again into quartz with increasing vertical or lateral distance from the ejecting centre.[3] Where true pegmatite-reefs cut quartz-reefs, there is no doubt that the former have originated from a higher horizon than the latter." The available field-evidence, however, does not support this view. On the contrary, pegmatites, aplites and bodies of pegmatitic quartz have been found occurring together in the same locality, both near and further away from granite-contacts and giving no indication of a gradual transition from pegmatite over aplite to quartz. In these cases no assumptions with regard to theoretical horizons and distance from the ejecting centre could account for their irregular and closely neighbouring occurrence. In addition, numerous bodies of pegmatitic quartz were found to be intrusive into ordinary pegmatite and to belong to a definitely later period of intrusion. Finally, wherever observed, as, for instance, on Paukwab and Erongo-Kanona and numerous other localities, the aplites, frequently present in great abundance, were invariably found to be cut and faulted by the pegmatites and, therefore, to belong to an earlier phase of injection.

[3] Heldring, O. G.: "Some Notes on the Tinfields of S.W.A.," *Mining Journal*, Vol. CLXI, Nos. 4837-4841.

It must be concluded, therefore, that in our case the aplites generally belong to an earlier phase of magmatic differentiation preceding the injection of typical pegmatites. They consist almost entirely of felspar and quartz, a large proportion of these minerals in graphic intergrowth, and pneumatolytic activity is generally still very restricted, though black iron-tourmaline, muscovite, and even occasional grains of cassiterite are found in them. These features, coupled with the fact that pegmatitic quartz was very generally intrusive and therefore later than the ordinary pegmatite, and the results obtained by Wright and Larsen[4] with regard to the different temperatures of crystallization of the quartz found in pegmatites, suggest that the theory of eutectic residues, mainly advocated by Vogt, possesses in many instances only a restricted application.

Tourmaline-Pegmatites.

The basis of these and the tin-bearing pegmatites is a coarse-grained pegmatitic rock consisting almost entirely of felspar (orthoclase, microcline, albite and perthitic intergrowths of albite and orthoclase) and quartz, a large proportion of these minerals usually in graphic intergrowth. The felspar when fresh is generally of a pure white colour, pegmatites of this type possessing red felspars being very subordinate.

Black iron-tourmaline (schorl), frequently in large well-formed crystals, is the characteristic mineral of the non-tin-bearing varieties of the pegmatites. Almost invariably it is found to be a product of replacement both of the felspar and quartz present. Tourmaline-crystals containing an irregular central core of unreplaced quartz are common.

The replacement of the felspars by tourmaline usually follows the cleavage of the felspars. Very frequently it is almost complete, particularly along joint-fissures in granite and pegmatite, with the production of an intimate intergrowth of quartz and black tourmaline. Occasionally distributed throughout the whole dyke-rock, it usually is more abundant in and even restricted to distinct bands of replacement, very commonly in the marginal portions of the dykes. Along the walls of the dykes it is common for the crystals to be arranged with their axis of elongation at right angles to the walls. If muscovite accompanies the tourmaline, it is seldom in large quantities. At Paukwab, tourmaline-bearing pegmatites occasionally carry biotite. At this locality black tourmaline is also directly associated with cassiterite.

Tourmaline pegmatites are most numerous in the parent granite and in the neighbourhood of the granite contacts, where they frequently occupy a definite zone of varying width. Further away from the contacts the tourmaline (schorl) is often almost entirely replaced by muscovite and cassiterite.

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[4] Wright and Larsen: "Quartz as a Geologic Thermometer," *Amer. Journ. Science*, Vol. XXVII, No. 162, 1909.

Garnetiferous Pegmatites.

Garnets, usually of the composition of almandine, frequently grading into spessartite, are a common constituent of many pegmatites and pegmatitic granites. Very commonly the garnet is associated with schorl, and the available evidence indicates that it is pneumatolytic in nature and similar to black-iron tourmaline in general deposited at higher temperatures than most of the other pneumatolytic minerals. The occasional association of these iron and manganese garnets with triplite, as, for instance, on Elliot's claims below the Hohenstein, is of special interest in this connection.

The Tin-Bearing Pegmatites.

All the tin-bearing pegmatites exhibit as their basis the same gangue-minerals as the tourmaline pegmatites: orthoclase, microcline, primary plagioclase (albite), often in micro-perthitic intergrowth with orthoclase, and quartz, a large proportion of the latter usually in graphic intergrowth with the felspars. Most pegmatites also contain considerable quantities of secondary quartz, particularly those appreciably altered by pneumatolytic action.

The grain of the rock varies greatly, no doubt partly as the result of pneumatolytic alteration, particularly albitisation. Usually coarse-grained, the pegmatitic rock also assumes a fine-grained habit and becomes aplitic in appearance. It is common to find a composite dyke consisting of a coarse-grained and fine-grained aplitic portion, both tin-bearing and sometimes separated by a narrow schist parting. Very commonly the typical rock consists of coarse portions characterized by large felspar crystals separated by a fine-grained mesostasis, of which graphic intergrowths of felspar and quartz form a considerable proportion. This portion of the rock evidently was the last to crystallize.

The mode of occurrence of the cassiterite, as well as its mineral associations and the general habit of the tin-bearing pegmatites, vary to a considerable extent, and several types of tin-occurrences were observed associated with the pegmatites.

Mode of Occurrence of the Cassiterite.

The cassiterite is generally distributed in definite zones and bands of replacement, these having a definite relationship to the contours (walls) of the dykes or the intrusive bodies of pegmatitic quartz, but is occasionally scattered throughout the whole rock as fine tin. This is more often the case in the finer-grained aplitic-looking pegmatites, in which very frequently the cassiterite is unaccompanied or only very sparingly associated with other pneumatolytic minerals such as tourmaline or muscovite, though a widespread albitization of the primary potassium-felspars is noticeable.

The cassiterite occurs in well-formed crystals, irregular grains, and also in the form of large lumps, which frequently exhibit a few crystalline faces. Some of these lumps attain extraordinary dimensions, as may be judged from the fact that at Dawib a homogeneous mass of cassiterite weighing 500 lbs. was found in the early days of the fields. Large lumps and crystalline aggregates are usually found in association with an intense greisenization of the original pegmatite, the size of the lumps usually being directly proportional to the dimensions of the muscovite and the intensity of greisenization. The crystals of cassiterite, which vary in size from microscopic dimensions to a diameter of several inches, are commonly twinned and in consequence exhibit characteristic re-entrant angles. The habit of the crystals is predominantly pyramidal, the prism faces being as a rule very poorly developed. In thin sections the mineral very frequently exhibits a zonal structure, the crystals showing symmetrical or irregular patches of darker and lighter colour, brown and yellow.

The colour of the mineral also varies considerably, the prevailing tints, however, being yellowish-brown and brown. Occasionally, however, the colour is almost black, as, for instance, at Paukwab. Here the mineral occurs intimately intergrown with black iron-tourmaline and, similar to this mineral, it is also minutely brecciated. As a result it is very difficult to distinguish the two minerals, macroscopically. Frequently a reddish streak is the only indication of the presence of cassiterite in a mass apparently consisting entirely of black tourmaline.

At Otjimboyo and a few other localities true ruby tin is found. Here also large well-formed crystals of a beautiful resinous-yellowish-brown, transparent variety of cassiterite were taken from drusy cavities in the schists.

An interesting sample which was obtained shows the bulk of the crystalline cassiterite to consist of a whitish-grey variety but displaying a number of zones, parallel to pyramid faces, formed by dark-brown and light-yellowish-brown varieties in successive stages of growth of the crystalline mass.

Different Types of Tin-Occurrences.

With the exception of a few isolated tin-occurrences not connected with pegmatites and to be discussed subsequently, the cassiterite is found to be associated with pneumatolytically altered pegmatites. There are, however, a number of types of tin-bearing pegmatites, each with different mineral associations and exhibiting distinct characteristics. Two main divisions may be made:—

A. Tin-bearing pegmatites situated in the parent granite.

B. Tin-bearing pegmatites situated in the adjoining schists.

The latter group may be further sub-divided into:—

(*a*) Pegmatites containing cassiterite unaccompanied by tourmalinization and greisenization on any extensive scale.

(*b*) Ordinary, common type of tin-bearing pegmatite containing cassiterite accompanied by muscovite and, to a lesser extent, black tourmaline.

(*c*) Intensely greisenized pegmatite associated with intrusive bodies of pegmatitic quartz.

C. Cassiterite deposited from highly silicic aqueous solution and not associated with pegmatites.

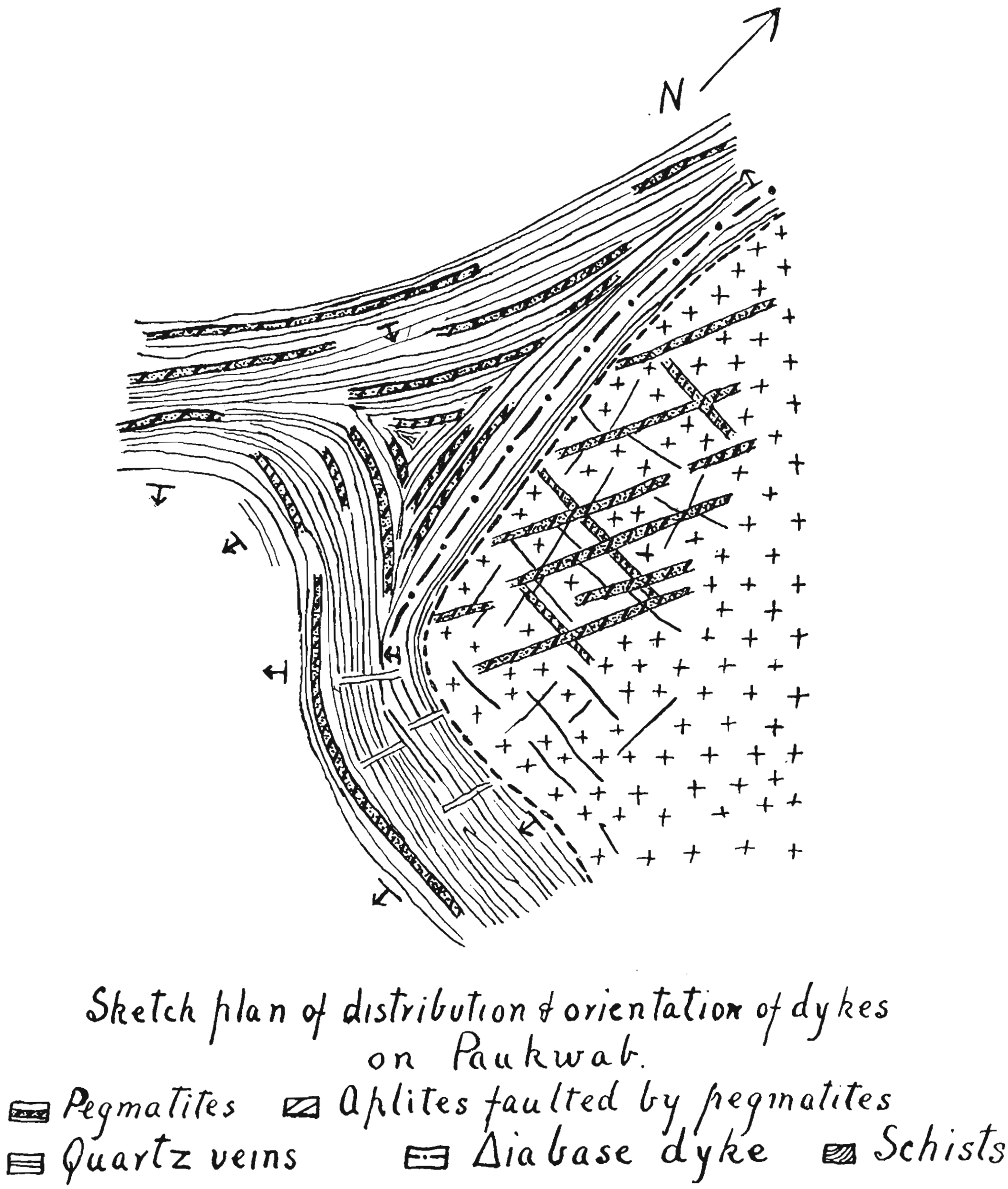
A. *Tin-Bearing Pegmatites situated in the Parent Granite.*—Compared with the number of tin-bearing pegmatites occurring in schists, these are comparatively limited in number. At Paukwab and in the Erongo-Kanona area, are to be found the most important examples. At Carsie, where the tin-bearing pegmatite is situated in a very small extension of the main granite mass and thus not really in the parent body, it shows features comparable to the schist-type of tin-bearing pegmatites.

