GEOLOGICAL FEATURES OF THE PANASQUEIRA TIN-TUNGSTEN ORE-OCCURRENCE (PORTUGAL)

BY

C. BLOOT and L. C. M. DE WOLF

PREFACE

In the summer of 1951 Professor ir H. F. Grondijs, retired professor at the Technical University of Delft, Holland, enabled some of his former students to make a visiting tour through some of the mining districts of Spain and Portugal. Introduced by Professor Grondijs we had an opportunity to visit the Panasqueira tin and tungsten mines in Portugal. During this visit the necessary samples and data were collected in order to write the hereafter presented report.

We are therefore particularly indebted towards the Staff and Management of the Beralt Tin and Wolfram Ltd. for their hospitality and cooperation during our stay at Panasqueira and afterwards.

We want to express our feelings of gratitude towards Professor Grondijs also who offered us this unique opportunity to get acquainted with many aspects of life on the Iberian Peninsula.

Furthermore we want to thank Professor Décio Thadeu of the Instituto Superior Técnico at Lisbon for his assistance and his critical reading of the report and the Department of Mining at the Technical University of Delft where the report was written, for the assistance we did receive in many respects.

Delft, September 1953.
Gebouw voor Mijnbouwkunde.
SUMMARY

The concession of the Beralt Tin and Wolfram Ltd., the main European tungsten producer, is located in the Beira Baixa province of Portugal.

The centre of this mining region, Barroca Grande, is 34 km. distant from Fundão and 290 km. from Lisbon, the export harbour for the concentrates.

At an altitude ranging from 350 to 1080 m. above sea level this area belongs to the Cordilheira Central at the foothills of the Serra da Estrela, the highest mountain range of Portugal.

The tin-tungsten mineralization took place during the Hercynic orogeny, during which period the granite intrusions of the surrounding massives Serra da Estrela and Gardunha originated. The deepest workings at Panasqueira have now reached the granite-greisen apophyses of these intrusions.

Production comes entirely from mineralized quartz veins in Algonkian metamorphosed sediments; in a genetic classification the ore occurrence has to be attributed to the lower limit of the hypothermal quartz vein deposits.

Greisenization without the development of topaz, fluorite and tourmaline is the usual type of wall-rock alteration in granite, while tourmalinization is the common type of alteration in argillaceous sediments near the veins; greisenization increases from the central part of the apophyses to the border zones.

The veins are mainly composed of massive quartz, a muscovite selvage and various accessory minerals. Wolframite and cassiterite are the ore minerals, from the sulphides arsenopyrite is most abundant and in decreasing order are found furthermore: chalcopyrite, pyrite, marcasite, sphalerite, pyrrhotite, and only small quantities of bismuth, bismuthinite, galena, stannite, tetrahedrite, rutile and traces of gold.

Mineralization followed joint planes, which can be divided into those with a low dip and those with a semi-steep dip. The low-dip veins, dipping S. W. and N. W. are the most important; the semi-steep veins dip S. E.

Ore bodies, chiefly confined to the S. W. dipping quartz veins are lenticular in form, up to 1.20 m. wide and thinning out at their edges; their average thickness is about 30 cm., their dip 10°.

Mining is mainly in the area East of the Main Fault, which originated during the Alpine orogeny, bringing a lead-zinc mineralization.
INTRODUCTION

Panasqueira is situated in the Cordilheira Central surrounded by the massives of São Pedro do Açor and Gardunha, in the foothills of the southern flank of the Serra da Estrela; it belongs to the Beira Baixa province, where temperatures are 4° C. in December, 24° C. in August, and rainfall resp. 195 and 10 mm.

The greater part of the concession which covers about 15 km.² is located North of the river Zézere, a tributary of the Tagus and the main drainage of this area, at an elevation ranging between 300 and 1080 m. above sea-level, in latitude 40° 10' N., and in longitude 7° 45' W.

Fundão, the nearest railway station, is at a distance of 40 km. from Panasqueira and 290 km. from Lisbon, the export harbour for the concentrate.

Mining for tungsten started in 1898 by a Portuguese company; legend has it that the Romans and later the Moors worked the property for cassiterite, but nowadays the output of cassiterite is about 10 % of the tungsten production; wolframite is the occurring mineral for tungsten.

Since 1928 the Panasqueira concession is worked by the Beralt Tin and Wolfram Ltd., which company brought the production from 25-30 Tons of tungsten concentrates up to over 200 Tons monthly.

Thanks to the reorganization and new investments in 1934 a steady and consistent increase in production caused Portugal to rank as the most important tungsten producer of Europe.

The export quota are of fundamental importance for the western hemisphere; longterm contracts with the U. S. guarantee the company a fixed price for this strategic mineral.
Fig. 1 — Map of Portugal showing position of Panasqueira Mines relative to schists and granite.

(After Allan, Smith and Lewis)
The production of 2,520.871 Tons in 1943 dropped in 1949 to 1,686.560 Tons, but has been equaled last year; this peak in production is for the moment probably the limit, for any increase beyond that is hampered by the size of the cable-way with a length of 4,150 m., and by the rather overburdened concentrating plant. The product is a high grade WO₃ concentrate (72.5 %) with very low tin and arsenic; recovery 90 %.

Diamond-drill holes indicate the persistence of wolframite for 200 m. below the present deepest workings, so the Panasqueira Mines may have a long future ahead, as the flat-lying vein system suggests an important lateral persistence.

Fig. 2 — Geological sketch of the Iberian Peninsula.

(After Schumacher)
GEOL OGY

1. General description

Geologic setting and ore-genesis are closely related in the tungsten area's of the world; grouped in metallogenetic provinces it is noteworthy, that nearly all of them border on oceans. The geological explanation of this phenomenon must be sought in the meeting places of the rising continental mountain ranges and the sinking sub-oceanic troughs, which are zones of special instability. These zones are predestined to reestablish the isostatic equilibrium, which effect is performed by orogenesis; this process is followed by an upward movement of magma and mineralizing solutions.

The mineral wealth of the Iberian Peninsula is reflecting on a smaller scale a similar relation between geological and metallogenetic factors.

The ore deposits are concentrated in the West, North and Southern border zones of the peninsula, while the central part of the Iberian Meseta, the E. and N.E. are devoid of, or poor in mineral deposits.

Geologically this is explained by the folded mountain ranges in this area, and on a tectonic-magmatic basis the Iberian metallogenetic province can be divided in three sub-provinces:

1) The Atlantic region in the W. (Randgebirge).
2) The Mediterranean region in the South.
3) The Cantabric region in the North.

Spain and Portugal are from a geological point of view so congenial, that they can be considered as one unit.

The middle part of N.W. Portugal consists of the so-called Hesperic Massif, bordered in the South by the Andalusian and in the North by the Cantabric-Pyreneaic folded mountain ranges.
GEOLOGY

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The middle part of N.W. Portugal consists of the so-called Hesperic Massif, bordered in the South by the Andalusian and in the North by the Cantabric-Pyrenean folded mountain ranges.
The old Iberian socle or Grundgebirge, outcropping in the Western border-zone of the Meseta especially in Galicia and Northern Portugal, is broken up by long mountain ranges in S.W.-N.E. direction reaching in height up to 2000 m. and dividing the peninsula into two parts.

The Atlantic region to which the Portuguese tin-tungsten deposits are confined, originated during the Hercynic orogeny and forms a broad longstretched belt extending from the outermost N.W. corner of Spain to the tertiary Guadalquivir Graben in the South. A dividing line at the height of Castelo Branco, not far from Panasqueira, cuts this belt into two parts; the Northern consisting of enormous granite masses, the Southern of proterozoic and palaeozoic sediments intruded by the former.

In this region are located the tungsten deposits: Pontevedra, the largest producer of Spain; Orense; Zamora; Salamanca; Caceres, and Coruña with the Las Phenicias mines all in Spain; and in Portugal: Trás-os-Montes with the Cerva, Borralha and Ifanes mines; and the Beira Baixa region with the Panasqueira mines, the latter being the most important tungsten producer in Europe.

2. The Panasqueira Region

In Portugal the tungsten deposits are found mainly North of the Tagus in a region of muscovite and muscovite-biotite granite. This region is intersected by two belts of palaeozoic and proterozoic metamorphic sediments running in a W.N.W. direction; one from Porto to Viseu, and the other from Vila Real following the course of the Douro to the Spanish border.

Panasqueira is located in the Beira Baixa province, that is integrated in the Hesperic Massif consolidated since the end of the Palaeozoic. The stratigraphic series in this area is a very incomplete one. The basement consists of precambrian marine formations, slates, graywackes and quartzites, which are attributed to the Algonkian. Over these strata are settled small discordant outcrops of ordovician formations, also consisting of marine sediments, followed by a large stratigraphic gap, which extends all
over the rest of the Paleozoic and probably almost the whole of the Mesozoic.

During this hiatus the Hercynian orogeny took place, ridding the ordovician outcrops N.W.-S.E. and giving rise to a schistosity of the algonkian formations in the same direction.

The granite and the tungsten mineralization of this region are related with this orogeny. According to some investigators it belongs to the Asturic phase, Post-Westphalian and Ante-Stephanian; much credit is given to Prof. Carlos Teixeira, who dates it Post-Stephanian and Ante-Permian, while others refer to the Saalic phase between Permian and Trias.

The ancient massif is covered by formations of continental sediments, whose geological age is difficult to determine on account of the lack of fossils. These formations consist of arkoses, sheet-floods and terraces, which are thought to date from the Upper-Turonian to the Holocene. A later orogenetic movement took place during the Alpine orogeny, possibly the Meso-Alpine phase. This resulted in a series of fault blocks in E.N.E.-W.S.W. directions, followed by an epithermal lead-zinc mineralization, which is also found at Panasqueira along fault lines.

The influence of the Alpine epirogenetic movements at Panasqueira is demonstrated by the Falha Principal and the Falha Poente forming a small Graben.

Aside from these tectonic periods the Caledonic orogeny has to be mentioned, but that was no metallogenic epoch, and its effects are nearly vanished by the influence exerted by younger mountain-building phases.

