ORIGIN OF COLOUR ZONING IN CASSITERITES FROM TIN DEPOSITS WITHIN THE BUSHVELD COMPLEX, SOUTH AFRICA

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Cassiterites with striking colour zones from the syngenetic tin deposits at Zaaiplaats and from the epigenetic tin deposits at Rooiberg, Leeuwpoort and Union Mines, in the Central Transvaal, have been analysed by microprobe.

The average niobium content (0.13 per cent Nb_2O_5) is higher, whereas the tantalum (0.05 per cent Ta_2O_5) and iron (0.62 per cent FeO) contents are lower in the orthomagmatic cassiterites from the disseminated Bobbejaankop granite than in cassiterites from the greisenized Lease granite (Nb_2O_5 0.03 per cent, Ta_2O_5 0.11 per cent, and FeO 0.79 per cent). The tungsten contents are similar, *i.e.* 0.49 to 0.47 in dark colour zones and 0.10 to 0.02 per cent WO_3 in light colour zones in all Zaaiplaats cassiterites.

The average niobium contents in Rooiberg, Leeuwpoort and Union cassiterites are 0.03, 0.03 and 0.02 per cent Nb_2O_5 and average tantalum contents 0.10, 0.08 and 0.12 per cent Ta_2O_5, respectively.

Generally, the substitution of SnO_2 by minor amounts of tantalum, niobium, tungsten and iron oxides is higher in the dark zones than in the light zones of the analysed crystals, which can presumably be attributed to the presence of the colour zoning itself. The very low level of trace and minor element contents is partly due to the great purity of Bushveld cassiterites from mineral inclusions in any scale.

Key words: cassiterite, zoning, composition, greisen, Bushveld Complex, South Africa.

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Introduction

The cassiterite crystals from the tin deposits within the acid phase of the Bushveld Complex display striking colour zoning and variable pleocroism. In this investigation, the chemical composition of these crystals and, particularly, the distribution of elements in the distinctive colour zones has been studied by electron microprobe techniques. The cassiterites analysed are from the Zaaiplaats, Rooiberg, Leeuwpoort and Union tin mines in the Central Transvaal, South Africa (Fig. 1).

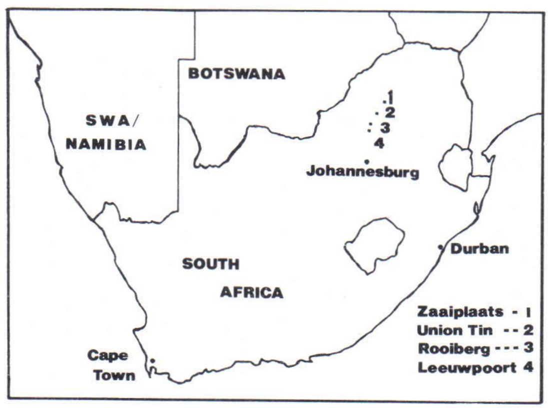

Fig. 1. The locations of the Zaaiplaats, Union, Rooiberg and Leeuwpoort tin mines in the Republic of South Africa.

Endogranitic tin deposits

Cassiterite occurs in three types of endogranitic tin deposits at the Zaaiplaats tin mine: the low-grade disseminated zones in the Bobbejaankop granite, at present the main source of ore; lenticular orebodies in greisenized Lease granite, which forms a metasomatized hood facies above the tin-bearing Bobbejaankop granite; and pipes cross-cutting Bobbejaankop granite.

The most important disseminated deposits occur in the upper parts of the Bobbejaankop granite, which is intrusive into the stratiform suite of granitoids called the Main granite. The mineralized granite with disseminated cassiterite is petrographically identical to the surrounding unmineralized granite. Several gently dipping ore zones are known. The most important, lower zone lies 120 m below the roof of the granite, the dips of the ore zone being parallel to the roof. Root-like apophyses of the Lease granite extend down to the disseminated ore zone.