On the whole these dykes are not as wide as the majority of dykes occurring in schists. Many of them are mere narrow and meandering veins.

At Paukwab, the bulk of them occupy joint directions parallel to the general strike of the schist (N.E.-S.W.) and not to the local, very much disturbed strike of these sediments. It is interesting to note, however, that the abundant dykes of aplite present conform to the local directions of strike and stress and, incidentally, are invariably cut and even faulted by, and therefore older than the pegmatites. (Fig. 1.)

The pegmatite dykes are coarse to fine-grained and sometimes contain both varieties in the same dyke. They are characterized by the abundance of black iron-tourmaline (schorl) and the intimate association of cassiterite with this mineral. Both associated and intergrown minerals generally occur in definite bands and zones of replacement throughout the pegmatitic rock and are usually most abundant along the walls of the dyke. Muscovite is almost entirely absent, but biotite is occasionally developed. In addition, garnet (almandine-spessartite) and topaz are associated with cassiterite and schorl in some zones of replacement. At the points of intersection of the earlier aplites with the later pegmatites, the rock of the former is sometimes also mineralized to some extent.

An interesting point is, that wherever the granite-schist contact is exposed, these pegmatites do not continue into the schists. On the contrary, a dyke intruded along or near the actual contact, the so-called "contact-reef" is of characteristic schist-type with an abundance of muscovite. Further, all the pegmatites occurring west of the diabase-ridge, separating the granite from the schist area, although occurring in the same or even at a lower level, are typical schist-pegmatites characterized by the mineral association: muscovite-cassiterite. The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Sketch plan of distribution & orientation of dykes on Paukwab.
Pegmatites
Aplites faulted by pegmatites
Quartz veins
Diabase dyke
Schists

FIG. 1.

change from one type to the other is therefore very abrupt here at Paukwab and takes place with the change of country rock. At Erongo-Kanona similar conditions hold, only that here a pegmatite dyke situated in Salem granite, but only a few yards away from the schist-granite contact, is of the schist-type.

The Salem granite at Paukwab is intruded more or less conformably into a synclinal structure of the sediments and the pegmatites occurring in the adjacent schists cannot be considered to be continuations of those occurring at the same level in granite. All the available evidence suggests that the site of actual intrusion and passage from the granite to the schists in the case of the former lies very much lower than the present surface and the level of the pegmatites exposed in the neighbouring granite. The schist pegmatites were evidently intruded from deeper-seated residual magma-portions at a period somewhat later than those pegmatites outcropping in the granite at the same level. The continuation of these latter pegmatites into schists must be looked for in higher horizons of the schist, now removed by denudation. This sequence, deduced from structural considerations, also accounts for the abrupt change in habit and mineral associations of the two series of pegmatites and is, moreover, corroborated by other evidence to be discussed later, *i.e.*, the deposition of black tourmaline and cassiterite when associated with this mineral at higher temperatures than muscovite.

Metasomatic Processes Involved.—It is quite clear from microscopic sections that both black tourmaline and cassiterite are secondary pneumatolytic minerals and the products of metasomatic replacement of felspar and quartz by gaseous solutions containing boron and tin. These pneumatolytic changes were accompanied by the albitization of orthoclase and particularly microcline on an extensive scale. The black tourmaline replaces both the primary felspar and the secondary albite, as well as primary quartz. The cassiterite also replaces both felspars and quartz, but shows a marked preference for felspar. The topaz present, no doubt, was also derived from the decomposition of the felspars.

Occasionally tourmaline is seen moulded on cassiterite, but on the other hand, according to a statement made by the mine manager, Mr. Davies, a crystal of cassiterite pseudomorph after tourmaline has been found at Paukwab. The very intimate association of the two minerals suggests that there was no appreciable interval of time between their respective deposition and that they were deposited more or less contemporaneously. It naturally depends on the concentration of their constituents in the gaseous solutions to determine which mineral would continue to be deposited after the vapours had become completely exhausted of the constituents of one of the minerals.

A further interesting mode of deposition of cassiterite at Paukwab is the zonal distribution in small bipyramidal crystal-grains in large uniform crystals of microcline, the bands of cassiterite being parallel to the zonal growth and cleavage planes of the felspar crystal. This was found to be of secondary origin. While the majority of cassiterite grains are euhedral and in the form of bipyramidal crystals, quite a fair percentage exhibit serrated edges and remnants of unreplaced felspar. In addition, bipyramidal crystals of cassiterite frequently show a narrow rim of later cassiterite, *i.e.*, an enlargement of the original crystal, which obviously replaces the microcline. The uniform crystal of microcline also encloses numerous small crystals and grains of orthoclase, primary plagioclase and quartz as earlier products of crystallization. These earlier minerals are frequently arranged in bands, *i.e.*, exhibit flow structure within the crystal of microcline. The cassiterite replaces both generations of felspar and encloses remnants of unreplaced quartz. Around some of the cassiterite grains the microcline is turbid and in the incipient stage of albitization. The crystals of cassiterite are most abundant along the bands of the earlier formed primary minerals, showing that the active vapours apparently penetrated the crystal of microcline most easily along lines of inhomogeneity. Finally, the crystal of microcline also shows a few minute clefts parallel to and in close proximity to bands of cassiterite crystals and along which alteration of the microcline with the production of secondary albite and secondary quartz has taken place. There is also no difference whatsoever between the successive zones of growth of the microcline and no evidence of a break in the growth.

It appears, therefore, that the cassiterite has replaced the felspar (first generation of orthoclase and plagioclase and the later microcline) along minute clefts and submicroscopic channels following the cleavage planes and successive zones of growth of the microcline and lines of inhomogeneity within the latter. The high pressure active on the gaseous solution accounts for the considerable quantities of cassiterite introduced along such very minute channels.

B. *Tin-Bearing Pegmatites situated in Schists.*

(*a*) *Cassiterite unaccompanied by tourmalinization and greisenization on an extensive scale.*—Occurrences of this type form only a subordinate portion of the pegmatites situated in schists. They are characterized by the comparative absence, frequently almost complete, of muscovite. Black tourmaline is generally more abundant, but on the whole sparingly distributed. The rock consists practically entirely of a white felspar (orthoclase, microcline, primary plagioclase and micro-perthite), primary quartz, secondary albite and cassiterite, usually disseminated as fine tin.

The dyke-rock is generally rather fine-grained and aplitic. This is probably to some extent a primary feature, but the widespread albitization of the coarse potassium felspar crystals no doubt considerably added to it. The unaltered-felspars are frequently somewhat turbid and clouded. Very commonly the cassiterite is practically limited to the fine-grained portions of the rock, thus suggesting a connection between the albitization and the introduction of the cassiterite. On Otjimboyo 2, east of the "Schlangenrivier," a trench exposes a dyke about 10 feet in width and consisting mainly of a coarse pegmatite with numerous closely spaced bands of replacement composed mainly of muscovite and quartz. The foot of the dyke is particularly altered in this way (Fig. 2). Unlike the behaviour of

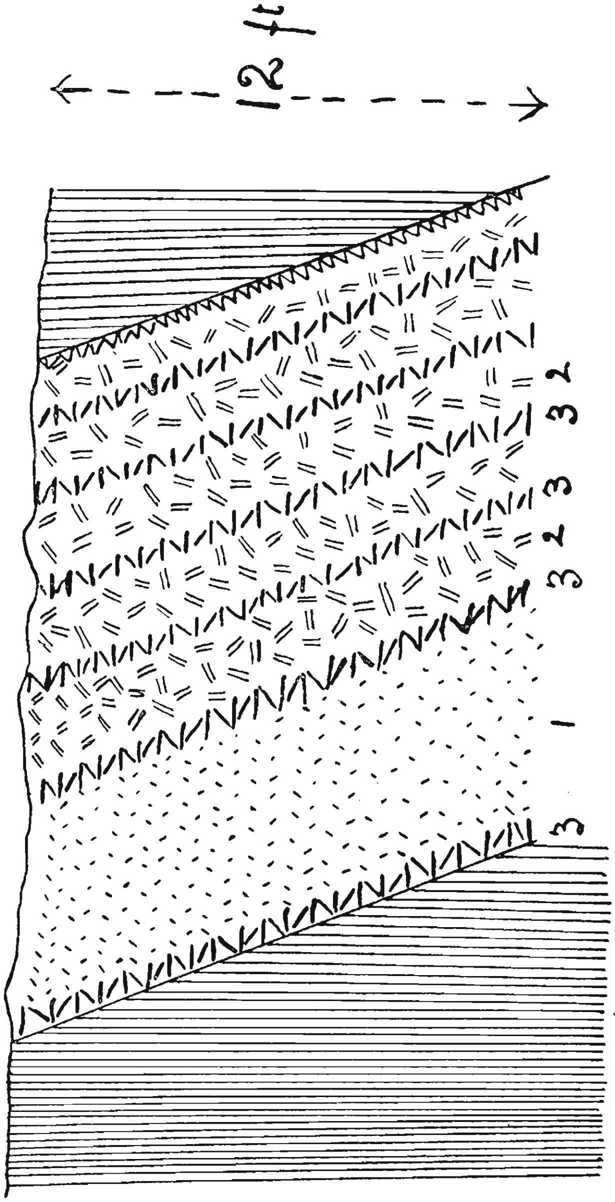

FIG. 2.