PETROGRAPHY

I. Granite

1. General Part

Concerning the problem ore genesis-petrogenesis, the intimate relationship between granitic magma and tungsten mineralization is accepted by all geologists. Both seem progressive
manifestations of the same process of igneous activity, of which the granite intrusion marks an earlier stage than the tungsten deposits.

All over the world this granite is a biotite, or biotite-muscovite granite, and if exclusively muscovite is present, it is most probable that part of the muscovite is a bleached biotite; examples are: Panasqueira, the Kiangsi-district in China, Banka and Billiton in Indonesia, Erzgebirge in Germany.

As for the genetic type of granite, it can be stated that in Portugal both types are found, the magmatist's as well as the transformationist's granite, both attended by tungsten occurrences.

The Panasqueira intrusion, a «granite en massif circonscriit» (Raguin) is marked by a sharp contact against the argillaceous rock and by an aureole of thermal metamorphism.

The Bragança granites however, consist part of a magmatic granite and part of an anatexis granite, attended by «lit par lit» injections and embrêchites; the latter is also the case in Egypt, but most of the world's tungsten output is related to the classic type of a magmatic granite.

2. **Granites of the Atlantic region**

Granite is the most wide-spread rock of Northern Portugal and Galicia; the outcrops reach from Castelo Branco, Guarda, Viseu and Porto in the South to the coast of Galicia in the North.

The Southern granites of the Atlantic region extend to the Guadalquivir-Graben, they are intersected by bands of schists, slates and gneissesse, or burried under recent formations.

This area, a belt of 700 km long and 225 km wide along the Western coast of the Iberian Peninsula, is characterized by tin-tungsten deposits.

The classification of these granites in Portugal is the subject of a fervent controversy.

Cotelo Neiva made a study on a petrographic-geochemical basis and concluded, that the majority forms a geochemically well defined group of the calcium-alkaline rocks of the Pacific province (Niggli), all of the same age, genesis and magmatic province.
The main granite introduction would have occurred in the Saalic phase of the Hercynic orogeny, Post-Permian and Ante-Triassic (Cotelo Neiva and Carrington da Costa); the former extends the geochemical relationship of these granites to those of the same orogenetic phase in Spain, France and Great-Britain.

Carlos Teixeira assumes for geologic reasons at least two periods of granite introduction, one Asturic and the other between Middle-Stephanian and Lower-Autunian; the tin-tungsten mineralization should be related to the latter.

An other classification is from Parga-Pondal:

1. Archaic granites; gneissic texture, feldspars kaolinized, rich in muscovite, little or no biotite.
2. Huronic granites; granular texture, feldspars altered, muscovite and biotite in equal quantities.
3. Hercynic granites; porphyroid texture, feldspars unaltered, rich in biotite:

3. Granites of the Beira Baixa Province

In spite of the controversy in age-determination, all investigators agree on the Hercynic origin of the granites of Beira Alta and Beira Baixa; and as most credit is given to Carlos Teixeira, the age of this granite and their related ore deposits may be assumed as Post-Middle-Stephanian and Ante-Lower-Autunian.

The predominating granite of the Beira provinces is a porphyroid biotite granite gradually passing into an equi-granular granite, with biotite prevailing over muscovite; going from granular to porphyroid there is an increase in feldspar phenocrysts and biotite.

This textural and mineralogical difference in granites, which originated from the same magma, is due to the gradual evolution in time and space of the physical and chemical factors ruling the process of differentiation and consolidation.

According to Cotelo Neiva the process of consolidation was extremely slow. In this respect has to be mentioned, that the intensive search for tungsten in Soviet Russia revealed, that from a geochemical point of view the ore-bearing characteristics indicate
a quietly cooling granite intrusion being the most favorable factor for the deposition of tin and tungsten ores.

The same is reported from Kalima in the Belgian Congo. The Panasqueira ore body is located in the Hesperic Massif in an area of Ordovician quartzites and slates, and Algonkian schists and graywackes, as a roof pendant between the wide-spread granite outcrops, nearest of which is the small Argemela outcrop at a distance of 12 km.

In the South the granite area of Castelo Branco and Idanha-a-Nova is found with border zones and apophyses of a coarse to medium grained texture and a predominance of muscovite, while the central part consists of a porphyroid granite, with a marked orientation of the feldspar phenocrysts.

![Fig. 4 - Schematic Section Panasqueira-Fundão.](image)

The contacts between the sediments and the intrusions are sharp.

An other large granite outcrop is in the area of Covilhã and Belmonte, North of Panasqueira. The texture of this rock is coarse-grained to porphyroid, and biotite is the main representative of the mica's, locally some white mica is present, but for most part it is a bleached biotite. In this area syenites and uraniferous veins are found together in granite.

Between those large granite area's lays the small outcrop of Fundão, with apophyses at Castelejo and Argemela in the direction of Panasqueira. In contrast with the previous outcrop this one is marked by irregular contours and inclusions of long-shaped belts of Algonkian schists, more or less following the contours; the whole suggests an apophyse structure of the granite. The medium grained rock is mesocrate by the abundance of biotite.

The Argemela granite, nearest to Fundão, is aberrant from
all other granite outcrops, it consists of a leucocrate, holocrystal-line, fine-grained granite, with a more porphyritic than granular texture; the border zones are attended by tin-tungsten bearing quartz veins.

The Micro-photograph 1 shows some six-sided quartz crystals, with hexagonally orientated inclusions of albite, a matrix of albite and muscovite, and but little orthoclase.

Dr. J. Brak-Lamy reports from the same rock clinzoisite; in the sample represented by Photo. 1 this mineral could not be identified, but amblygonite was found in stead of it; this mineral occurs in the ore-bearing quartz veins of Panasqueira also.

The border zone of this rock is by no means granitic, by composition it is too low in orthoclase and too high in albite, and by texture it is more porphyritic than granular.

The blurred edges of the quartz crystals suggest a deuteric quartz, possibly with albitization and introduction of the pegmatite mineral amblygonite.

To this granite the intrusive rocks encountered on the lower levels of the Panasqueira ore-body are presumably related.

4. The Panasqueira Granite-Greisen series

By the following section (Fig. 5) is demonstrated, that the deepest workings have reached a granite-greisen rock, but this does by no means imply, that the akro-batholith has been reached. By diamond-drill holes is proved the apophyse character of the granitic intrusion; moreover the mineralized quartz veins are posterior to the apophyses and suggest a vertical and lateral persistence of the ore below the granite-greisen series; the batholith is assumed by Prof. W. R. Jones to be 2,000 feet below the Main Adit Level. The probable orientation of the apophyses, deducted from drill holes is a N.W. strike and a S.W. dip.

This orientation suggests on a lower level the presence of the batholith dipping in the same direction. Reasons for this supposition are the lack of granite outcrops W. and S.W. of Panasqueira and the large granite area in the E. and N.E.; the end of the contact-metamorphism aureole W. of Panasqueira agrees
with this idea (see geol. section, Fig. 4) and further the character of the outcrop of Fundão, which is marked by apophyses following the contours of that outcrop; the apophyses of Panasqueira may have the same tendency and indicate the contours of the batholith.

The alteration of the original granite apophyses can be followed step by step in thin sections, and the first thing to note is the vertical reiteration of this alteration. The indication of the different stages may be effected by a greisenization-ratio.

As the index for greisenization is the alteration of the feldspars, this ratio is based on the feldspar content of the original granite.

As a standard for the original granite has been assumed the granitic middle-part of the lower apophyse (see Photo. 3a & b), which by texture is a granite, but by composition not the usual type of a granite (45% quartz and 35% feldspars), the granites
of other tin-tungsten area's however exhibit more than once a similar composition, cf. Cornwall.

To this rock, with 35% F., has been given the ratio 0.00, and to the greisen with 0% F. the ratio 1.00; the formula for the greisenization-ratio is: \( 1 - \frac{\% F.}{35} \).

### Greisenization of the lower apophyse

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<th>Greisenization Ratio</th>
<th>Photo No.</th>
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<td>55.80</td>
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The central granite is a leucocrate, pink coloured, medium to fine grained rock with a hypautomorphic granular texture (Photo. 3a & b).

The main minerals in decreasing order of abundance are: quartz, orthoclase, white mica, oligoclase, and apatite.

The allotriomorphic quartz exhibits unduloze extinction and strings of gaseous and liquid inclusions.

Orthoclase has a dusty appearance; perthite and myrmekite are frequent.

The polysynthetic twinned plagioclase is oligoclase, often embedded in orthoclase, and marked by apatite inclusions.

White mica is found in large flakes, sometimes asteroid radiating.

Remnants of biotite show a transition to chlorite and muscovite; around zircon and nuclei of an opaque mineral radio-active matter produced pleochroitic haloes in the bleached biotite.

Apatite crystallized early, and is rather abundant averaging 20\%.

The character of this central granite indicates by the presence of perthite and myrmekite the incipient deuteric alteration of this rock.

Myrmekite is, according to Sederholm, a deuteric intergrowth of quartz and feldspar, and perthite is assumed by Brøgger to be due to cooling of orthoclase, which at high temperatures may hold in crystal-solution other feldspar molecules, that may separate on cooling; but perthite may also originate by deuteric action.

From this granitic middle-part in both directions, upwards and downwards, the effects of alteration become more and more pronounced and metasomatic replacement results in a greisen consisting of about 60\% quartz and 40\% mica.

In the original granite orthoclase prevailed over plagioclase, but within a short range this ratio is reversed; this is not surprising as the instability of orthoclase is demonstrated by perthite and myrmekite, moreover most of the plagioclase is embedded in orthoclase so the latter is the first to disappear.

Orthoclase is replaced by quartz and mica, the bordering quartz grains penetrated from different sides and enlarged their
volume by silica derived from the feldspars, in optical continuity to the primary quartz. In the final greisen the existence of secondary quartz appears only by the random intergrowth of the meeting quartz fronts; the secondary mica differs from the primary by the smaller size of their flakes.

Plagioclase altered similarly but offered more resistance, ghost-structures are found even in the last stages of the process; in some cases there existed a certain preference for the replacement of some twin lamellae.

With a few exceptions tourmaline is rare in the granite-greisen series and if there is any it is the blue variety.

In the marginal part of the apophyse new minerals have been introduced by quartz veinlets, sometimes they are disseminated through the greisenized rock; marmatite, pyrite, arsenopyrite, chalcopyrite, carbonate and chalcedony. (see Photo. 6).