The lenticular orebodies are restricted to the Lease granite and occur immediately under the contact pegmatite. The orebodies are unusually concordant with the lower contact of the pegmatite, the larger ore deposits of this type have extremely irregular outlines, and are mostly elongated forms. As with the pipes, the pegmatite forms the upper contact of the lenticular orebodies.

The ore in the continuous, flat orebodies consists of sericitized microgranite containing irregular concentrations of cassiterite. Fluorite is abundant and widely distributed throughout the mineralized locus, while chlorite occurs prominently in many places. Tourmaline has developed more locally, with calcite, quartz, chalcopyrite and arsenopyrite as minor constituents (Strauss 1954).

The pipes are long, roughly cylindrical bodies varying in diameter up to 10—12 m, the average being between 1 and 2 m. Lengths are from 7 m to 1000 m. Their attitude may vary from horizontal to vertical. The most striking feature of the pipes is their annular structure and their sharp contact with the enclosing granite. The core of a pipe is usually composed of granite in various stages of alteration. All the quartz may be replaced by cassiterite and fluorite. Feldspar may be replaced by sericite and chlorite. The ultimate alteration product is a mass of sericite with disseminated cassiterite, pyrite, fluorite and scheelite.

Exogranitic tin deposits

All the cassiterite deposits in the Rooiberg tin field, irrespective of their modes of occurrence, are located immediately beneath or on top of the transitional sedimentary contact between massive, cross-bedded arkosites (Boshoffsberg Quartzite Member) and overlying rhythmically interbedded sandstones, siltstones and shales (Blaauwbank Shale Member) (Stear 1977). These rocks belong to a large mass of layered rocks known as the Rooiberg Fragment, a remnant of the uppermost Pretoria Group of the Precambrian Transvaal System occurring as a gigantic roof-block within acid rocks of the Bushveld Complex (Leube and Stumpfl 1963). The tin deposits are of two types, depending on the nature and mode of occurrence of the orebodies replacement deposits in stratabound zones, where they formed by replacement within a stratigraphically defined, orthoclase-rich arkosite horizon (the Rooiberg type), bedded lodes in fractures initiated by the emplacement of the Bushveld granite (the Leeuwpoort type). These orebodies, which fill open spaces, occur in low-dipping tensional and shear fractures and also follow closely the sedimentary stratification.

The pockets formed by replacement of the quartzite are generally of irregular shape, the most common form being elliptical or round. Some of the pockets are flattened at the top and terminate sharply against the bedding.

The structure of the tin deposits at the Leeuwpoort mine is characterized by the most intense fracturing, which is responsible for the localization and partly for the development of the orebodies (Leube and Stumpfl 1963). The cassiterite-bearing lodes display a number of prevailing features although the mineral composition and the width of the lodes change from place to place. The mineralogy of the lodes is characterized by the association of cassiterite with magnetite, haematite, pyrite and chalcopyrite.

The tin deposits at the Union tin mine formed by replacement of a shale horizon within the Rooiberg felsite by very fine-grained cassiterite and associated sulphides. The Rooiberg felsite has been related to two phases of eruptive activity, the lower felsite being overlain by a zone of a fine-grained rock-type designated ignimbrite by Menge (1963). The ignimbrite is overlain by a zone of thinly bedded, siliceous shale with its cassiterite replacement deposits. The cassiterite deposits are confined to the immediate vicinity of several sets of fractures, which have been grouped into four types according to their possible origin and nature: N-lode, cross-strike lode, strike lode and cross-bedding lode or bedding lode types (Menge 1963). The intensity of the mineralization is never constant within a fracture set and in general varies from one fracture set to another.

Mineralogy and chemistry

Cassiterite at the Zaaiplaats tin mine occurs mostly as euhedral crystals with grain sizes varying between 0.5 and 8 mm in diameter. Macroscopically cassiterite is almost black or dark brown with a reddish tint. The cassiterite crystals are usually zoned in thin sections, displaying a variety of very irregular patterns between dark brown, light brown or nearly colourless patches or zones.