Section of pegmatite dyke on Otjimboyo 2.

1. Fine-grained aplite with bands of fine tin. 2. Coarse pegmatite with occasional tin.
3. Close bands of mica and quartz; no tin. 4. Schists dipping 85° S.E.

cassiterite in the ordinary type of schist-pegmatite, this mineral is very rare in these bands of greisen, but it mainly occurs in a fine-grained, aplitic portion of the rock as abundant fine tin and in the form of numerous closely spaced bands parallel to the walls of the dyke. The aplitic portion of the dyke here, however, shows numerous flakes of muscovite. In the coarse pegmatitic rock cassiterite is not abundant. Albitization is very much more pronounced in the fine-grained, highly stanniferous portions than in the coarse sections of the dyke. There is evidence suggesting that the albitization and deposition of cassiterite preceded the greisenization of this dyke.

A notable feature of the dykes consisting of similar rock in this locality is the highly decomposed nature of the fine-grained rock and the presence of abundant iron oxides. Not only is the rock here very much stained by the latter, but the weathering of the rock has also produced numerous nodules very rich in tin. The weight of such nodules is often very considerable, and it appears that large and small lumps of cassiterite or patches particularly studded with fine tin acted as inoculation centres around which iron oxide and hydroxide were deposited during weathering or the later hydrothermal phase to form stanniferous nodules.

Metasomatic processes involved.—It is this and the previously discussed type of tin-bearing rocks, in which previous authors considered the cassiterite to be a primary constituent. There are, however, even macroscopic features that do not favour this view. The cassiterite very generally occurs in distinct bands parallel to the walls of the dyke. In dykes of low dip the tin-bands are usually concentrated and frequently entirely limited to the hanging portion of the dyke. Where dykes intersect or are sharply bent along their strike or dip there is frequently a marked enrichment of cassiterite. All these phenomena suggest the activity of metalliferous vapours ascending the fissure marked by the dyke. Where their upward ascent was impeded marked enrichments of cassiterite are found.

The replacement of felspar by cassiterite is frequently seen macroscopically. Crystals of felspar are in part replaced symmetrically along their cleavage cracks, and in this way pseudomorphs of cassiterite after felspar result. (Fig. 3.)

Microscopic sections afford complete proof of the secondary nature of the cassiterite. First of all any flakes of muscovite that do occur are almost invariably associated with grains of cassiterite. Further, even euhedral crystals of cassiterite very frequently exhibit remnants of unreplaced quartz and felspar, and sieve-like grains of cassiterite are the result. (Fig. 4, a, b, c.) The boundaries of the individual grains of cassiterite are often serrated and were obviously determined by the contours of the replaced felspar crystals and quartz grains, *i.e.*, rectilinear along cleavage cracks of felspar and highly irregular and serrated, when in contact with quartz. Narrow long lath-shaped bodies of cassiterite pseudomorph after felspar laths are common.

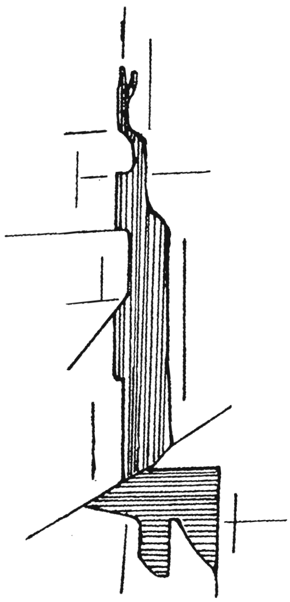

FIG. 3.

Cassiterite macroscopically replacing felspar along cleavage. Ameib.

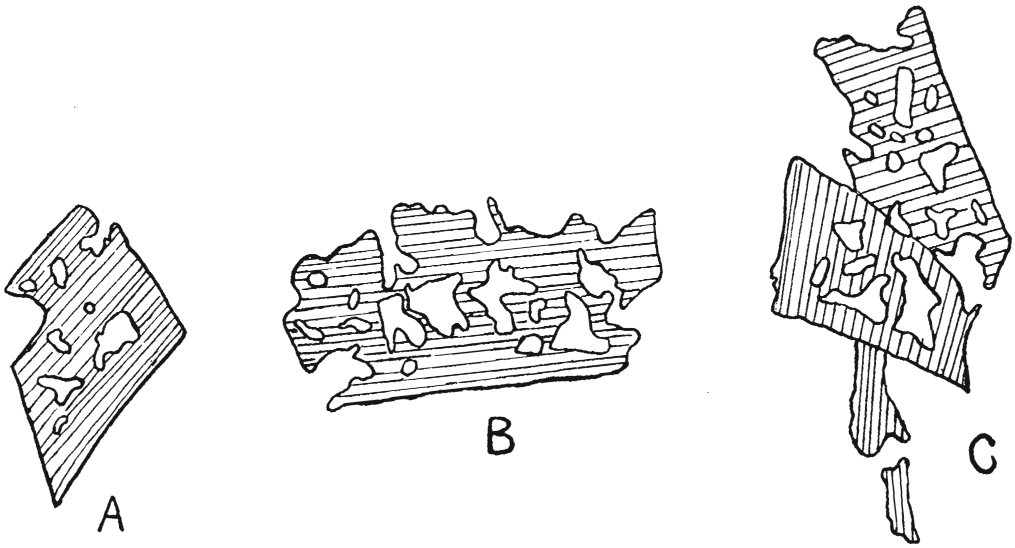

FIG. 4.

Cassiterite replacing felspar and quartz in microscopic sections

The cassiterite is therefore a product of the pneumatolytic replacement of felspar and quartz, particularly the former. This replacement is accompanied by the extensive albitization of the potassium-felspars.

C. *Ordinary type of Tin-Bearing Pegmatites in Schist; Association of Muscovite and Cassiterite.*

This type of tin-bearing pegmatite is by far the most widespread representative of the pegmatites occurring in schists. Its characteristic feature is the constant association of cassiterite with muscovite and its lithia- and fluorine-bearing varieties. Sometimes lepidolite is present in great abundance, occasionally preponderating over muscovite.

The base of these altered pegmatites is the same as in the previously discussed cases, namely—white felspar (orthoclase, microcline, primary plagioclase and microperthite) and quartz. The former, *i.e.*, the potassium-felspars have generally suffered extensive albitization.

Frequently black iron-tourmaline (schorl) is absent, and coloured lithia-tourmalines are associated with cassiterite and muscovite in this type, e.g., at Nobgams, Tsomtsaub, Kohero, etc. In other cases black tourmaline (schorl) is abundant. It usually occupies separate bands and irregular zones of replacement almost devoid of cassiterite and muscovite, and has therefore been deposited earlier. Where this is not the case and all three minerals occur together in the same portions of the pegmatitic rock, the mineral sequence is not quite clear, although the black tourmaline hardly ever occurs in direct juxtaposition to cassiterite.

The degree of greisenization and replacement in this type of tin-bearing pegmatite is moderate, though portions rich in cassiterite occur. The replacement by muscovite and cassiterite has usually taken place in distinct bands or irregular zones. The marginal portions along the walls of the dykes are particularly liable to be altered in this way. If the dip of the dyke is steep both walls are generally affected to an equal degree, but in the case of a low dip the hanging wall portion is usually altered and mineralized to a greater extent. Structural features involving a concentration of the metalliferous gaseous solutions or the impeding of their upward ascent play an important role in determining the relative abundance of cassiterite. The points of intersection of one or more dykes: sections marked by a sudden thinning of a dyke: the saddle portions of folded anticlinal dykes: the hanging wall portion of synclinal dykes: sudden vertical or lateral twists of a dyke and the upper portion of dykes suddenly pinching out are generally very heavily mineralized and sometimes represent the only sections containing payable quantities of cassiterite.

At the time of mineralization the pegmatites had evidently completely solidified and the metalliferous vapours were forced to ascend along narrow fissures marked by the walls of dykes, clefts

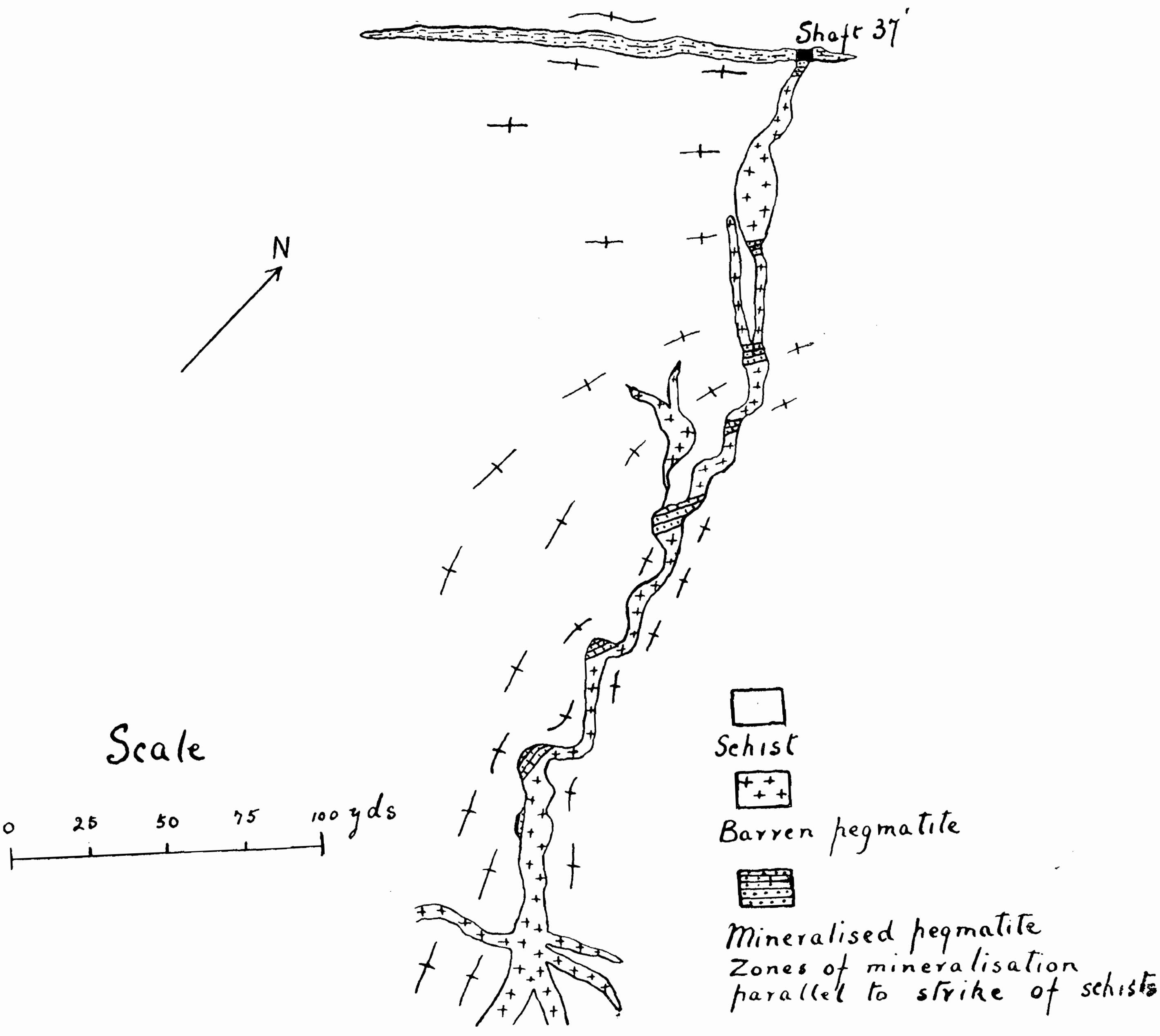

Fig. 5.