The alteration of the original rock is marked by a loss of lime, soda, iron and magnesia, and the concentration of silica and potassium, partly residual.

By Raguin the process of greisenization is considered pneumatolytic, but the presence of sulphides, carbonates and chalcedony indicates, that this process extended to a late hydrothermal phase; so at Panasqueira it may be called deuteric or transitional pneumatolytic-hydrothermal.

The vertical reiteration of the greisenization phenomenon is a typical feature of the complex of apophyses. The transforming solutions are not the autochthonous products of differentiation within the apophyses themselves, but they escaped from the batholith during the deuteric phase.

The explanation for the reiteration within the lower apophyse may be, that posterior quartz veins intruded the granite and greisenized the rock along their contacts, a common type of wall-rock alteration.

An other hypothesis may be, that the lower apophyse is a complex one, and that the highly mobile fluids followed the mutual contacts as they did along the contact apophyse-schist.

In any case, the deuteric alteration of the intrusion, with a thickness of about 50 m, wether due to greisenization along different apophyse contacts, or to the influence of posterior quartz veins,
it is certainly not due to auto-metasomatosis, but the result of allochthonous, deuteric fluids.

II. Wall-rock alteration near the granite apophyse

The contact between the argillaceous schists, «Complexo xisto-grauváquico das Beiras», with the apophyses is extremely sharp. The alteration of the schists is identical on both sides of the granite-greisen apophyses.

Harker states, that the sequence of processes following the intrusion of a granite falls into three stages:
1. Thermal metamorphism.
2. Pneumatolysis.
3. Invasion of iron-bearing solutions and introduction of sulphides.

The effects of thermal metamorphism are found throughout both Beiras.

Duparc reports from the Viseu area chiastolite and an isotropic, greenish-gray substance, which is interpreted as a glassy, or crypto-crystalline matter, indicative of the initial thermal metamorphism. In Panasqueira the same phenomena occur, and Décio Thadeu proposes cordierite for the above described matter. Cordierite is a common mineral in low-grade thermal metamorphism and it is in accordance with the presence of chiastolite. The pseudo-hexagonal habitus of the unclear cordierite is demonstrated by Photo. 14; in Photographs 7, 8 and 9 pressure may have caused an aberrant appearance.

Near the immediate greisen contact these spots consist of biotite, this zone is half a meter wide and is preceded by a zone of chlorite. The sequence of cordierite-chlorite-biotite parallels with an increase of iron and magnesia; this may be due to introduction of these elements from the apophye, or may be derived from the original clayish sediment itself.

In the first case this would imply a basic front, as the greisenization of the granite is accompanied by the expellation of these elements by the transition of biotite to white mica. If the expelled elements travelled into the surrounding sediments, the
transition from cordierite to chlorite and from chlorite to biotite might be possible.

On the other hand, the presence of pyrite, ankerite and a chloritic paste in the original sediment (see Chapter IV) proves, that the needed elements could have been supplied by the sediment itself. In this case the sequence is due to thermal metamorphism with cordierite as the lowest and biotite as the highest grade of it.

The pneumatolytic stage of the wall-rock alteration parallels with that of the transition of granite to greisen. The rock altered by silification, sericitization and the introduction of sulphides, mainly pyrite and arsenopyrite. Tourmalinization was rather insignificant as compared to the effects around the mineralized quartz veins, the average content of tourmaline is only a few percents, but occasionally it reaches higher values.

A typical feature of these sediments is the content of apatite, up to 2%: the perfect hexagonal habitus indicates, that this mineral is not an original constituent of the rock, but has been introduced by deuteric fluids.

Another phenomenon easily seen by the unaided eye (Photo. 8) is the occurrence of carbonate dots, rarely larger than 2 mm, the sediment contains 1 to 10% of it. This carbonate differs completely from the coherent carbonate introduced into the greisen; Photo. 9 demonstrates the loose and cloudy texture of these dots.

According to Cotelo Neiva this occurrence is related to the presence of apatite; as will be explained in Chapter IV, there is reason to consider those concentrations and part of the pyrite metacrysts as products of diagenesis.

III. Wall-rock alteration near the mineralized quartz veins

There is no fundamental difference between the alteration of the granite, the wall-rock of the granite, and the wall-rock of the mineralized quartz veins.

The analogue is the sericitization, chloritization, silicification, apatitization and tourmalinization. The difference is gradual, whereas the granite underwent silicification, sericitization, and but
little tourmalinization, the granite wall-rock is marked by sericitization, biotitization, chloritization and some tourmalinization.

The wall-rock of the mineralized quartz veins exhibits the same features, but silicification, and tourmalinization prevail over the sericitization, apatitization, and introduction of sulphides.

As can be seen from the adjoining diagram (Fig. 6) the development of the veins and their influence on the country-rock is symmetric. As a rule most lodes are bordered with mica-walls, when traversing sedimentary rocks, and invariably have adjoining greisen bands in granite.

This mica lining is directly followed by wolframite crystals in radiating clusters, or perpendicular to the walls.

Wolframite is attended by cassiterite, and the sulphides occur throughout the rest of the milky and glassy quartz vein. Locally completely tourmalinized fragments of the sediment are included.

The milieu of the quartz veins, devoid of tourmaline, offered the borium-bearing fluids no matter for precipitation, whereas the
aluminous country-rock could supply this in abundance. Within the range of one meter the tourmaline content drops from 90% to 0%.

The ways of access for borium were different, at some places the highly mobile fluids filtered homogeneously into the sediment (Photo. 12) at others they followed fissures in the rock (Photo. 11).

These fissures persist for some decimeters, and are perpendicular to the veins; a miniature of this occurrence is demonstrated by Photo. 10. The origin of the fissures may be due to the heat and pressure exerted by the intrusion of the veins.

In the immediate contact zone, the faint influence of thermal metamorphism is completely wiped out by tourmalinization and silicification. After some decimeters the influence of deuteritic action gradually dies out, then the cordierite metacrysts and carbonate dots appear again, attended by an increase in sericite.

Micro-photograph 13 demonstrates the superimposition of stress; the parallel orientation of sericite, the flattened shape of cordierite, and the growth of secondary quartz on both sides of pyrite in accordance with the principle of Riecke, all indicate one and the same direction of stress.

Accessory minerals are leucoxene and zoisite.

IV. The Sediments

The Panasqueira ore-body is located in Algonkian, marine sediments, which predominate in the Beira provinces. This formation mainly consists of argillaceous schists, the so-called «Complexo xisto-grauváquico das Beiras».

The lithologic varieties range between a sandy-shale, fine-grained quartzite, graywacke, and argillaceous schists; they have a lenticular mode of occurrence and are difficult to map.

Probably by Caledonic movements these sediments are displaced, the present situation at Panasqueira is: the dip varying from 40° to 50° S.E., the strike from E.-W. to N.E.-S.W.

In the immediate neighbourhood, discordant to the Algonkian formations, lies an arkose outcrop, which can be correlated with the Upper-Cretaceous or Lower-Eocene of the «Grés de Buçaco». 
The Panasqueira rocks grade from a lutaceous arenite to an arenite, they belong to the following classification of Pettijohn:

<table>
<thead>
<tr>
<th>Sandstone</th>
<th>Quartz + chert</th>
<th>Quartz + Chlor. + Seric. + Chert</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medium</td>
<td>Quartzite</td>
<td>Low-rank Graywacke</td>
</tr>
<tr>
<td>Fine Shales</td>
<td>Quartzose</td>
<td>High-rank Graywacke</td>
</tr>
<tr>
<td></td>
<td>Shale</td>
<td>Micaceous Shale</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Chloritic Shale</td>
</tr>
</tbody>
</table>

Although most part of the rock consists of a lepidoblastic aggregate of clayish matter, and for a smaller part of graywacke, the lithologic unity within this complex has to be emphasized. By a gradual change in the percentages of sericite, chlorite and detrital grains the different rocks grade into each other, and the whole can be indicated as a graywacke-shale.

The following features are shared by all members of this lithologic series: a dark appearance, macroscopically a more or less pronounced parallel structure, and the above cited clayish constituents. Particulars are cloudy carbonate dots, pyrite metacrysts, and badly developed pleochroitic haloes around nuclei of zircon and opaque matter.

They differ in the content of detrital grains, angular to sub-angular, absent in the schist and up to 60 % in the graywacke.

As graywacke contains all the constituents of the shales, the lithologic phenomena of the graywacke-shale series will be considered following the graywackes.

On account of a marked scarcity of feldspars, seldom exceeding 5 %, the rock is a sub-, or low-rank graywacke. By definition a sub-graywacke contains 15-85 % quartz, 0-10 % feldspar, 15-75 % silty and clayey matrix, and has a better rounding and sorting than the high-rank variety. To this type the Panasqueira rock belongs by composition and texture (see Photo. 14 & 15).

Microscopic examination reveals unclear and blurred boundaries of the detrital grains, it seems that chemical interaction has
taken place between the argillaceous matrix and the sand-fraction. The alignment of sericite and chlorite imparts a crude schistosity to the rock. The thickness of the formations and their disturbed geological past may be responsible for this chemical readjustment, which according to Pettijohn takes place upon the least provocation. By intensification of this process the rocks grade into crystalline schists.

A typical feature of the Panasqueira rocks is the occurrence of pyrite and carbonate disseminated throughout the whole graywacke-shale series. The pyrite occurs in euhedral cubes, which appear to have replaced the matrix in which they are embedded. Carbonate suggests the same but, as its crystallization-force is much lower, it resulted in a cloudy concentration of small dots marked by high refractory indices.

Cotelo Neiva, when dealing with these carbonates, assumed a relationship between the hydrothermal introduction of apatite and the hydrostatic level; he found carbonate attended by strongly altered ore-minerals above this level and apatite below it.

This is contrary to the facts; for example in a thin section of a diamond-drill core from a hundred meters below the present deepest workings at Panasqueira, or five hundred meters below the surface, the schist of the lower apophyse contact contains 10% apatite and 30% carbonate.

A second hypothesis, mentioned by Décio Thadeu, is the hydrothermal origin of this carbonate; this is possible, but not very probable.