In the disseminated zones of the Bobbejaankop granite and in the greisenized Lease granite, *viz.* the lenticular orebodies, cassiterite crystals are invariably fine-grained, the diameter of the grains being less than 0.5 mm, and usually with anhedral or subhedral habit. These cassiterite crystals do not, however, show any remarkable variation in colour, zoning or pleochroism in contrast to the euhedral crystals, pods and small vugs of the Bobbejaankop or Lease granites.

The following colours and pleochroism were recorded in the thin section study of the zoned cassiterites:

(i) dark brown, non-pleochroic,
(ii) light brown, non-pleochroic,
(iii) colourless,
(iv) pleochroic, colourless to deep red and
(v) pleochroic, light yellow to dark yellow.

In the countless small vugs and pods of both the Bobbejaankop and the mineralized Lease granite the idiomorphic cassiterite crystals are associated with a variety of minerals, such as quartz, alkali feldspar, fluorite, sulphides (mostly arsenopyrite) and scheelite.

In the greisenized orebodies cassiterite occurs with a sequence of other minerals (Ollila 1981, 1984). Quartz and the original feldspars of the Lease granite are usually associated with cassiterite (Fig. 2), where it seems to occur preferably with alkali feldspar that is strongly altered into sericite. In the richer parts of the greisenized ores, plagioclase can also be associated with cassiterite.

The Leeuwpoort mine cassiterite occurs as well developed, euhedral crystals that are frequently twinned (Fig. 2). The diameter of the crystals is usually below 5 mm. The grain size of the cassiterite is distinctly larger than that of the Rooiberg mine cassiterite. At Leeuwpoort, cassiterite occupies the footwall contact of the bedded lodes, and also occurs in granular aggregates around country rock fragments. The pleochroism of Rooiberg cassiterites is weak, and the following colours and pleochroism were recorded:

(i) dark brown, non-pleochroic,
(ii) light brown, non-pleochroic,
(iii) pleochroic, light brown to dark brown and