Showing mode of greisenization in pegmatite on Gantschows claims, near Tsomtsaub.

within the pegmatitic rock, joints, bedding planes and planes of schistosity in the schists.

There are several very clear instances of the ascent of pneumatolytic vapours along fissures marked by bedding planes in the schists which produced alterations only where they came in contact with pegmatites. Gantschow's claims near Tsomtsaub on the Omaruru river supply, perhaps, the most interesting example. Here a dyke parallel to the strike and dip of the schists and having a strike of about 100 yards over the whole length is well mineralized, the cassiterite being associated with muscovite. A cross-dyke, however, branching off at right angles from this main dyke near its eastern termination (Fig. 5), widening out in several places and then through a succession of bends turning into the strike of the schists again, is only mineralized at intervals, its general tin-content being very poor. At various intervals, indicated on Fig. 5, this dyke contains numerous bands of greisen running at right angles through the dyke, but parallel to the strike of the schist, thus continuing their bedding planes through the pegmatite. The metalliferous vapours responsible for the greisenization and deposition of the tin therefore appear to have ascended along several fissures parallel to the main, uniformly altered pegmatite dyke and represented by the bedding planes of the schists. They became active only where they met and intersected the cross-dyke, and felspar and quartz for replacement thus became available. The phenomena described also suggests that the cross-dyke, only partially mineralized, does not go down to great depths, and at the time of pneumatolysis did not stand in direct communication with the body of magma from which the vapours were derived.

Other examples of the mode of introduction of the metalliferous gaseous solutions are found on Kohero. Wagner[5] cites a case of a well-mineralized body of pegmatite completely pinching out at a depth of 92 feet. Below this depth the country rock (mica-schist), however, was finely impregnated with tourmaline and cassiterite along the continuation of the line of fissure. The metalliferous vapours in this case produced appreciable alterations only when coming in contact with the body of pegmatite, while below it impregnation of the schists on a limited scale took place.

More interesting still are features presented by the numerous large pegmatite dykes on this property. Some of these are very massive and the majority closely parallel, cutting the strike of the schists with an angle of 40-45° (Fig. 6). On the whole they are sparsely mineralized. The interesting feature is, that where these dykes turn into the strike of the schists, as, *e.g.*, near the dynamite magazine, they are appreciably greisenized and well mineralized. The same applies to a few dykes which, unlike the majority, are parallel to the schists along their whole length. A large pegmatitic blow, moreover, occurring on

[5] Wagner, P.A.: "The Geology and Mineral Industry of S.W.A.," *Geol. Soc. Mem.*, No. 7, p. 114.

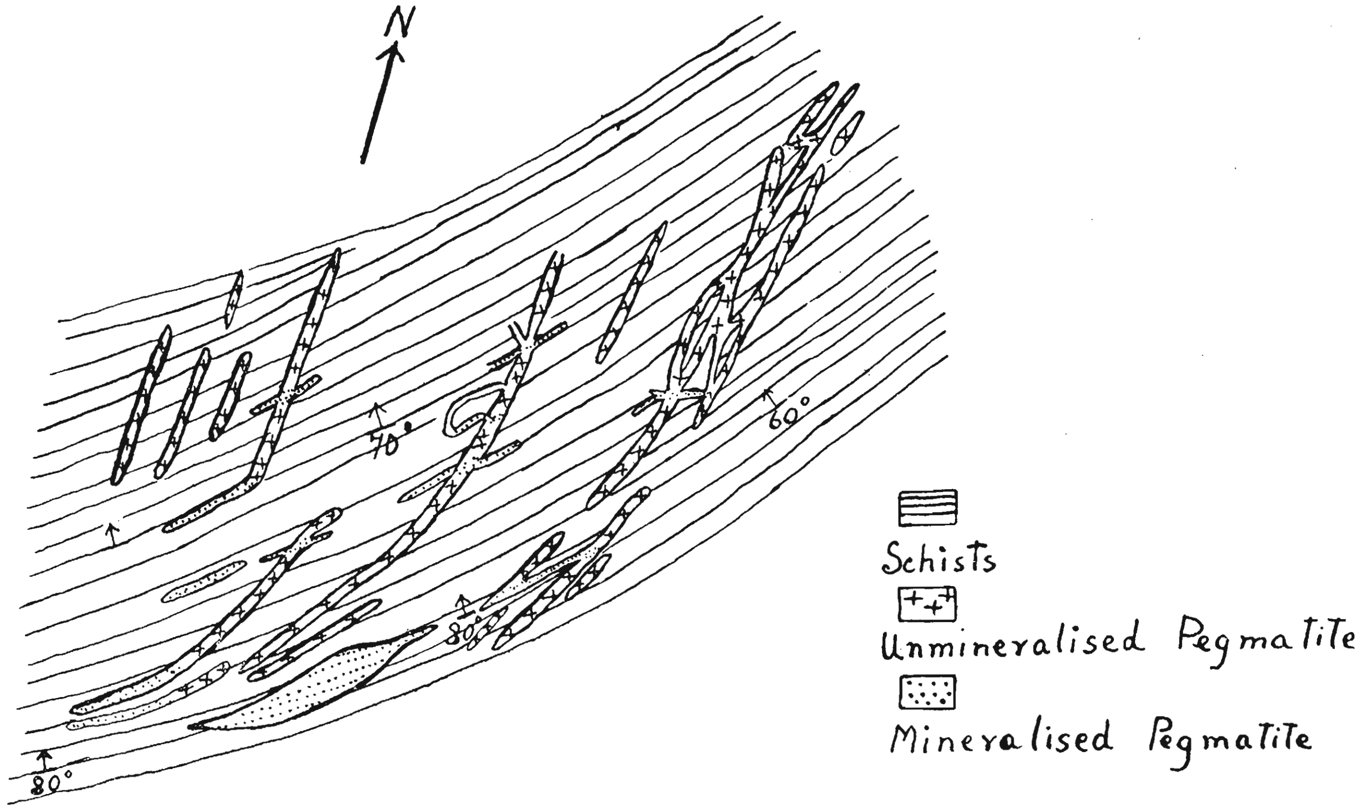

FIG. 6.
Sketch plan of pegmatites on Kohero.

this property, is greisenized and mineralized in distinct zonal bands parallel to the strike of the schists and continuing their bedding planes across the blow.

At numerous localities the massive dykes, which are not appreciably mineralized, have sent off narrow offshoots extending into the schists parallel to their strike or occasionally at right angles to it and sometimes only a few yards in length. Some of these connect closely adjoining massive dykes. All of these offshoots are heavily greisenized and mineralized and, in consequence, are being worked for tin. At no place were they found actually to cut through the massive dykes, and apparently they represent apophyses of the same magma. The interesting feature, however, is that the pneumatolytic alteration is carried across the massive pegmatite along the lines of continuation of these narrow offshoots and such sections of the former are being worked for tin.

It also frequently happens, that there are small wedges of schists protruding conformable to their strike into the massive dykes, or that the latter are interrupted by such schist wedges. In such cases the pegmatitic rock of the massive dykes is almost invariably also pneumatolytically altered and mineralized on one or both of the contacts with the schist wedge.

These features clearly indicate the influence of the bedding planes of the schists on the direction of pneumatolytic vapours.

Metasomatic process involved.—In this type of tin-bearing pegmatite the pneumatolytic changes consist mainly of the destructive alteration of felspar to muscovite and lepidolite, the albitization of the potassium felspar and the replacement of felspar and quartz, particularly the former, by cassiterite and tourmaline. Both the muscovitization and albitization of the felspar, as well as its replacement by cassiterite, begin along cleavage cracks. Pseudomorphs of cassiterite after felspar are very frequently produced in this way. Muscovite and cassiterite are usually directly associated and the heavier the greisenization the richer the tin content. Further, the coarser the muscovite or lepidolite the larger the crystalline aggregates and lumps of cassiterite.

It is a curious fact that usually both cassiterite and muscovite avoid large crystals of felspar and very coarse portions of pegmatite except in their marginal portions or along definite cleavage cracks or clefts. They are usually far more abundant in the finer-grained portions of the rock. The easier permeability of finer-grained aggregates by volatile substances evidently plays an important role in this connection. This feature is not altogether an original one, the finer grain of the heavily altered portions being in part also due to the destruction of larger felspar crystals by the process of albitization and muscovitization and the production of small grains of secondary quartz.

(c) *Intensive greisenization of Pegmatite associated with intrusive bodies of pegmatitic Quartz.*

This type is characterized by the intense and frequently complete greisenization of large bodies of pegmatite, often in the form of blows, along and in the immediate neighbourhood of their contacts with intrusive bodies of pegmatitic quartz. Usually the replacement of the felspar by muscovite and its lithia-bearing varieties is most intense along the quartz contact, and the bands of massive greisen therefore follow the contours of the quartz bodies. Irregular bands of massive greisen, 3 to 9 feet in width, and consisting almost entirely of very coarse muscovite or lepidolite with spasmodic lumps of cassiterite weighing 100 lbs. or more result. The greisenization of the pegmatite in irregular bands may, however, extend for more than 30 feet away from the quartz contact.

Not only the pegmatitic blows but also the intrusive body or bodies of quartz and, as a consequence, also the irregular greisen bands, are usually arranged parallel to the strike of the schist.

The mineralization of such occurrences is, as a rule, highly erratic. Where the quartz-body does not extend down to any great depth or rapidly narrows in width, the bands of stanniferous greisen on either side usually converge rapidly, and there is a possibility that with the actual pinching out of the quartz the greisen band will become very narrow in width and perhaps limited to the walls of the fissure along which the quartz was intruded. At no place, however, has work been carried out deep enough to prove this, though the converging of the greisen bands with the attenuation of the quartz can quite clearly be seen at Sandamab (Fig. 7.)

Other occurrences belonging to this type are the "Sidney Mine," on Dawib West, and the main working on Drew's claims on Kudubis. At the former locality black tourmaline (schorl) is developed in great abundance in distinct zones of alteration, but has very little or no tin associated with it. Its zones are also distinct from the greisen bands and the black tourmaline was evidently deposited during an earlier phase of pneumatolysis.