The above cited features are found in similar rocks, far away from any intrusion, in other parts of the world; moreover the character of the hydrothermal carbonate in the granite-greisen series differs greatly from the carbonate in the wall-rock.

According to Krynine the euhedral pyrite cubes and the carbonates are related, both should be products of authigenesis. During the earliest pene-contemporaneous phases of diagenesis the sulphate-reducing bateria are thought to have attacked the sulphate, that was dissolved in the interstitial water, thereby forming sulphides.

These sulphides in turn reacted with CO₂ to form carbonates, in this way possibly magnesia-carbonates were precipitated in the pore-spaces of the mud.
This explanation is modified by Pettijohn, who prefers ankerite on account of the high refractory indices. In this respect the Panasqueira sediments exhibit the same features as are reported from other localities, so there is no reason to accept a hydrothermal origin for these carbonate concentrations.

Finally, it has to be mentioned that, sub-graywacke is indicative of a special tectonic environment, particularly of the post-orogenetic or Molasse phase.

V. Veins and dykes

The quartz veins can be divided in barren and ore-bearing veins, respectively anterior and posterior to the related granite.

The ore-bearing quartz veins, the Campo Filoniano, intersected the granite apophyses and caused greisenization along their contacts, so they are certainly posterior to the granite. Their structure is lenticular, and the veins are connected with each other in a complicated way, wedging out as «rabos de enguia», eel-tails, but marked by a uniform orientation, which persists when the veins pass over into the granite.

The veins are reduced to strings when entering the apophyse.

Besides the ore-minerals, which will be considered in detail in the following chapters, they consist of a milky and a glassy quartz.

The wall-rock of these veins is marked by intensive tourmalinization.

The barren quartz veins, the «Seixo bravo» system, differ fundamentally from the formers. They are devoid of ore-minerals, and not attended by tourmalinization of the wall-rock.

The quartz is of the milky type and has, in contrast with the other Seixo Bravo veins of the Beira Baixa district, a saccharoidal appearance.

The lenticular veins followed the schistosity of the schists, which underwent chloritization and the formation of pyrite meta-crysts.
Thermal metamorphism exercised by the posterior granite intrusion may have caused the saccharoidal appearance of quartz.

Diabase dykes are frequently found throughout the Hesperic Massif in a most uniform mode of occurrence. The majority has an E.-W. strike, some however N.-S.; their dip is almost vertical and the average thickness about 1-1.50 meter. According to Carlos Teixeira the E.-W. dykes are Post-Carboniferous and Ante-Liassic fillings of Saalic fractures.

Décio Thadeu classifies the diabase dykes of Hesperic Massif in:
1. Before the Hercynic granite intrusion in N.-S. direction, and,

At Panasqueira region, the former system prevails.

The fine-grained, mesocratic, porphyritic rock, a typical greenstone, consists of amphibole phenocrysts a few millimetres in diameter, embedded in a matrix of minute amphybole and plagioclase crystals; ore-minerals are a few streaks of pyrrhotite and magnetite. The amphibole of the phenocrysts is a secondary one, it is an altered pyroxene.

Photographs 16 and 17 demonstrate the porphyroid character of the N.-S. orientated diabase dykes by the amphibole phenocrysts, and a diabase structure; furthermore the rock has a sub-conchoidal fracture.

The intensive alteration is mainly due to amphibolitization even the small plagioclase crystals are affected by this hydrothermal process. The influence of stress and chloritization is subordinate, but Décio Thadeu reports from other places these as being the main causes of alteration.

The chronologic sequence of the various intrusivas is: 1. Ante-Hercynic diabase; 2. the barren quartz veins; 3. the granite-greisen apophyses; 4. the mineralized quartz veins; 5. the Post-Hercynic diabase.
VI. Mode of occurrence and morphology of the plutonic rocks

The surrounding granite outcrops indicate the intrusive character of the magma by sharp contacts, the lack of assimilation and palingenesis, and the presence of a normal contact aureole.

In the granite classification of H. H. Read, based on the genetic relationship between the rise of a granitic magma and orogenesis, the Beira's granite is a parautochthonous granite, i.e., a granite with the above cited features, which should have to be placed in the late geosynclinal phase of orogenesis.

The granite apophyses at Panasqueira exhibit the same character as the surrounding outcrops do; according to W. R. Jones the batholith itself may be at least 2000 feet below the Main Adit level, this is deduced from the aureole of thermal metamorphism around the other granite massives.

As has been stated at pg. 14 the S.W. dipping apophyses are supposed to run parallel to the granite cupola.

The ore-bearing quartz veins have not the same intrusive character as the granite apophyses, they are fissure fillings of pre-mineralization joint planes (Raguin: filons de diaclases).

The vein channels had already been opened up as a result of tension induced in the rocks during the process of intrusion and consolidation of the granitic magma; the uprising mineralizers found their way into these flat-lying fissures, and pressure was greatly reduced with consequent ore-formation. These ore veins intersect the apophyses, so the tension fissures must have been originated after this intrusion, otherwise the apophyses should have formed a barrier against the mineralizing fluids.

This is in contrast with the hypothesis of Allan, Smith and Lewis; they supposed that, «mineralization accompanied the granite intrusion and followed joint planes formed as the result of the main crustal movement which had previously affected the Iberian Peninsula.»

The structure of the quartz veins of the Campo Filoniano at Panasqueira is complicated, the lenses cross and meet each other, separate and peter out in a most peculiar way; but regardless of
this strange pattern their strike and dip, both in magmatic and sedimentary rock, is most uniform, over large areas.

They occur in parallel groups of overlapping lenses in every variation, from wide veins traceable for hundreds of meters along their dip to mere stringers. Granite and schist diverge widely in physical properties, so the vein pattern differs in both rocks.

A similar mineralization along pre-existing joint planes is found at Kiangsi (China) and Mawchi (Burma).

The relation between the intrusion and the mineralized vein system is visualized by Décio Thadeu in the adjoining diagram (Fig. 7) for Cabeço do Pião, the eastern part of the concession.
ECONOMIC GEOLOGY

VII. Morphology of the Mineralized Quartz Veins

The mineralized area of Panasqueira is divided by several faults of which the Main Fault is the most important one. This fault, definitely of later age than the mineralization of the veins, divides the deposit into two different parts on behalf of the position and the arrangement of the veins.

The veins in fact consist of a series of lenticular bodies with a length of a few meters up to a 100 mtrs. or more and these veins on account of their dip and strike and because of their mineralogical composition can be grouped in the following systems. (See also the following sections, Fig. 8 and 9).

Area east of the Main Fault:

This part of the deposit is by far the most productive as the veins in this part are highly mineralized with wolframite, whereas cassiterite only occurs in subordinate quantities. The veins east
of the Main Fault can be classified in two distinct systems, depending upon their dip and strike:

1) Normal System. A number of parallel veins dips 10-12° S.W. The vertical distance of the lenticular bodies with an average thickness of about 0.30 meter, varies from 5-20 meter. At least 10-12 of these bodies are of economic importance. The system is coincident with a well developed and easily recognizable joint-plane system in the country rock.

2) Galo System. The veins belonging to this system consist of quartz bodies with a dip varying from 30-70° S.E. The mineralization of these bodies is the same as that in the Normal System veins and most important are two steeply dipping
veins which traverse the area in a N.E.-S.W. direction (these veins are called: Galo Nascente and Galo Poente). The thickness of the veins, belonging to the Galo System, varies from 0.50-0.90 meter, while their spacing is irregular. This vein system also is coincident with a joint-plane system in the country rock.

The above mentioned steeply dipping veins (Galo Nascente and Galo Poente) are at the Main Adit level about 300 meters apart but downwards they seem to converge in a N.E. direction.

Area, west of the Main Fault:

In this part of the deposit short veins with an alternating dip of 7-8° S.E. and 7-8° N.W. are found.

Apart from the different positions of the veins belonging to different systems there are also differences in the mineralization to be noted.

The S.W. dipping veins are highly mineralized with wolframite, disseminated irregularly along the walls of the veins or embedded in quartz in the centre of the veins, cassiterite mostly occurring along the walls, chalcopyrite, sphalerite and arsenopyrite commonly associated with each other, mica lining the walls and quartz as the most abundant component. A close observation of the mineral arrangement in the veins cannot fail to suggest that both wolframite and cassiterite are invariably accompanied by mica along the walls and that wherever mica is present, wolframite and/or cassiterite also can be found.

The S.E. dipping veins are poorly mineralized, except the two already mentioned steeply dipping veins, the Galo Nascente and the Galo Poente. These veins show about the same features as the veins of the S.W. dipping system.

Fig. 10 shows the position of the bodies of one vein towards each other. A particular feature of these bodies is that at their extremities they are sometimes highly mineralized with wolframite and cassiterite whereby the body deserts one joint-plane to a higher or a lower one. The bodies are usually connected with each other by means of a thin quartz stringer.
Fig. 11 shows some examples of bodies belonging to different vein systems crossing each other. It is interesting to note that no traces of ore-enrichment or indications concerning the age-relationship between the systems are found.

Fig. 10 — <Rabos de engnia> or eel-tails. In these extreme parts of the lenses, cassiterite and wolframite occur enriched. Following Thadeu, cassiterite occurs especially enriched in the outermost parts of the lenses (see zone a, b and c).

a, cassiterite only; b, wolframite and cassiterite; c, ordinary mineralization of the lens. a and b are the enriched zones of the lenses.

Fig. 11 — Some examples of veins, belonging to different systems, crossing each other. No enrichment of ore nor any indication concerning the age relationship between the vein systems can be seen on these crossing points.

The N.W. dipping veins (on the western side of the Main Fault) show about the same features as the S.W. dipping veins on the eastern side of the Main Fault.
VIII. Vein Minerals

Macroscopic and microscopic examinations of samples as well as observations on the ore «in situ» show the presence of the following mineral assembly in the veins:

- **Oxydes**: quartz, cassiterite, rutile.
- **Tungstates**: wolframite.
- **Phosphates**: fluorapatite, manganous fluorapatite.
- **Halogenides**: fluorite.
- **Carbonates**: siderite, a.o.
- **Silicates**: tourmaline, mica.
- **Sulphides**: arsenopyrite, sphalerite, chalcopyrite, pyrite, pyrrhotite, stannite, tetrahedrite, bismuth, bismuthinite, galena, pyrite-marcasite, a few flakes of chalcocite.

Quartz is by far the most abundant mineral in the veins and offers a good guide in the ore-dressing plant as white quartz is easily recognized and therefore easily handpicked.

Fluorite has not been observed in samples but only «in situ» where it occurs in vugs along with quartz.

The mineralogical composition of the veins shows much resemblance to the mineralization in other tin-tungsten deposits of the world where always the same mineral assembly is found. (for instance: Burma, China). It will therefore be interesting to refer to literature on these deposits later on, on determining the distribution of tin and wolfram in the Panasqueira deposit.

**Ore minerals:**

*Cassiterite*— Usually cassiterite occurs coarse-grained but polished sections also reveal the presence of small grains. In quartz it often shows well developed crystal-faces and some perfectly developed cassiterite crystals were found, partially enclosed in quartz crystals (see Photo, 18). Sometimes cassiterite fills the remaining space between parallel quartz crystals. Thus a polished section of cassiterite shows a «seeve-like» structure and the screen-holes are six-sided on account of the quartz crystals. Contiguous
to wolframite cassiterite shows sometimes crystal-faces. The colour varies from light brown to black. No difference between differently coloured parts in the same crystal could be detected under the microscope.

**Wolframite** — Occurring in small as well as in large specimens of sometimes more than 8 cm. in length wolframite is found along the walls of the veins or embedded in coarse white quartz in the centre of the veins. Wolframite crystals also grew inwards from a selvage along the walls of the veins. Wolframite shows crystal-faces against cassiterite, arsenopyrite and quartz. Sphalerite and wolframite, nearly the same in reflectivity under the microscope, are easily distinguished between X-nicols and by the invariable presence of droplets of chalcopyrite in sphalerite.

**Arsenopyrite** — Arsenopyrite is predominantly found massive, with a fine granular structure, but is also found in well developed idiomorphic crystals. It is veined by sphalerite and chalcopyrite. Some mica is also interstitial to arsenopyrite.

**Chalcopyrite** — Coarse crystals of chalcopyrite are found but the main part occurs as droplets in sphalerite and as veinlets crossing through other minerals.

**Pyrrhotite** — Occurring widely scattered throughout the whole deposit pyrrhotite is not abundant. It occurs as flakes in chalcopyrite, arsenopyrite and sphalerite.

Remarkable is the occurrence of numerous flakes, partially coloured black in a groundmass of pyrite-marcasite. Photo. 19 shows pyrrhotite flakes being replaced by pyrite-marcasite. This replacement starts along the cleavage of pyrrhotite and gradually widens out thus forming so-called «birds eyes» of marcasite-pyrite in pyrrhotite (see Ramdohr). Finally pyrrhotite is totally replaced by pyrite-marcasite, the resulting mineral, pyrite or marcasite, depending on the prevailing conditions.

**Sphalerite** — Invariably accompanied by chalcopyrite, sphalerite occurs abundantly, chiefly in form of the black variety: marmatite. It occurs as irregular masses interstitial to minerals such as wolframite, mica, cassiterite, arsenopyrite and is replaced by chalcopyrite, pyrrhotite and pyrite along its cleavage.

**Pyrite-Marcasite** — Two varieties of pyrite are present, an easily polishable «smooth» pyrite invariably accompanied by mar-
casite. The latter assembly contains numerous remnants of pyrrhotite and carbonate and is of a definitely later age than the former, smooth pyrite. Photo. 20 shows mica next to wolframite. Wolframite is replaced by smooth pyrite with a typical flame—structure and veined by quartz.

*Galena, Stannite, Tetrahedrite* — These minerals occur in small quantities only and are invariably accompanied by chalcopyrite and sphalerite.

*Bismuth, Bismuthinite* — Both minerals occur separately as small flakes in chalcopyrite and arsenopyrite and together whereby bismuthinite invariably surrounds bismuth. (Ramdohr remarks: bismuthinite often replaces bismuth; bismuthinite however is replaced by chalcocite, especially in the cementation zone). See Photo. 21.

*Rutile* — Only minute flakes of rutile enclosed in quartz have been found. The presence of Ti-compounds is also confirmed by the analysis of some fluorescent apatite samples (see chapter on fluorescent apatites from Panasqueira).

**Gangue minerals:**

*Quartz* — Coarse white quartz is the main vein component. Occasionally quartz occurs as well developed transparent crystals in vugs. It is without doubt that there occurs more than one generation of quartz in the veins. This is clearly demonstrated by the form of quartz against the other vein minerals.

*Tourmaline* — Though tourmaline predominantly occurs in the wall-rock part next to the veins, some sharp needles of black tourmaline are found in vugs along the walls of the veins (see Photo. 22).

*Mica* — Usually mica occurs as a lining along the walls of the veins. Some mica is interstitial to wolframite and arsenopyrite. In this case the flakes are often distorted. See Photo, 22 and 23.

*Siderite* — Widely scattered throughout the whole deposit, siderite (and other carbonates) occur as well developed crystals
with the typical rhomboid saddles and as small veins crossing through other minerals. Photo. 24 shows a contact of siderite and quartz where triangles of siderite have been broken out on polishing the section. Photo. 25 shows the same features, accompanied by a carbonate crystal fragment and a pattern of parallel lines, in a polished section of pyrite-marcasite. It seems that carbonate has been replaced by pyrite-marcasite. Photo. 26 shows pyrite filling the remaining space between saddle formed siderite crystals. A section through a crystal assembly shows so-called «gothic windows» of siderite in pyrite-marcasite. Photo. 27 shows pyrite-marcasite replacing a gothic window along its contourlines and it seems that the crystal faces of siderite do not give any way of entrance to the pyrite that therefore has to look for another line of attack to replace siderite (note the zonal structure of siderite on Photo. 26 and 27).

Apatite—Well shaped crystals as well as small grains of apatite occur throughout the whole deposit in veins and in the country rock. Photo. 23 shows mica, veined by pyrite, and apatite interstitial to mica. Remarkable is the occurrence of fluorescent apatites (see chapter on fluorescent apatites from Panasqueira).

IX. Mineralization Sequence

A study of thin and polished sections shows that the mineralization of the veins can be divided in three important stages:

1. Early stage minerals: cassiterite, wolframite, apatite, mica, quartz, tourmaline, arsenopyrite.

2. Sulphide stage minerals: chalcopyrite, pyrrhotite, sphalerite, stannite, tetrahedrite, bismuth, bismuthinite, pyrite, galena, quartz, carbonate (a.o. siderite).

3. Late hypogene replacement stage: pyrite-marcasite, quartz, carbonate.

It stands to reason that this division does not mean that these three periods form sharply outlined and separate stages that all-together represent the mineralization of the veins. The
three stages are connected by transitions and one might say that the division is based upon the maxima of the formation periods of the minerals as these maxima were observed from samples and polished sections.

Furthermore the place of the minerals in one stage does not mean anything as it is impossible to determine their exact position towards each other more definitely.

For instance: the formation of sphalerite may have started before the end of the arsenopyrite period but the replacement structures and the intergrowths between these two minerals indicate that the maximum of the sphalerite formation followed after the maximum of the arsenopyrite period.

Perhaps it is possible to establish a more detailed mineralization sequence after the study of some hundreds of samples but in any case it will turn out that the formation periods of the minerals partially overlap each other.

As for example some outstanding replacements and intergrowths are described:

1) Cassiterite and wolframite show crystal faces against each other and against quartz. Cassiterite and wolframite sometimes partially envelop each other. There were found a few but perfectly developed examples of wolframite, replaced by cassiterite and some structures which suggest a replacement of cassiterite by wolframite. (see Photo 28 and 29).

2) Wolframite, cassiterite, arsenopyrite and mica are replaced by pyrite, sphalerite, chalcopyrite, galena, bismuth and bismuthinite.

3) Chalcopyrite accompanied by stannite, sphalerite and tetrahedrite replaces arsenopyrite.

4) Sphalerite is replaced by chalcopyrite, pyrite and pyrrhotite along its cleavage.

5) Pyrite replaces wolframite and penetrates into mica along the contours of the flakes.

6) Siderite and pyrrhotite are replaced by marcasite-pyrite that in turn is replaced by carbonate.

The mineralization sequence in the Panasqueira deposit shows much resemblance to the sequence in other tin-tungsten deposits of the world as can be seen from publications on this
subject. It also becomes clear that the formation periods of wolframite and cassiterite in every deposit considerably overlap. (see chapter on the distribution of tin and wolfram in other deposits).

It is therefore strange that Décio Thadeu in his discussion concerning the mineralization sequence at Panasqueira refers to the geochemical diagram of Fersman. Apart from the problem whether this diagram can be applied without any further argument to the mineralization at Panasqueira, it appears that, following this diagram, cassiterite and wolframite would have been deposited during separate periods. However the intergrowths and polished sections that have been studied show without any doubt that the formation periods of wolframite and cassiterite considerably overlap. It is however impossible to determine whether cassiterite or wolframite started formation first.

A remarkable feature of the deposit is found in a conspicuously constant mineralization along the dip of the veins, especially the S.W. dipping veins on the eastern side of the Main Fault show a constant mineralization along a considerable distance, about 2 km.

The Panasqueira deposit can be described as a mineralized roof-pendant. The only traces of igneous activity that have been found up till now are the granite-greisen apophyses. The apophyses and the mineralized quartz veins are closely related. Both are products, resulting from the differentiation of the actual batholith of which the apophyses mark an earlier stage than the quartz veins. The batholith itself has not yet been reached and drill-holes show that 200 meters below Main Adit level the mineralization subsist. This uniform mineralization over hundreds of meters along the dip is one of the striking features of the deposit and it will be interesting to investigate a bit further upon the controls that permitted the deposition of a uniform set of veins over such a considerable length in low dipping (7-8°) veins.
X. Distribution of tin and tungsten

For various reasons it is very important to get acquainted with the distribution of tin and wolfram throughout the deposit. This applies to the distribution in a horizontal as well as in a vertical sense. It is therefore logical that authors in papers on tin-tungsten deposits deal with this problem more or less in detail.