The main working on Rubner's claims, on Dawib Ost, presents similar features to this type of tin-occurrence, in that large bodies of pegmatitic quartz have been intruded into the pegmatite and the cassiterite appears limited to zones of replacement around the quartz. Muscovite is here, however, only sparingly developed. Schorl is abundant, but not in direct association with cassiterite.

A noteworthy feature of all these occurrences characterized by an intense greisenization is the invariable association of large lumps of triplite with the greisen and cassiterite. At Drew's working, on Kudubis, wolframite occurs with the cassiterite in small quantities.

The most extraordinary instance of this type is the occurrence on Irle's claim, on Otjokatjonga and Otjimboyo Ost. Here the body of pegmatite, intruded by large masses of pegmatitic quartz, is situated

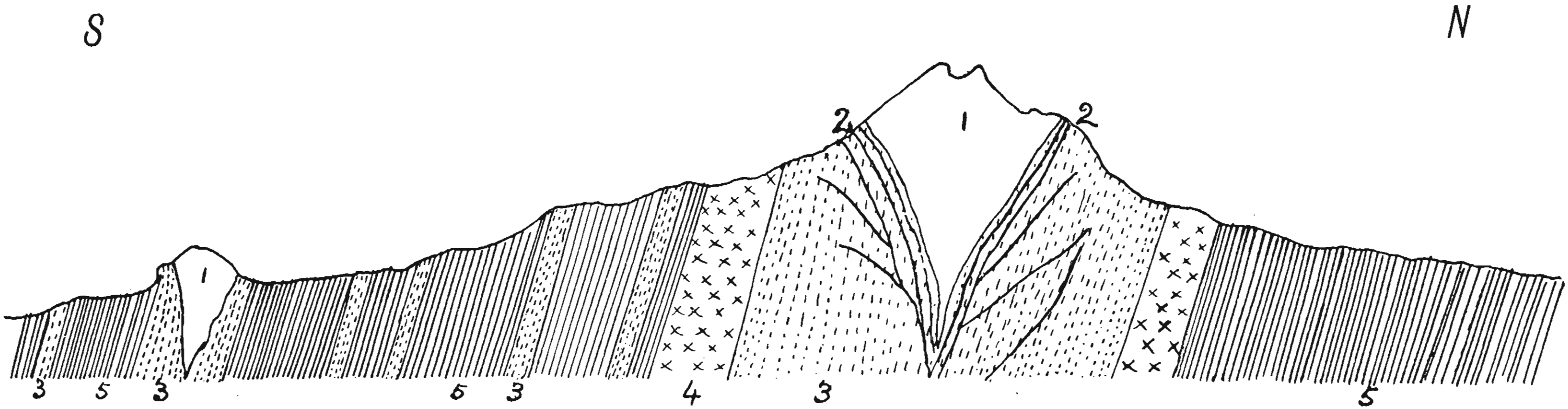

FIG. 7.

Schematic Section through the Sandamap Hill.

1. Pegmatitic quartz. 2. Stanniferous greisen bands. 3. Pegmatite with mica and tourmaline. 4. Ordinary Pegmatite. 5. Schist.

in crystalline limestones of the marble series and not in schists. The pegmatite itself is of the ordinary type, but has suffered extensive alteration. The initial phases of pneumatolysis were marked by the extensive deposition of black iron-tourmaline (schorl), very frequently in the form of circular or elliptical rings (Fig. 8), in mode of formation no doubt somewhat similar to the tourmaline suns and nests so abundant in the Erongo granite of the Erongo area. Very frequently the schorl also encrusts, *i.e.*, replaces marginally large crystals of felspar. Whether this early tourmalinization preceded the intrusion of the pegmatitic quartz it is difficult to say. It must be stated, however, that those portions of the pegmatite characterized by schorl are entirely barren and carry no tin.

The next phase of pneumatolysis, either contemporaneous with or immediately subsequent to the intrusion of the pegmatitic quartz, brought about the main alteration of the pegmatite. The cassiterite is mainly limited to the more intensely altered portions of the rock, which is characterized by the development of peach-blossom coloured lepidolite in bands and zones of replacement, particularly around the margin of quartz bodies. Associated with the lepidolite occur secondary quartz and a large number of beautiful crystals of coloured lithia-tourmalines. Their colour varies from dark bottle-green and light sea-green to a delicate pink and wine-red. The bulk of the crystals are zoned and consist of alternate green and pink layers. Beautifully zoned crystals several inches in diameter are common, but they are all fractured on a minute scale and on exposure break into small fragments. They are most abundant in the lepidolite-greisen-bands and the marginal portions of the pegmatitic quartz. They also occur within large felspar crystals and are thus obviously formed by the replacement of the latter.

The cassiterite is entirely limited to those portions of the pegmatitic rock which exhibit an intense replacement by lepidolite and coloured lithia-tourmalines during the later pneumatolytic phase. As already stated, those portions characterized by the earlier-formed schorl are devoid of cassiterite. The coloured lithia-tourmalines are frequently found to be moulded on crystals of cassiterite.

Of special interest is the occurrence of lumps of argentiferous bismuthinite in the lepidolite-greisen-bands, in the marginal portions of pegmatitic quartz and the contacts of these rocks. It is thus apparently of pneumatolytic origin. Bismuthite and bismuth ochre occur as its products of weathering.

About 150 yards away from the main working there occurs a dyke of massive lepidolite about 2 feet in thickness, but only of short length. At this locality there is also a small occurrence of copper sulphides: bornite with malachite and azurite, apparently also associated with an altered pegmatite. In the crystalline limestones of the same area there also occur narrow stringers of galena and quartz veinlets carrying auriferous iron and copper sulphides.

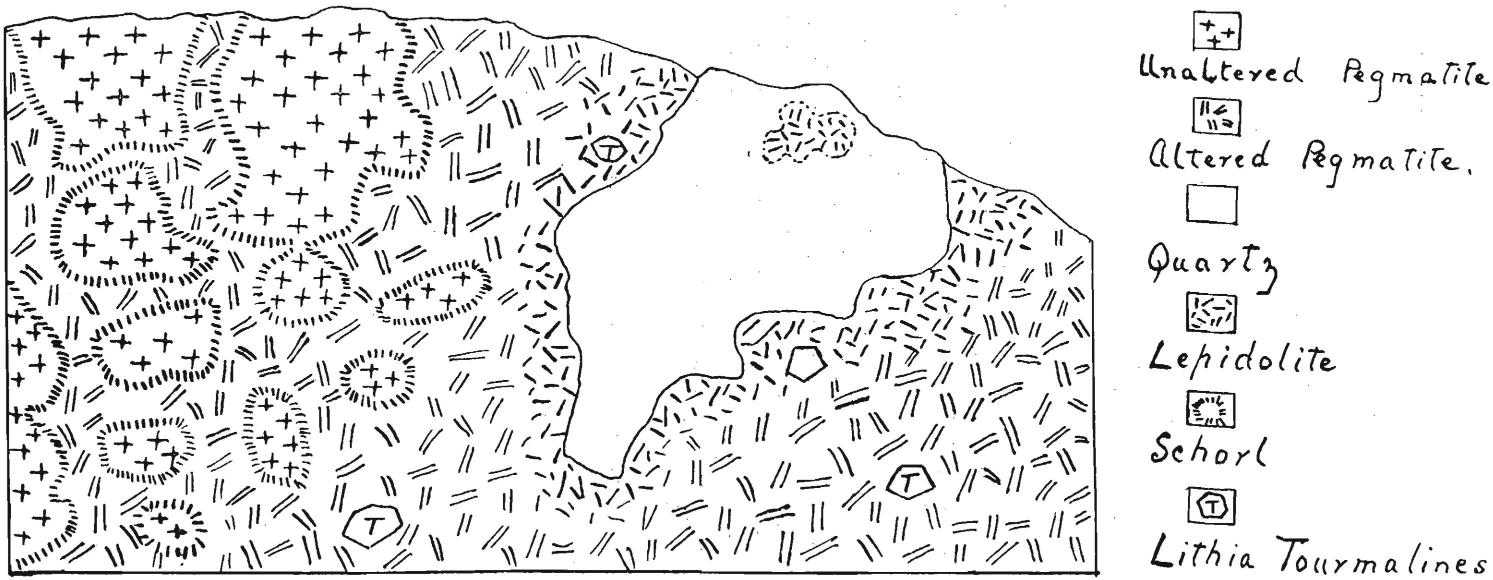

Fig. 8.

Schematic section seen on two walls of open working on Irles' claims on Otjakatjongo.

Metasomatic process involved.—It appears that originally the deposits of this type consisted of ordinary pegmatitic rock forming a blow or irregular thickening of a dyke. Probably the deposition of schorl during the initial phases of pneumatolysis preceded the intrusion of the pegmatitic quartz which was injected as a final magmatic residue along the same fissures to form irregular bodies within the pegmatite. The quartz appears to have been heavily charged with volatile constituents, notably water vapour, which diffused into the adjoining pegmatite and altered it to a considerable extent. More metalliferous vapours then ascended along the same fissure and, following the quartz-pegmatite contact, brought about an intense and, in places, complete greisenization of the adjoining pegmatite. These processes are similar to those of the previous type, restricted to more limited masses of pegmatite and consequently on a more intense scale. The cassiterite appears to have been deposited entirely during the later pneumatolytic phase and is both contemporaneous with and subsequent to the intrusion of the pegmatitic quartz. Along with it came muscovite, lepidolite, wolframite, argentiferous bismuthinite, coloured lithia-tourmalines, triplite and lazulite. The high lithia and fluorine content of the associated minerals is worth noting, and also the difference in chemical composition of the tourmalines; the deposition of schorl at higher temperatures, containing dense radicles of the heavy metals, and at lower temperatures the coloured lithia-tourmalines with lighter radicles and quantities of fluorine. Volatilized phosphoric acid appears to have been present in the water vapour responsible for the bulk of the pneumatolytic alterations.

C. *Cassiterite deposited from Aqueous Solution.*

This type of tin occurrence is represented by only a few isolated instances. At Otjimboyo, in the valley of the Hardersrivier, there is an extensive sheet of pegmatite much jointed and fissured along tectonic directions. The tin-content of the pegmatite itself is poor, but some of the joints contain narrow veins of pure massive cassiterite bounded on both walls by thin bands of muscovite.

This type shows the presence of a pneumatolytic mineral, *i.e.*, muscovite, and probably belongs to the last stages of pneumatolysis and leads over into tin-deposits in which the cassiterite is no longer associated with pneumatolytic minerals, but with minerals characteristic of the early hydrothermal phase and in which its mode of occurrence suggests deposition from aqueous solution.

Close to the former locality on Otjimboyo and situated about 10 feet below a pegmatite sheet, occurs an elongated cavity in the schists about 8 feet in length and with a maximum height of one foot. When first opened, the floor, roof and sides were found to be encrusted with beautiful drusy crystals of cassiterite, some of them of large dimensions and encrusted by pure milky quartz, the latter showing numerous casts of the former. In addition, films of arsenopyrite were found to encrust crystals of cassiterite. Muscovite is still present in limited quantity. The whole therefore represents a cassiterite druse from which 800 kgs. of pure cassiterite are said to have been extracted.

Genetically closely related to this occurrence is a vein of pure massive cassiterite bounded by a narrow selvage of quartz and occurring in schists on Otjimboyo 10. In its upper portions the cassiterite vein was about $1\frac{1}{4}$ inches in width, but it gradually thinned out till at a depth of 26 feet it pinched out, together with the quartz. In a prospecting shaft, 177 kgs. of pure cassiterite were recovered from this vein over a vertical distance of 18 feet.

The largest occurrence of this type is a stanniferous quartz vein situated on Müller's claims, on Kohero East. Here there is a quartz-reef about 4-5 feet wide at its maximum with a total visible length of 45 feet. The cassiterite is disseminated throughout the quartz in small grains and larger crystalline masses and is associated with chalcopyrite and bornite. Muscovite and tourmaline are entirely absent. Considerable quantities of cassiterite, amounting to a total of 38 tons, have been recovered from this quartz-reef during a period of four years. Another similar quartz vein of lesser width occurs near by, but has not been opened up.

While in the case of the other occurrences the cassiterite was found to be a product of pneumatolytic replacement of the felspar and quartz, in the above examples no replacement of any kind has taken place, the cassiterite being apparently merely deposited from solutions along with quartz and sulphides. It seems justified therefore to assign these occurrences to the early hydrothermal phase, during which cassiterite was deposited from highly siliceous aqueous solution at a temperature in the neighbourhood of 358°C.

The Genesis of the Cassiterite.

The nature of the pegmatites and the mode of occurrence of the cassiterite having been described in the foregoing pages, it now remains briefly to discuss its origin and genetic history.

Source of the Metalliferous Vapours and Solutions.

In regard to this point there can be no reasonable doubt. It is clear that the source of the metalliferous vapours and solutions is the same as the source of the pegmatites in general, and that the deposits are connected genetically with the intrusion of the old granites. The close association of the pegmatites with the various phases of the main intrusion of old granites, commencing with that of Salem granite, has already been made sufficiently clear. The tin-deposits are in no way connected with the intrusion of the very much younger Erongo granite. Their occurrence together in the same area is quite accidental. Excepting a second tourmalinization on a restricted scale, at no place did these younger granites produce new pneumatolytic alterations of the old pegmatites. While the age of the Erongo granite is most probably Karroo or post-Karroo, that of the old granites and associated pegmatites falls well back into the Archaean.

The primary or secondary nature of the Cassiterite as a constituent of the Pegmatites.

Cloos, who was the first to investigate the tin-bearing pegmatites of the Erongo area, was of opinion that the cassiterite is a primary constituent of the pegmatites deposited during their solidification.[6] In this view he was followed by both Wagner and Heldring (*loc. cit.*) for some of the modes of occurrence of the cassiterite, while both recognised the fact that in a number of instances it is clearly of secondary origin.

Theoretical considerations already suggest that the alteration of the pegmatitic material by pneumatolytic vapours and gaseous solutions, though taking place in several well-marked stages, nevertheless probably represents a continuous process. It is quite conceivable that, since the pegmatitic magma during the process of intrusion no doubt already contained considerable quantities of volatile constituents, pneumatolytic action in its strict sense can already set in, while the pegmatitic magma is solidifying and prior to the complete crystallization of the main minerals. This stage may be referred to as the Primary Pneumatolytic or Pegmatitic phase. Pneumatolytic reactions taking place after the crystallization of the main minerals of the pegmatite and due to the streaming up of metalliferous vapours from lower, still liquid residual portions of the magma may then be said to belong to the Secondary or Principal Pneumatolytic phase.

In this way Broegger, in his classic researches on the aegerite and nepheline-syenite-pegmatites of southern Norway,[7] has distinguished four periods of crystallization:

(1) The phase of magmatic consolidation, during which the essential minerals of the pegmatites crystallized and a subordinate degree of primary, syngenetic pneumatolysis took place.

(2) The principal pneumatolysic phase.

(3) The phase of zeolite formation.

(4) The phase of carbonate and fluo-carbonate formation.

In general pneumatolytic action may therefore be described as *Syngenetic* and *Epigenetic*.

It has already been shown that with the exception of the quartz-cassiterite veins and drusy cavities, the cassiterite in all the tin-bearing

[6] Cloos, H.: "Der Erongo. Beitrage zur geol. Erforschung der deutch.," *Schutzgebete*, Vol. 17, Berlin, 1919, p. 167.

[7] Broegger, W. C.: "Die Mineralien der Syenitpegmatitgänge der südnorwegischen Augit- und Nephelin-syenite," *Zeitschr. f. Krystallographie*, Vol. XVI, 1890.

pegmatites investigated was found to be a product of replacement mainly of the felspar, but also of the quartz constituting the pegmatite. The question now remains: did the replacement of felspar and quartz by cassiterite commence before or after solidification of the pegmatite? The evidence available suggests that most probably there was a considerable interval of time and temperature over which pneumatolytic alteration took place, and that the replacement of the felspar and quartz already commenced before the complete solidification of the pegmatite. Theoretically, of course, this replacement could commence as soon as crystals of felspar and quartz began separating out from the magma highly charged with gaseous solutions, but macroscopically and under the microscope it is frequently seen that the cassiterite avoids the earlier formed coarser aggregates of felspar and quartz and is most abundant in the finer grained portions forming a kind of mesostasis between coarser portions. This and other evidence suggests that at the time of the first appreciable pneumatolytic replacement the pegmatite had already more or less solidified, though it may still have been in a plastic state.

Although most probably, therefore, the formation of cassiterite by the pneumatolytic replacement of felspar and quartz was a long continuous process extending over a considerable interval of time and temperature, nevertheless at least two successive stages of replacement may be made out. It is clear, of course, that their limits are somewhat ill-defined and that considerable amounts of overlapping take place.

Cassiterite as the Product of Pneumatolytic Replacement.

Stage I (Initial phases): Cassiterite occurring alone or associated with Black Iron-Tourmaline.

These mode of occurrence of the cassiterite have already been discussed in detail in the descriptive portion of this paper. It is also this type of tin-bearing rock of which previous authors considered the cassiterite to be a primary constituent. It has been shown, however, that also in these cases the cassiterite is a product of pneumatolytic replacement and was derived from ascending metalliferous gaseous solutions. The more uniform and consistent distribution of cassiterite throughout the rock, *i.e.*, the more general and uniform permeation of the pegmatite by the stanniferous vapours, and the greater independence of the cassiterite from actual fissures and other structural features, as well as other evidence, suggest that the deposition of cassiterite alone or associated with black iron-tourmaline represents the earlier phases of pneumatolysic alteration of the pegmatites, which took place at a higher temperature and probably began before the complete solidification of the pegmatite.

Stage II (Later phase): Cassiterite accompanied by Greisenization.

Most likely there was no break between this and the former stage, the different mineral associations of the cassiterite being no doubt due to the change in composition of the metalliferous vapours with decreasing temperature. During the later phases of pneumatolysis the pegmatites appear to have been completely solidified, at least in the horizon now exposed. The metalliferous gaseous solutions were now forced to stream up along narrow fissures and channels such as the contact walls of pegmatite-dykes, bedding planes of the schists, joint fissures within pegmatites and schists, etc. While phenomenal enrichments occur locally, the cassiterite deposited during these later stages of pneumatolysis is far more erratically distributed and very much more dependent on structural features. Very often it is entirely limited to the channels of easy ascent for the gaseous solutions.

The cassiterite in the ordinary type of tin-bearing pegmatite situated in schists, *i.e.*, showing moderate amounts of replacement and an almost constant association of cassiterite with muscovite, probably belongs to a somewhat earlier stage than the heavily greisenized occurrences associated with bodies of pegmatitic quartz. In the latter case the ascent of the metalliferous vapours was, no doubt, in part at least, connected with the intrusion of the pegmatite quartz during the last stage of pneumatolytic action, when the gaseous solutions already consisted mainly of water-vapour and had become highly silicic.

The Early Hydrothermal Phase.

It is characteristic of all occurrences, in the case of which the cassiterite was deposited from vapours and gaseous compounds, to find the cassiterite disseminated as grains or crystalline aggregates throughout the rock. When the temperature, however, has fallen below the critical temperature of water 358°C., or closely approaches it, so that the water, if not actually in the liquid phase, is nevertheless in a highly condensed and less mobile state, one would expect any mineral precipitated from solution to be deposited in a more or less continuous manner to form veins or lenticular bodies.

This is precisely the mode of occurrence of the cassiterite associated purely with quartz and already described as having been deposited from aqueous solutions. The temperature at the time of deposition, if not actually below, must have been at least in the vicinity of the critical temperature of water, 358°C.

Mineral Association of the Cassiterite.

Cloos (loc. cit.), led by the interesting phenomenon that in a number of instances a definite band of cassiterite-bearing pegmatites, situated at a definite distance from the parent granite-massif, is found to encircle the latter, and that on approaching the granite-contact the cassiterite is often entirely replaced by black iron-tourmaline (Schorl), promulgated the view that schorl and cassiterite always mutually exclude each other. In this view he was followed by Wagner (*loc cit.*). Very many more occurrences of tin have, however, been discovered since the visit of these authors to the tin-fields, and very much more development work has been done since then.

It is clear from all the material collected over the whole of the tin-fields that the process of mineralization was not nearly as simple as imagined by Cloos, but that, on the contrary, it varied very materially from place to place. There were many factors which may have influenced the composition of the metalliferous vapours and the nature of the chemical reactions and minerals deposited from place to place. The chief of these seems to have been temperature, and the temperature gradient in the adjacent sediments away from the parent magma is found to play a dominant role. Further, when two or more minerals occur together in the same pegmatite, it does not necessarily follow that they were deposited at the same time by a contemporaneous series of chemical reactions. Also pneumatolytic processes frequently being of a highly destructive nature, subsequent reactions may completely alter the whole aspect of the mineral associations.

The minerals that have been found occurring together with the cassiterite, apart from the gangue-minerals, felspar and quartz, and which, similar to cassiterite, are clearly of secondary origin, are black iron tourmaline (schorl), coloured lithia-tourmalines, muscovite, lepidolite and lithia-bearing varieties of the former cookeite, etc., triplite, lazulite, garnet (almandine-spessartite), apatite, topaz, fluorite, beryl, tantalite, wolframite, monazite and columbite, molybdenite, argentiferous bismuthinite, arsenopyrite, chalcopyrite and bornite.

The majority of these minerals, however, are only sporadically and sparsely distributed. Of widespread occurrence and of importance from a genetic point of view only are black tourmaline and coloured lithia-tourmaline, muscovite and lepidolite, triplite, and to a lesser extent the sulphides.