1. Distribution of tin and tungsten in the Panasqueira deposit

Already it has been mentioned that the Main Fault divides Panasqueira deposit in two parts with a different vein-facies each. In the eastern part occur, next to the less abundant S.E. dipping «galo» veins, the more abundant S.W. dipping veins (normal veins) that are highly mineralized with wolframite; cassiterite occurs subordinate, but increases with the depth. In the western part occur N.W. and S.E. dipping veins, predominantly S.E.; these veins are mineralized with wolframite, whereas cassiterite occurs rarely or is totally absent, even at the deeper levels. As the S.W. dipping veins on the eastern side of the Main Fault are the most important ones, it is interesting to discuss some problems concerning the «mise en place» of the minerals occurring in these veins. The main problem concerns the distribution of tin and wolfram in those parts of the deposit that have not yet been developed. Although it is impossible to predict with any certainty the changes in the tin-wolfram ratio that will be met with in the deeper parts of the deposit it is helpfull to approach this question by discussing the following features:

1. Differences in age between the vein systems.

a) No indications concerning an age difference were found between the vein systems (see chapter VII. Morphology of the veins).

b) In the S.W. dipping veins wolframite and cassiterite
are found next to each other and it is without doubt that both minerals were formed contemporaneously (see chapter IX. Mineralization Sequence).

2. Zonal distribution.

According to many authors on this subject in other tin-tungsten deposits many times a zonal distribution of tin and tungsten is found: in the deeper parts cassiterite, higher up a wolfram zone and in the upper parts of the deposit only wolframite. It is therefore a striking feature that this distribution also is found in the Panasqueira deposits, where the tin-content increases much with depth and attains its maximum in the apophyse zone.


In studying these problems one has to bear in mind that the «mise en place» of the minerals in a deposit is determined by the influence of the controlling factors (temperature, pressure, wall-rock, relative solubility, concentration of compounds, alkalinity of the mineralizing fluid, to enumerate a few). Concentration cannot have played an important role as both wolframite and cassiterite occur abundantly in the deposit taken as a whole.

It is beyond doubt that the fissures that have been mineralized were pre-existing before the approach of the mineralizing fluid. The position of the S.W. dipping mineralized veins in the granite-greisen apophyses shows that the fissures were formed after the intrusion of the granite-greisen apophyses. If this were not the case then the veins could not have their actual position. The rock in which these fissures were formed played an important role and influenced the habitus of the fissures (wall-rock control). Apart from the mechanical properties of the country rock, the presence of «mineralizers» may have had an important bearing upon the mineralization processes. Unfortunately, different types of rock are irregularly distributed throughout the deposit and it is difficult to map the various types of country rock. This means that it is almost impossible to determine the influence of the wall-rock factor precisely.

4. Metamorphism of the country rock.

The metamorphism of the country rock can be divided in two phases:
a) The batholith and the granite-greisen apophyses caused a slight thermal metamorphism of the country rock. The mineralogical composition of the rock shows no particular minerals, indicating a high temperature influence of the batholith and the granite-greisen apophyses (see also the petrographic description of the rocks).

b) After the intrusion of the mineralizing fluids which did not have to force their way, but more or less «filled» the open fissures, the wall-rock again was metamorphosed. From the study of thin sections it becomes clear that this second metamorphism took place along veinlets, perpendicular to the walls of the lenses. Along these veinlets tourmalinization and silicification of the wall-rock took place, but this alteration took place over a short distance only. Beyond this distance, where metamorphism and introduction of «material» took place, no typical high temperature changes are found.

One may picture that the mineralizing fluid in a lens tried to expand but only succeeded in cracking the walls of the lens thus causing small cracks that permitted the entrance of the metamorphosing compounds into the wall-rock.

5. Typical features of the lenses.

The mineralization of the lenses and the arrangement of the minerals is very particular as the extreme parts on both sides of the lenses show an enrichment with cassiterite and wolframite. Following Décio Thadeu cassiterite occurs especially enriched in the extremities of the extreme lense-parts (see Fig. 10). These parts are called: «rabos de enguia» (eel-tails) and the distribution of the minerals is pictured in the adjoining diagram. Thadeu explains this occurrence as follows: In general the mineralization of the veins is ruled by the laws of van 't Hoff and le Chatelier. In the extreme parts of the lenses however special conditions prevail because of a change in velocity and pressure of the mineralizing fluid following the law of Bernouilli.

The pressure-velocity change following Bernouilli might present, following Thadeu, an explanation for the typical enrichment of cassiterite in the extreme parts. This effect can not be neglected as the pressure change is inversely proportional to the square of the velocity.
There are however two difficulties: can the law of Bernouilli be applied to a mineralizing fluid and is cassiterite more pressure sensitive than other minerals, i.e. wolframite? These two questions have to be answered first. Furthermore Thadeu assumes the formation periods of wolframite and cassiterite as being two separate periods and therefore special conditions have to be assumed to explain the position of cassiterite in the extreme parts of the lenses.

To keep on the safe side, one may say that in the extreme parts of the lenses an enrichment of wolframite and cassiterite is found and that obviously in these parts the circumstances for the deposition of wolframite and cassiterite were favorable.

On the other hand it is still possible that at the extreme parts of the lenses, where the mineralizing fluids were squeezed through a small connecting stringer with the next one, pressure-velocity changes have caused the already mentioned enrichment, but without preference towards wolframite or cassiterite.

6. The influence of even the faintest movements of the veins during the mineralization or the ascent of the mineralizing fluids may have had an important bearing upon the mineralization of the veins. One may picture that a movement of the walls of the veins, for instance parallel to each other, caused a considerable pressure change with consequent results towards the wolframite-tin distribution.

2. Distribution of tin and wolfram in other deposits

Although the mineralization of the important tin-tungsten deposits shows a striking resemblance, along main lines, mineralogical and structural, it turns out, on reading publications dealing with deposits in Burma, China and other countries that following the authors the distribution of tin and wolfram in particular shows no such features. It is therefore interesting to investigate further upon the problem of the relative age of wolframite and cassiterite and the distribution of these minerals in other deposits.

Prof. Jones, on discussing the genetic classification of tin and tungsten states:
«All the evidence goes to show that the wolfram fraction of the mineralizing fluid is more volatile than the tin fraction and the former is deposited farther away from the margin of the granite than the latter.»

Prof. Jones bases his theory on the following points:

1. The intimate association of cassiterite with high temperature minerals such as topaz, tourmaline and the absence of these minerals in wolfram deposits, i. e. the quartz vein deposits that have produced the bulk of the world supply of wolfram.

From the fore-going description of the Panasqueira deposit it will be clear that this point does not hold for the Panasqueira quartz veins as wolframite, cassiterite and tourmaline are found in close company.

2. Macroscopic examination of wolframite-cassiterite intergrowths. On account of the samples that have been studied by Prof. Jones, Dr. Morrow Campbell remarks that he (Mr. Campbell) also studied these samples and that in his opinion these samples demonstrate the reverse.

«If cassiterite really did precede wolframite, surely Prof. Jones ought to have been able to obtain examples of a much more convincing nature and I have (Mr. Campbell states) seen numerous samples from Tavoy that wolframite preceded cassiterite.»

3. Solid lumps of wolframite from wolframite-cassiterite deposits are found on analysis to carry appreciable amounts of tin.

Dr. Morrow Campbell objects that this is by no means uncommon as a wolframite crystal during its growth in a tin-tungsten carrying mineralizing fluid may easily include some of the tin present.

Finally Dr. Morrow Campbell, describing some Burmese deposits, declares that he has seen numerous examples of wolframite, preceding cassiterite and not one sample demonstrating the reverse. It is however unfortunate that Dr. Campbell in his publication does not present any illustration of these intergrowths.

Mahmoud Sayed Amin reports about a tin-tungsten deposit in Egypt and he states as follows: «the crystallization of wolframite started later than that of cassiterite; its main deposition
was during the formation of the massive quartz since wolframite is generally found embedded in this quartz. Cassiterite is attached to the walls of the veins along with tourmaline and topaz. The growth of the cassiterite crystals seems to have been nearly completed before the deposition of the massive quartz since little or rare cassiterite has been found embedded in massive quartz and the growth-zones of the cassiterite are perfectly well developed towards the massive quartz. In this deposit the two minerals are vertically distributed. Wolframite dies out and cassiterite seems to increase towards the lower levels.

Ke Chin Hsu describes an opposite relation in Kiauksi (China): «Cassiterite was found abundant in the upper levels but less in the lower ones where wolframite increases and cassiterite replaces wolframite». Hsu regards this relation as an abnormal one and he explains that this is due to the relative concentration of compounds in the ore-forming liquid which following Hsu, should be a determining factor in the sequence of mineralization. However why Hsu looks upon this distribution as an abnormal one is not clear. It will be understood that if cassiterite really precedes wolframite, whenever the circumstances are favorable for the deposition of tin, whatever small quantities might be present, cassiterite will be deposited first and not wolframite.

On the other hand it is possible that the development of the mine did not yet reach deep enough to indicate the presence of a deep-seated tin zone. If the observation concerning a replacement of wolfram by tin is correct, it might be that the tin zone is overlapped by wolframite on both ends.

Dr. Dunn in his description of the Mawchi deposit remarks: «Though the periods of formation of wolframite and cassiterite overlapped very considerably, wolframite was the first to form and cassiterite formation continued after wolframite formation had ceased.»

Dr. Dunn illustrates his publication with some convincing examples of wolframite, replaced by cassiterite.

Vernon Hobson points out that field evidence appears to be in conflict with this view, i.e. the view of Dr. Dunn. «If wolframite were the earlier mineral it would be expected that the
Sn-Wo ratio would show a decrease with increasing depth until tin was finally absent altogether. It was however well known that this was not the case and that the Sn-content increased with depth at the expense of wolfram. It was suggested that this apparent anomaly may be due to other factors such as pressure having controlled mineral formation rather than temperature.

Hobson then carried out another investigation and he sampled some of the veins of the Mawchi deposit. The conclusion is that wolfram probably was the first to form, but that when cassiterite started to form, it developed much more rapidly than wolframite. After a renewed increase of wolframite the formation of the latter decreased rapidly and it is possible that had mineralization not been checked (i.e. by a limestone bank) a stage would have been reached in an upward direction where wolfram no longer existed and cassiterite was the only mineral.