(*a*) *Black Iron-Tourmaline.*

Tourmaline, which is intimately associated with cassiterite in pegmatites situated in granite (Paukwab and Erongo-Kanona) is frequently moulded on cassiterite, but the latter is also found to replace the former. The minerals are probably deposited more or less contemporaneously at high temperatures.

At numerous localities tourmaline is also found together with muscovite and cassiterite in pegmatites situated in schists, but it is hardly ever in juxtaposition with the latter, and is usually in separate zones of replacement, and then apparently deposited earlier than cassiterite.

In many instances black tourmaline and cassiterite mutually exclude each other, schorl being deposited at higher temperatures in the parent granite and a belt adjoining the granite contact. Further away from the latter the schorl is then replaced by muscovite and cassiterite, to form a tin-bearing belt.

It is evident from these brief statements that no hard and fast rule can be given for the relationship existing between cassiterite and black tourmaline. Slight changes in temperature and concentration of the boron-content in the gaseous solutions as against SnO_2 may bring about destructive changes. Generally black tourmaline seems to be deposited earlier and at a higher temperature than cassiterite. In the absence of a suitable flux or volatilizer, tin may, however, be deposited at a higher temperature than usual, contemporaneously with black tourmaline. It is also obvious that any segment or horizon of a pegmatite dyke with progressive decline in temperature can successively come within the sphere of deposition both of black tourmaline and cassiterite.

(*b*) *Coloured Lithia-Tourmalines.*

Are very widely associated with cassiterite and muscovite in schist pegmatites, and when occurring together with schorl are always deposited later than this mineral.

Their association with muscovite and cassiterite and deposition at a lower temperature than black iron-tourmaline, and their absence in the high temperature zone, illustrate the important influence of the addition of more volatile and the removal of very dense radicles on the volatility of certain types of compounds. Very often they occur moulded on cassiterite, so that, if anything, they were deposited slightly later than this mineral.

(*c*) *Biotite* was found to accompany cassiterite only at Paukwab, *i.e.*, in pegmatites situated in granite. Even in the altered pegmatites this mineral is very rare, though in the parent granite, *e.g.*, the Salem granite it is abundant. The reasons for its almost complete absence in the pegmatites are probably its high freezing point, which is higher than that of black iron-tourmaline, and its great instability in the presence of pneumatolytic vapours. Its tendency to suffer metasomatic alterations is even greater than that of felspar.

(*d*) *Muscovite and its Lithia-bearing varieties* is the characteristic mineral associated with cassiterite in schist pegmatites. Microscopic sections of these rocks show felspar in all stages of replacement ranging from incipient to complete. In the incipient stages the felspar is usually rendered turbid and the growth of muscovite begins in the form of fine, feathery aggregates. In heavily greisenized rocks there is usually also an abundance of secondary quartz. The muscovite almost invariably contains traces of lithium and fluorine and by degrees passes over into lepidolite. Massive lepidolite occurs associated with cassiterite at Kohero and Irles claims, near the Goldkuppe.

In microscopic sections the muscovite is frequently moulded on the cassiterite or fills cracks in the latter. The deposition of the minerals, however, was probably more or less contemporaneous, but that of muscovite continued after the gaseous solutions had been exhausted of their SnO_2 content.

(*e*) *Triplite.*

This fluo-phosphate of iron and manganese is a very regular associate of cassiterite and muscovite in the intensely greisenized types of tin occurrence. It also occurs, though more sparingly, in the less highly micaceous pegmatites, as, for instance, on Müller's claim, Kohero East, and on Elliot's claims below the Hohensteine. At the latter locality, the triplite was found to enclose icositetrahedra of garnet (almandine-spessartite), thus showing that the formation of the garnet, here pneumatolytic, preceded that of triplite. Lazulite is associated with the tin on Dawib Ost and on Gantschow's claims at Tsomtsaub.

(*f*) *Tantalite and Wolframite.*

The tantalite and tungstate of iron and manganese occur sporadically in the altered pegmatites throughout nearly the whole of the tin-fields. Their mode of occurrence and mineral associations are similar to those of cassiterite in the ordinary schist-pegmatite exhibiting a replacement of felspar by muscovite. On Ploeger's claims, near the Brandberg, there occurs a pegmatitic dyke almost completely greisenized and studded with small grains and crystals of tantalite, but containing practically no cassiterite. The genetic histories of these two minerals and their temperatures of crystallization are evidently similar to those of cassiterite, and their association with muscovite and its lithia- and fluorine-bearing varieties suggests a similar vehicle, *i.e.*, water-vapour containing alkaline fluorides in solution.

(*g*) *Sulphides: argentiferous bismuthinite:*

Accompanying cassiterite, lepidolite and lithia-tourmalines in greisenized pegmatite intruded by pegmatitic quartz on Irle's claims, Otjakatjongo.

Chalcopyrite and bornite: accompanying cassiterite in a dyke of quartz on Müller's claims, Kohero East.

Arsenopyrite: accompanying cassiterite in a pegmatite, and also in a cassiterite-quartz druse on Otjimboyo.

METAMORPHISM OF THE TIN-BEARING PEGMATITES.

Owing to the large amount of folding that some of the dykes have undergone, they have developed a distinct gneissose structure. Some dykes at Nobgams, Tsomtsaub and the Von Goldfuss claims have completely lost their original character and have been changed to sillimanite-albite-muscovite gneisses. Thin sections show that sillimanite, in the form of fibrolite, is one of the last minerals formed, and it is passing through broken crystals of cassiterite. Associated with the sillimanite, but previously formed, are large prisms of clinozoisite. The formation of the sillimanite at a late stage seems to indicate that originally it was present in some other form.

The aluminium which these minerals require has evidently been supplied by the parent magma. Although the granites were observed to have absorbed considerable amounts of the schists, the pegmatites have not.

At Tsomtsaub and Dawib Ost the presence of the phosphate of aluminium, lazulite, associated with the cassiterite gives further evidence of the presence of this radicle in the magma.

Summary of the History of the Tin-Deposits.

	Prevailing Temperature
Pegmatitic Phase (Phase of Magmatic Consolidation)—	
Crystallization of felspar and quartz to form pegmatite; very subordinate deposition of biotite.	About 575°C.
Principal Pneumatolytic Phase—	
Initial phases: Deposition of black iron-tourmaline, cassiterite, garnet and topaz, albitization of potassium felspars.	Not far below 575°C.
Later phases: Intrusion of pegmatitic quartz; continued albitization of potassium felspars; deposition of cassiterite, tantalite, wolframite, coloured lithia-tourmalines, muscovite, lepidolite, secondary quartz, triplite lazulite, aplite, beryl, topaz, fluorite, argentiferous bismuthinite, molybdenite, arsenopyrite.	Below 575°C. and above 358°C.
Early Hydrothermal Phase—	
Deposition of cassiterite, quartz, arsenopyrite, chalcopyrite, and bornite, chlorite and sericite.	About 358°C.
Late Hydrothermal Phase—	
Deposition of Cu- and Fe-sulphides and galena, in places auriferous; formation of siderite and chlorite.	Below 358°C.
Alteration by descending Meteoric Waters—	
Formation of bismuthite and bismuth-ochre, malachite and azurite, iron oxides, kaolin and secondary chlorite.	Ordinary atmospheric temperature.

Nature of the Vehicles by which Minerals were Introduced.

There still exists considerable uncertainty in regard to the nature of the vehicle or carrier responsible for the introduction of cassiterite. The intimate association of cassiterite with fluo- and boro-silicates in many of the classical tin-deposits of the world led to the suggestion that the tin was most likely introduced in the form of volatile compounds of tin with fluorine and boron. The mineral associations of the cassiterite in the tin-bearing pegmatites of the Erongo area very strongly suggest the active co-operation of those elements and alkaline fluorides, particularly LiF, as well as of boron compounds. These mineral associations have already been described. It may also be noted that Sandberger proved a small content of SnO_2 in many lepidolites.

It is clear, however, from the description of the greatly varying mineral associations of the cassiterite in the Erongo tin-fields, that most probably no single element or one chemical reaction brought about the deposition of the cassiterite. The available evidence suggests that the conditions of deposition varied greatly and that the primary factor responsible for the different mineral associations and modes of deposition of the cassiterite was the gradually declining temperature of the vapours and gaseous solutions and their changing composition brought about in this way. Several features quite clearly prove this.

(a) *The Effect of the Temperature Gradient.*

Reference has already been made to the fact that in numerous instances the pegmatites surrounding any parent body of granite exhibit a zonal distribution of their pneumatolytic minerals: black iron-tourmaline without cassiterite being practically limited to the granite body and a zone of pegmatites adjoining the latter, while cassiterite and muscovite occur in a definite zone of pegmatites further removed from the parent granite. At Paukwab and Erongo-Kanona cassiterite and black tourmaline without muscovite occur together in pegmatites situated in granite, and the change to muscovite-cassiterite-bearing pegmatites of schist-type is very abrupt and coincident with the change in country rock. The width of the various zones varies with the width of the strip of schists between two bodies of granite, and is also dependent on a number of structural features.

This common zonal arrangement is no doubt merely the result of a temperature gradient, the temperature gradually declining in a direction away from the parent granite-body, both vertically and laterally. With a progressive decline of temperature the composition of the vapours and gaseous solutions on their way from the still unconsolidated residual portions of the granitic magma will progressively change and different mineral associations will result from pneumatolytic metasomatic reactions. Reactions proceeding most favourably and rapidly at higher temperatures will generally be those involving the less volatile constituents of the gaseous mixture. The more volatile constituents will, on the other hand, be able to penetrate to greater distances before their most favourable reaction temperatures are reached.

The freezing points of the new-formed pneumatolytic minerals naturally have an important bearing in this connection. Black iron-tourmaline crystallizes sooner than cassiterite and muscovite, and away from the granite contact the gaseous solutions will in general already have been deprived of their boron-content. Minerals formed by pneumatolytic interaction with the gangue-minerals possessing a lower freezing point will in general be deposited further away from the granite-contact.

(*b*) *The difference in the mineral associations of Cassiterite in Pegmatites situated in the parent Granite and in the adjoining schists.*

Temperature is without a doubt also the primary factor in determining this very marked difference previously outlined. "Granite-pegmatites" are characterized by the schorl-cassiterite combination, and "schist-pegmatites" by the almost constant association of muscovite and cassiterite. The transition, as already stated, is usually very abrupt. At Paukwab the actual contact is taken up by a pegmatite of schist type. This indicates that temperature is not the only factor, but that the nature of the country rock also exerts an influence, though it has already been shown that at Paukwab the "granite-dykes" belong to a somewhat earlier period of intrusion than the bulk of the "schist-dykes" exposed on the present surface. A higher temperature at the time of pneumatolytic alterations in the granite-dykes therefore most readily explains this difference, though not completely. It is suggested that since there is no evidence indicating any reactions between the country rocks and the pneumatolytic vapours, except, of course, marginal albitization and replacement of felspar and quartz in the granite-walls of "granite-dykes," the very much greater power for absorbing water vapour and aqueous solution in the gaseous state displayed by the schists, as opposed to the solid, impervious granite, plays a role, even if a subordinate one. The active mass of water in the gaseous state would, as a consequence, be considerably higher in the case of pegmatites situated in schists than in the case of dykes situated in solid non-porous granite, particularly since the greisenization of the pegmatites usually commences from the walls of the dykes. This would in part explain the abrupt change denoted by the sudden appearance of muscovite in schist-dykes.

(*c*) *The constant association of Cassiterite and Muscovite.*

As previously mentioned, the mineral associations of the cassiterite strongly suggest the active co-operation of boron compounds and particularly of fluorine and alkaline fluorides in its introduction. These same mineral associations, however, also suggest that the cassiterite was not deposited as the result of a single chemical action. For how is the widespread, almost constant association of cassiterite and muscovite to be explained on this basis, unless it be supposed that the stannic fluoride was introduced previous to the water vapour necessary for its decomposition? It is true that often the cassiterite can be shown to have been formed somewhat earlier than the bulk of the muscovite, but, as mentioned above, most probably there was no appreciable interval of time and temperature between the deposition of the two minerals, and the formation of muscovite continued after that of the tin. Further, the fact that almost invariably in this type of occurrence the amount of cassiterite present is directly proportional to the degree of greisenization, and that the coarser the muscovite or lepidolite the coarser the cassiterite, strongly suggests that the cassiterite was introduced together with the water-vapour responsible for the hydration of the polysilicate felspar at high temperature and pressure to form the orthosilicate muscovite.

In the case of the plagioclase, this process also involves the addition of K_2O and removal of Na_2O. Since, however, albitization on an extensive scale generally accompanies the muscovitization, both processes in part merely involve a mutual exchange of alkali-radicles.

The frequent occurrence of cassiterite and muscovite in fixed proportion is so apparent that Heldring was induced to speak of a muscovite-cassiterite eutectic (*loc. cit.*). This idea, however, cannot be upheld, for the minerals are neither primary constituents of the pegmatite, but products of pneumatolytic replacement of felspar and quartz. In addition, there are extensive sections of greisen and almost pure muscovite practically devoid of cassiterite.

This intimate association of the two minerals and the frequent dependance of the bulk of one on that of the other, as well as the fact that in general they were deposited more or less contemporaneously, strongly suggest that in this type of tin occurrence water-vapour at temperatures between 575°C. and 358°C. was the main active carrier of the tin-oxide. The fact that the muscovite nearly always has a slight content of lithia and fluorine and by degrees passes into lepidolite and is often associated with lithia-tourmalines and occasionally fluorite, as well as the general accompaniment of greisenization by albitization of the felspars, indicates that the solving power of water-vapour was considerably reinforced by the presence of HF or more probably alkaline fluorides (LiF and NaF) and boron compounds held in solution.

In the light of this evidence it may safely be assumed, that in those tin-occurrences in which the cassiterite is associated with muscovite and lepidolite, the water-vapour responsible for the hydration of the felspars was also mainly responsible for the introduction of the cassiterite, its solving power being still further increased by the presence of alkaline fluorides (LiF, NaF), boric acid and borates, as well as phosphoric acid (association of triplite and lazulite with muscovite and cassiterite) held in solution.

In the case of cassiterite being deposited from aqueous solution during the early hydrothermal phase, the presence of sulphides, among them arsenopyrite, suggests that sulphur and arsenic served as additional aids to solution.

In the initial and earlier phases of pneumatolysis, conditions appear to have been different. In the occurrences belonging to these types muscovite is sparsely developed or altogether absent, and in the pegmatites situated in granite cassiterite occurs intimately associated with black iron-tourmaline. Hydration of the felspars to form muscovite was quite a subordinate process in the deposition of the tin, and for this the higher temperature of the vapours and their consequent different composition were no doubt mainly responsible. But why do black iron-tourmaline and cassiterite, in the ordinary case governed mainly by the effects of a temperature gradient, mutually exclude each other, while in the pegmatites situated in the parent granite at Paukwab the two minerals are intimately intergrown? Possibly at these higher temperatures, before water-vapour began to take an active part in the metasomatic reactions, boron and tin were originally actually combined. Such compounds of tin and boron exist in nature, as, for instance, in the rare minerals paigeite and hulsite, found in the tin-occurrences of Seward Peninsula, Alaska. Further, the rare mineral nordenskioldine, described by Broegger, represents a borate of calcium and tin. Subsequent alterations of a related compound of boron and tin, perhaps by hydrolysis, may then have produced the intimate intergrowth of tourmaline and cassiterite.

In the case of those pegmatites in which the cassiterite is not associated with any other pneumatolytic mineral except secondary albite, it is difficult to express an opinion as to the nature of the carrier of the tin oxide. These occurrences also belong to the initial phases of pneumatolysis and the cassiterite was deposited at a higher temperature. As the cassiterite is accompanied by secondary albite and black tourmaline is usually present in small amounts, and moreover compounds containing fluorine and boron are distributed in great abundance throughout the fields, most likely fluorine and boron compounds were the active agents in these latter cases. It is possible that the SnO_2 was deposited by the direct action of SnF_4 on quartz and felspar, as suggested by Wagner.[8] It is interesting to note in this connection that the fluo-silicate topaz, which would be one of the products of the action of SnF_4 on felspars, occurs together with black iron-tourmaline and cassiterite in a number of localities, particularly in the pegmatites situated in granite at Paukwab.

Wagner cites as one of the most notable features of the various occurrences of tin on the Mutue Fides-Stavoren Tinfields in the Transvaal[8] the constant and intimate association of cassiterite with quartz. In a great majority of cases the cassiterite has selectively replaced the

[8] Wagner, P. A.: "The Mutue-Fides-Stavoren Tinfields," *Geological Survey Memoir*, No. 16, p. 167.

quartz in preference to felspar. As an explanation, he suggests the fact that silicon and tin are closely allied elements, both belonging to the carbon group in the periodic classification, and, even more important, the fact that quartz and cassiterite possess nearly the same molecular volume. The replacement of quartz by cassiterite in preference to felspar would thus involve a minimum expenditure of energy. In the case of the tin-bearing pegmatites of the Erongo area just the reverse is the case. While quartz has also been extensively replaced, nevertheless invariably the cassiterite shows a preference for felspar. The same is true of tourmaline, though to a lesser degree, since here the cassiterite was deposited more or less simultaneously with muscovite. While the hydration of the felspars was in progress, the stannic oxide held in solution would also tend to be deposited, replacing the felspar in process of decomposition by its solvent. The cassiterite would be most readily precipitated where its solvent was actually involved in chemical reaction with the felspar, particularly since this most probably also involves a saving of energy, apparently more so than in replacing quartz.

A somewhat similar reasoning would also apply to the association of cassiterite with tourmaline, which, however, also replaces quartz to a large extent.

In the case of cassiterite unaccompanied by either muscovite or tourmaline, microscopic sections show that the cassiterite still preferably replaces felspar, but not to such a great extent as previously, and for this the fact that the potassium felspars were at the same time undergoing albitization, while the quartz suffered no contemporaneous change, is probably responsible. It may be, however, that a definite chemical reaction takes place between felspar and cassiterite or its fluoric compounds, apart from mere metasomatic replacement. What this reaction, if existing, actually is, is difficult to say.

Before closing this discussion, it may be pointed out that the sequence arrived at, *i.e.*, the formation of black iron-tourmaline or tinstone alone or in association with each other at higher temperatures, the deposition of muscovite and the bulk of the cassiterite, phosphates and compounds of lithium and fluorine at lower temperatures and the precipitation of cassiterite from aqueous solution, together with sulphides of iron, copper and arsenic at lower temperatures still, closely agrees with the composition of fumaroles with declining temperature. For it has been found that the hottest fumaroles emanate essentially compounds of boron, fluorine, chlorine and phosphorus. With decline of temperature these change into exhalations of sulphur, arsenic and their compounds, while those possessing the lowest temperature emit mainly water and carbonic acid.

Vertical Ranges of the Minerals.

Apart from theoretical considerations based on the vertical zonal distribution of the various minerals found in the Cornish Tin-mines (Malcolm MacLaren, *Mining Magazine*, 1917), in the Erongo Tin-fields there is very little definite evidence to go on. At most localities very little development work has been done. The deepest shaft put down does not exceed 240 feet, and that is an isolated instance.

A noteworthy feature of the tin-fields is the occurrence of deposits belonging to various stages of pneumatolysis and hydrothermal activity and theoretically to different horizons, side by side on the same level, *i.e.*, the present day surface. This is no doubt due to the long extent of the process of granitic intrusion while the ancient sediments were being actively folded, the intrusion of the magma in several successive phases to form numerous isolated and closely adjoining conformable bodies, the very varying heights within the sediments to which the various bodies were intruded and the fact that the tin is associated with more than one phase of the granite intrusion. A considerable amount of overlapping and intersection of the theoretical horizons is therefore bound to be the result.

To use the altitudes of the various localities on the present-day surface to obtain an idea of the thickness of the tin-horizon is not permissible. It cannot be sufficiently stressed that the present surface is no indication whatsoever of a former uniform horizon, not only on account of the reasons just stated, but also because subsequent to the intrusion of the old granites and associated pegmatites the ancient sediments and intruded rocks have been extensively and intensely folded, and with them any tin-horizons that may have existed.

Evidence enabling a rough estimate of the vertical range of cassiterite in at least one region of the tin-fields is, however, not altogether wanting. Along the western slopes of the Erongo, below the Hohensteine, some of the occurrences are situated high above those on the adjoining plains. On Schimansky's claims a deep gully exposes a measured vertical distance between two closely adjoining well-mineralized occurrences of about 800 feet. The numerous occurrences situated at the foot of the mountain on the edge of the adjoining plain are still 200-300 feet below the lower of these two outcrops. It is evident, therefore, that at least in this limited region the cassiterite occurs over a considerable vertical height.

Generally, however, it must be stated that while there is evidence of a reliable character,—in the above instance even proof—of the considerable vertical range of the cassiterites, there is absolutely no assurance as to the continuity or workability of any particular occurrence in depth, for it is a well-known fact that all tin-occurrences not of secondary alluvial origin are liable to be erratic in nature. With the exception of a few isolated occurrences belonging to the early hydrothermal phase, the cassiterite throughout the fields is a pneumatolytic mineral and was introduced by gaseous solutions that travelled along narrow channels under high pressure, and very frequently appear to have rushed from point to point, where favourable conditions existed for their concentration, frequently leaving the intervening spaces absolutely barren. Very seldom did anything like a general and uniform permeation of the pegmatitic rock take place. The conception of deposition having taken place from gaseous solutions under higher pressure also serves to explain how very considerable quantities of cassiterite were frequently introduced from what in many instances were mere cracks and even submicroscopic channels.