Many reports from tin-tungsten deposits in Bolivia point out that in these deposits wolframite invariably formed before cassiterite. This is demonstrated with many examples of wolframite-cassiterite intergrowths and by sampling of veins in these deposits. However it turns out every time that exactly as in the Mawchi deposit cassiterite development started immediately after wolframite and that cassiterite thereby develops much faster than wolframite.

From the fore-going references it will be clear that the arguments provided by those authors who support the theory of wolframite formation prior to cassiterite formation are more convincing (macroscopic and microscopic examination of samples, sampling of the veins) than those arguments for the reverse of the mentioned theory. It is also apparent that in any case the formation periods of both wolframite and cassiterite partially overlap each other.

It will be clear that the distribution of both minerals depends on many different controls and that it therefore is impossible to determine fixed rules that from before can be applied without further argument on determining the distribution of wolframite and cassiterite in a deposit.

One hardly can escape the impression that the structure of
the Panasqueira deposit shows much resemblance to the structure of the Mawchi deposit (see: Vernon Hobson).

It is unfortunate that in the Panasqueira deposit no terminal ends are found, such as are found in the Mawchi deposit where a limestone bank checked mineralization and furthermore that in the Panasqueira deposit up till now no contact has been made with the actual batholith. In any case sampling of the S.W. dipping mineralized quartz veins on the eastern side of the Main Fault, may give valuable data concerning the tin-tungsten distribution in Panasqueira.
SYNTHESIS

The genesis of the Panasqueira ore is intimately related to the granites of the area; in fact the formation of the deposit merely was one phase in the evolution of the magma. The following genetic and chronologic sequence may present a synthesis of the complexity of phenomena observed in the deposit.

I. Early magmatic. A granitic magma intruded in a series of algonkian argillaceous sediments, during one of the last phases of the hercynian orogeny. These sediments underwent a low degree of thermal metamorphism.

II. Late magmatic. Aplite and porphyrite veins radiated from the granite.

III. Paulo-Post. Deuteric effects lead to the alteration of the wall-rock and greisenization of the granite intrusiva. The rate of tourmalinization was low. Tension fractures originated around the batholith and traversed the apophyses and the sediments.

IV. Hydrothermal. The evolution of the residual magma is marked by an increase of volatiles. Tourmaline, the guiding mineral for the mineralized quartz veins, precipitated in enormous quantities in the argillaceous sediment within a range of one meter from the veins.

The effects of thermal matamorphism, if present at all, are masked by the rate of tourmalinization. The ore-bearing fluids filled the preexisting joint-planes and ore deposition was mainly ruled by pressure changes and control of the wall-rock.


JONES, W. R. (1918). Lectures delivered at Tavoy under the auspices of the Mining Advisory Board. Rangoon.


APPENDIX

1. Fluorescent Apatite from Panasqueira

In view of the not unusual presence of scheelite in tin-tungsten deposits the samples of ore and wall-rock were subjected to observation under ultra-violet light. Although this examination did not reveal the presence of scheelite, the result was not entirely unsuccessful as some small specks on samples of ore showing a bright yellow fluorescence were observed.

Besides the above mentioned specks which are invariably found in contact with, or very near to wolframite, a crystalfragment with a strong zonal fluorescence effect was found. Photo 30 shows this fragment and the diagram, in the same plate, illustrates the position of the fluorescent and non-fluorescent parts.

The fluorescent colour can be described as much like the colour of freshly broken auripigment under day-light observation. Chemical and microscopic analysis of the specks as well as of the fragment pointed towards fluor-apatite.

This crystalfragment forms part of a short tabular hexagonal crystal, 1,5 cm. in diameter and 0,5 cm. thickness. The central part is pale-green coloured whereas the outer part is milky-white. Both parts are opaque. The small zone of fluorescence, parallel to the base of the fragment and only distinguishable under u. v. light has the same colour as the outer part. A suggestion that the cause of the fluorescence effect might be found in green coloured «impurities» in the centre part loses therefore some of its strength and a vertical section through the fragment shows a gradual transition in colour from green to milky-white outwards.

Before dealing with the examinations to establish the cause of the fluorescence effect, it is interesting to refer to some literature on this subject. (1, 2, 3, 4, 7, 9).
The occurrence of fluorescent apatites is by no means an unusual phenomenon and several authors (2, 7, 9) enumerate numerous examples from different deposits and countries. (Austria, California, Moravia).

According to papers on the fluorescence of minerals the cause of this effect can be found in:

1) The presence of «strange» compounds or so-called activators (for instance: Uranium-compounds, rare earths) resulting in a disturbance of the lattice of an usually non-fluorescent mineral. This disturbance effects a fluorescence under radiation with light of specific wavelengths.

2) A mere disturbance, imperfection or doublure (if, for instance, any of the normal components occurs more frequently than would be expected for strict stoichiometric proportions) also sometimes causes a fluorescent effect. These minerals are the so-called self-activated minerals.

Therefore some authors point out that it is possible to evoke a fluorescence from non-fluorescent minerals by merely heating samples of these minerals to a high degree. It seems probable that in those cases the fluorescence is caused by a «thermal» disturbance of the lattice. On the other hand not every mineral yields to this treatment. One might say the disturbance must be near at hand so as to be easily effected.

In order to get the fullest possible review of all the properties of the fluorescent crystalfragment, some preparations were made and samples of the fragment were compared with samples of a non-fluorescent apatite also from Panasqueira.

I. The crystalfragment was divided in three parts and of each part a sample was taken:

a) the fluorescent centre part,
b) the non-fluorescent outer part,
c) the fluorescent part of the outer part.
II. Samples were taken from an «ordinary» apatite crystal also from Panasqueira.

These samples, I\(^a\), I\(^b\), I\(^c\) and II we subjected to:

a) An X-ray analysis. The diagrams (Debye-Scherrer) did not show any difference between the samples.

b) Chemical analysis. Only rough tests were made and all of them indicated the presence of Ca, PO\(_4\), and F, (fluor-apatite) with a specific gravity of 3.4.

c) Microscopic examination. All samples have the same optical properties of apatite, except for sample I\(^b\) with a 2\(\nu\) varying from 0\(^o\)-15\(^o\).

d) Spectrographic analysis:

<table>
<thead>
<tr>
<th></th>
<th>I(^a)</th>
<th>I(^b)</th>
<th>I(^c)</th>
<th>II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ca (CaO)</td>
<td>100 (100)</td>
<td>100 (100)</td>
<td>100 (100)</td>
<td>100 (100)</td>
</tr>
<tr>
<td>Mn (MnO)</td>
<td>15 (13.7)</td>
<td>1.4 (1.3)</td>
<td>15 (13.7)</td>
<td>3 (2.6)</td>
</tr>
<tr>
<td>P (P(_2)O(_5))</td>
<td>70 (114)</td>
<td>70 (114)</td>
<td>60 (96)</td>
<td>60 (96)</td>
</tr>
<tr>
<td>Fe (FeO)</td>
<td>0.4 (0.36)</td>
<td>0.12 (0.1)</td>
<td>0.45 (0.36)</td>
<td>0.2 (0.18)</td>
</tr>
<tr>
<td>Mg (MgO)</td>
<td>0.04 (0.04)</td>
<td>0.03 (0.03)</td>
<td>0.03 (0.03)</td>
<td>0.03 (0.03)</td>
</tr>
<tr>
<td>Si (SiO(_2))</td>
<td>0.1 (0.2)</td>
<td>0.15 (0.22)</td>
<td>0.06 (0.09)</td>
<td>0.2 (0.3)</td>
</tr>
<tr>
<td>Ti (TiO(_2))</td>
<td>0.2 (0.16)</td>
<td>0.4 (0.32)</td>
<td>0.3 (0.24)</td>
<td>0.3 (0.24)</td>
</tr>
</tbody>
</table>

(All percentages refer to a content of 100 gram Ca (CaO) in each sample)

A striking feature of this analysis is found in the extremely high manganese content of the samples I\(^a\) and I\(^c\), the samples taken from the fluorescent parts of the crystal fragment. According to Dana (1) an amount of some tenths percents of manganese is not unusual in common apatites, and Doelter (9), referring to apatites belonging to the manganese apatite group, refers to analyses of such apatites with a manganese content up to 10 %. It seems, following Doelter, that manganese can replace Ca in the apatite lattice. Furthermore Doelter states that an extended study of apatites on the occurrence of fluorescence pointed out that in most cases a zonal distribution of the fluorescence effect can be seen. McKeag and Ranby (8) discuss the importance of the alkaline earth phosphates for industrial purposes in view of
fluorescent lamps. «A remarkable feature of this class of phosphors is that no fluorescence results from use of manganese only as an activator. The primary activator is antimony». «The colour of an Sb-Mn activated apatite with 5% of manganese is described as yellow».

Calculations from table 1 show that there is at least 7.5% of manganese present in the fluorescent parts of the fragment.

According to McKeag and Ranby, it would appear that antimony has to be present as a primary activator, but it might be possible that apatite becomes activated if, during the growth of the crystal, some manganese is included.

The presence of manganese in some apatites from Panasqueira is not strange for the fluorescent apatites are found in contact with or very near to wolframite (see also Quensel and Mason 6).

With reference to the afore mentioned, it will be clear that the high manganese content of samples I^a and I^c in contrast with the content of samples I^b and II affords a good explanation for the cause of the fluorescence.

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2. Pleochroitic Haloes

1. The granite-greisen series.

The Panasqueira rocks are extremely rich in pleochroitic haloes, which are found around nuclei of zircon and some opaque minerals in white mica, biotite, chlorite and tourmaline.

During the initial stage of crystallization, the content of radioactive matter causing these haloes was too low to lead to the formation of a separate mineral, so the early zircon crystals can be considered as "entraineurs" for this material. Radio-active minerals of hydrothermal origin are found in many localities of the Iberian metallogenetic province.

From the time of their discovery in 1873, haloes are reported from everywhere, but references to the presence of haloes in white mica and other Fe-free minerals are scarce, or according to Joly never found; this investigator based the explanation of the halo-phenomenon on the transformation of a ferrous ion into a ferric one. The \( \alpha \)-particles, or He-atoms, radially discharged in all directions, would liberate oxygen by the decomposition of water performing the Fe-oxydation "this theory does satisfactorily account for the absence of haloes in quartz, feldspar and muscovite".

As early as in 1877, haloes are reported in white mica by H. Rosenbusch, but it has to be stated, that haloes in this mineral are rather scarce, so from this point of view the Panasqueira rock is an extraordinary one. Other localities are Kiangsi in China and Erzgebirge in Germany.

All over the world wolframite occurrences are mostly related to biotite or biotite-muscovite granites, the Panasqueira granite-greisen apophyses however nearly completely consist of white mica's, and contain but a few flakes of biotite and chlorite.

Microscopic examination reveals, that some part of the white mica is a bleached biotite, so the theory of Joly on the origin of the haloes can still be applied to this exceptional occurrence.
If the chemical composition and density of a mineral are known, the range of $\alpha$-particles in that medium can be calculated by a conversion factor applied for Geiger’s determination of ranges in air by means of the Bragg-Kleeman formula:

$$\frac{\text{Range in } A \times \text{density of } A}{\text{Range in } B \times \text{density of } B} = \frac{\text{Atomic weight of } A}{\text{Atomic weight of } B}$$

that is for muscovite, $\text{H}_2\text{KAl}_5\text{(SiO}_4)_3$:

$$\frac{\text{Range in musc.} \times \text{density of musc.}}{\text{Range in air} \times \text{density of air}} = \frac{\frac{0/00 \text{H}}{100} \times \text{At. wght. of } \text{H} + \frac{0/00 \text{K}}{100} \times \text{At. wght. of } \text{K} \text{ etc.}}{\text{Atomic weight of air}}$$

The conversion factor of muscovite at $15^\circ \text{C}$ and 760 mm Hg appears to be:

$$\frac{1}{100} \times 472.14 \times 1 \times 0.00122$$

Range in Muscovite = $\frac{2.88 \times 3.762}{0.000532} = 0.000532 \text{ cm.}$

(on theoretical basis)

This means, that for an $\alpha$-particle 1 cm in air is equivalent to 5.32 micron in muscovite.

A more directly deducted conversion factor is found by assuming the Ra.C' ring as a standard; the measurements of the radii of this ring resulted in a mean radius of 0.003625 cm, so the conversion factor is now:

$$\frac{0.003625}{6.971} = 0.00052$$

(on practical basis)

The radius of the Ra.C' ring in air is 6.971 cm.

The study of the pleochroitic haloes is complicated by the existence of three radio-active families, whose numerous members are represented by different rings marking the end of the ionization tracks, so the haloes can be considered as the integral ionization effect of all three series.
In a few cases some inner rings could be measured, most of the following data however are from outer radii of haloes, which are referred to by Joly as being overexposed i.e. "at a very late stage the whole of the internal detail may be obliterated by the general darkening of the halo".

Microphotography of the haloes combined with microphotometry would reveal more details of the inner-rings of the so-called over-exposed haloes.

The measurements have been carried out by means of a microscope with micrometer-ocular on central sections of haloes with small nuclei; big inclusions are not suitable for this purpose as radio-active matter may be dispersed at random within the nucleus.

The remarkable observation has been made, that the smallest inclusions display the strongest colouring effects, which are generally faint; pleochroism ranges from green-yellow to colourless.

The results of the measurements made on 160 haloes are compared with the very accurate investigations of F. Mendes on haloes in biotite of other Portuguese rocks.

<table>
<thead>
<tr>
<th>Ring</th>
<th>Radius in mica in microns</th>
<th>Radii in mica converted into radii in air (in cm) by means of a conversion factor based on a:</th>
<th>Radio-Active Families</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Theor. basis</td>
<td>Practical basis</td>
<td>Uranium</td>
</tr>
</tbody>
</table>
| VI   | 16.00        | 3.01 3.08 3.10 | \{3.194 Io  \\
|      |             |                 | 3.27 U \_II | 2.90 Th  | 3.27 Ac. U |
| VIII | 18.50        | 3.48 3.56 3.57 | -       | -       | 3.50 Ac  |
|      |             |                 |         |         | 3.673 Pa |
| X    | 23.00        | 4.32 4.42 4.16 | \{4.09 Ra.C  \\
|      |             |                 | 4.122 Rn | 4.354 Th.X | 4.369 Ac. X |
| XII  | 26.50        | 4.98 5.09 5.09 | -       | 5.063 Th | 4.976 Ra. Ac |
|      |             |                 |         |         | \{6.60 Ac. C\'} |
|      |             |                 |         |         | \{6.584 Ac. A\'} |
| XIV  | 32.50        | 6.11 6.25 6.16 | -       | -       | -       |
| XV   | 36.25        | 6.82 6.97 6.97 | 6.971 Ra.C' | -       | -       |

Panasqueira  
Mendes
The reports of haloes in igneous rocks are as abundant as they are scarce in metamorphic rocks. Some parts of the Panasqueira deposit however, are extremely rich in these haloes, several thin sections contain a few hundreds per square cm.

Generally they are found in sericite, but also in biotite, chlorite and tourmaline; as a rule they are not fit for measurements on account of their flaky character. The same phenomena are found by Corin in the schists and tourmaline rocks of Remagne.

These haloes are not suitable for measurements; they are blurred and the minute quartz grains in the sericite mass prohibit the development of a spherical halo; in the chlorite metacrysts however some fully developed haloes are found.

The radii, as far as measurable, reach in most cases the Ra.C' ring; the nuclei are zircon and an opaque mineral, exactly like that in the granite-greisen series.

Zircon, one of the earliest minerals to crystallize from a cooling magma, is rather unlikely to have been introduced into the metamorphic rock.

Zircon has to be considered as an original constituent of the Algonkian rock, but this does not imply the same age for the haloes.

The thermal effect of the Hercynic intrusion must have wiped out the results of an eventual former halo-development, particularly for the haloes in the chlorite-biotite metacrysts there is good reason to fix their age on the time of metamorphism.

3. Conclusions.

In 1907 Rutherford made his first artificial haloes in glass by means of radium emanation, some twenty years later he made time calculations on haloes in biotite comparing these with artificial haloes of the same colour-intensity in the same mineral. Rutherford's premiss was, that the colour depends on the:

1) radio-activity of the central inclusion, and
2) age of the mineral, in which it occurs.
As it was impossible to measure the exact strength of the radio-activity, his calculations were based upon an assumed U-content of the nuclei, his results in consequence were not encouraging, and the haloes as a means of geologic age determination were assigned to oblivion.

By this time however, there are new ways to approach the problem.

A quantitative method for measuring on micro-scale the strength of radio-active emission is found in micro-photography with Ilford $\alpha$-plates; this is done by counting the $\alpha$-tracks after some weeks of exposure.

Instead of Rutherford's assumed content of radio-active matter in zircon, now the actual content and the exact radio-active centre within the nucleus are available for time-calculations.

Furthermore, micro-photometry of an ordinary photograph of an halo may represent the absolute colour-intensity of the halo.

By means of this equipment it must be possible to make an improvement on the result of Rutherford's investigations.

An artificial halo of exactly the same colour as the natural one can be made by exposing mica to radio-active matter of known strength, matching the colour by means of a sensitive photometer. From this halo is obtained the number of He-atoms needed for the required colouring-effect.

By $\alpha$-plate photography of the natural halo is known how many He-atoms are discharged within the time of exposure; with these data the age of the haloes can be calculated.

This is, in a few words, the way in which the old problem can be approached; in this respect the Panasqueira haloes are an excellant material for checking the results of an eventual geologic age-determination, as their age is fairly well known. Prof. Carlos Teixeira fixed the date as Post-Stephanian and Ante-Permian.
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Photo. 1 — Deuteric altered rock from the marginal facies of the Argemela granite outcrop (crossed nicols, 42×).

Photo. 2 — Incipient greisenization of the upper granitic zone.

Composition: Quartz 70%, mica 22%, feldspar 5%, apatite 2%, carbonate 1%.
Photo. 6 — Marginal part of the greisen series.

Composition: Quartz 57 %, mica 40 %, chalcedony 2 %, apatite 1 % (crossed nicols, 30 ×).
Photo. 8 — Upper contact greisen schist.

*Composition of schist:* Sericite 70 %, biotite 12 %, quartz 8 %, tourmaline, 5 %, carbonate 2 %, ore 2 %, apatite 1 % (crossed nicols, 13 ×).

Photo. 9 — Lower apophyse contact.

*Composition of schist:* Sericite 70 %, biotite 15 %, quartz 8 %, carbonate 5 %, tourmaline 1 %, apatite 1 % (Actual size).
BLOOT & DE WOLF — Panasqueira Tin-Tungsten ore-occurrence

Photo. 10 — Quartz veinlet in tourmalinized schist (crossed nicols, $13\times$).
Photo. 12 — Wall-rock, 5 cm. from quartz vein.

*Composition:* Tourmaline 70%, quartz 25%, sericite 4%, apatite 1%. (30 X).

Photo. 13 — Chloritized slate, 60 cm. from quartz vein.
Photo. 14 — Sub-graywacke, detrital quartz and feldspar grains in chlorite-sericite matrix. (42×).
Photo 16 — Diabase. (Ordinary light, 13 X).
Photo. 18 — Cassiterite (1), quartz (2), carbonate (3).
(Thin sec., 45×).
**Photo 20** — Mica (1), wolframite (2), pyrite (3), quartz veinlet (4).
(Pol. sec., 150×).

**Photo 21** — Rismuth (1), hismnthinite (2), arsenovrite (3), mica (4).
Photo. 22 - Quartz (1), tourmaline needles, cassiterite (black).
(Thin sec., 45×).
Photo. 24 – Contact of quartz (1) and siderite (2).
(Pol. sec., 45×).

Photo. 25 – Carbonate structures in pyrite-marcasite.
Photo. 26 — «Gothic windows» of carbonate (1) towards pyrite-marcasite (2).
Pol. sec., 150 X).
Photo 28 — Wolframite (1) replaced by cassiterite (2) and quartz (3); mica (4) and sphalerite (5). (Pol. sec., 150×).
Photo. 30 — Fluorescent crystal-fragment of apatite.
Photo. 31 — Pleochroitic haloes in greisen. (30×).