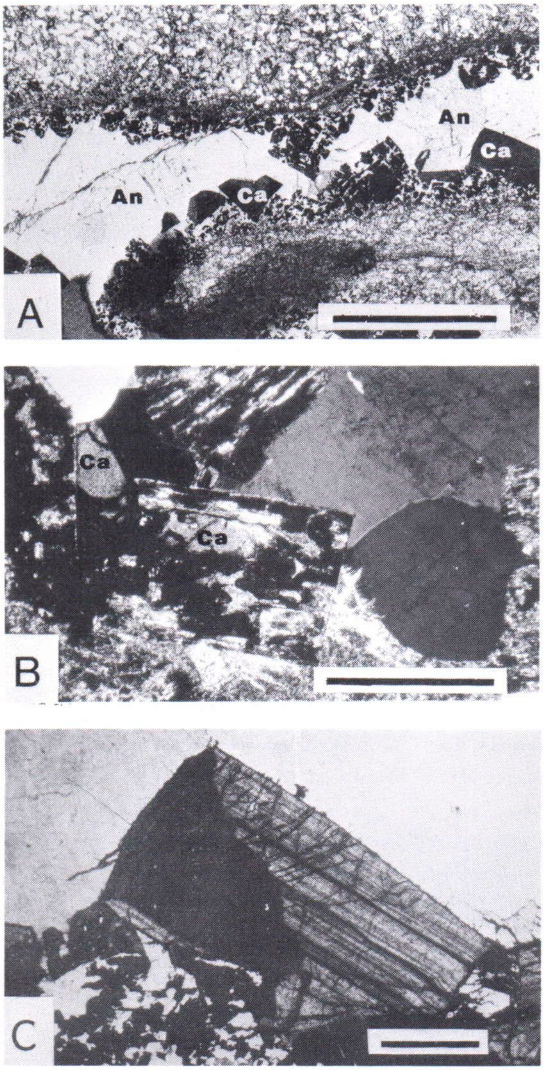

Fig. 2. Microphotographs of the mode of occurrence of the analysed cassiterite crystals. The length of the scale bars is 100 μm. A. A texture of mineralization in a bedded lode cassiterite deposit at the Leeuwpoort tin mine. A tectonically opened fracture is filled by ankerite (An) and cassiterite (Ca) that have crystallized along the hangingwall and footwall contacts with the country rock, arkosite. Gap Lower Lode, 1740' Level. Leeuwpoort tin mine. B. Microstructure of the Zaaiplaats tin ore. Cassiterite (Ca) occurs as irregular patches in euhedral alkali feldspar crystals in the greisenized orebody of the Lease granite. Lease Workings, Zaaiplaats tin mine. C. A typical zoned cassiterite crystal with irregular patterns of colour zones. In hand specimens this type of large cassiterite crystal can sometimes be seen oriented parallel to the footwall contact, the twinning planes being normal to it. Transmitted light, 1740' Level, GL Drive. Leeuwpoort tin mine.

(iv) pleochroic, light yellow to deep yellow.

Most of the cassiterite crystals are zoned. Tourmaline prisms were commonly found enclosed in the Rooiberg cassiterites. The Leeuwpoort cassiterite has been brecciated as a result of tectonic, postmineralization movements in the bedded lodes. The cracks and fractures in the cassiterite crystals are usually filled by ankerite. The cassiterite also contains rounded zircon crystals in the pocket mineralization.

The Union tin mine cassiterite occurs as irregularly shaped grains and clusters with grain sizes never exceeding 0.05 mm. As a result, many of these grains are nearly submicroscopic. In thin sections, the cassiterite is found to be overgrown by sericite, haematite and in a few cases, magnetite. The colour zoning typical of Rooiberg and Zaaiplaats cassiterites could be also observed in the largest cassiterite grains. Arsenopyrite is the only sulphide closely associated with cassiterite mineralizations, but it was never found to enclose the small cassiterite grains.

A number of quantitative microprobe analyses were carried out to investigate the relation between colour zoning and the minor element distribution of the dark and light zones of cassiterite. Analyses were made using an ARL-SEMQ microprobe with accelerating voltage 15 Kv, sample current on brass 20 nA and counting time 20 seconds.

The microprobe analyses are summarized in Table 1, which gives the oxide-percentage values, as the mean of two spot analyses, for the dark and light zones of four cassiterite crystals from the Bobbejaankop granite, three from the Lease granite, eight from bedded lodes (Leeuwpoort), four from replacement pockets (Rooiberg) and four from replacement deposits (Union).

The light zones of the Union tin-mine cassiterites have the highest tantalum contents (mean value 0.16 % Ta_2O_5) in the analysed Bushveld cassiterites. On average, the tantalum contents are low, *i.e.*, below 0.11 % Ta_2O_5.

With regard to tungsten, the dark portions of the Zaaiplaats and Rooiberg tin-field cassiterites

Table 1. Microprobe analyses (%) of dark and light portions of cassiterite crystals.

Rooiberg tin mine

	06377-2 Dark	Light	06377-7 Dark	Light	06377-13 Dark	Light	06377-15 Dark	Light	Mean	
									Dark	Light
Ta_2O_5	0.12	0.09	0.15	0.17	0.07	0.02	0.01	0.11	0.09	0.10
WO_3	0.00	0.72	0.07	0.67	1.09	0.07	1.03	0.00	0.55	0.37
Nb_2O_5	0.00	0.01	0.00	0.00	0.00	0.00	0.24	0.00	0.06	0.00
SnO_2	94.82	97.77	96.97	99.88	98.16	98.72	95.82	97.34	96.44	98.43
FeO	2.26	0.31	2.27	0.34	0.59	1.25	0.66	1.33	1.45	0.81
Sb_2O_3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CuO	0.03	0.00	0.01	0.04	0.00	0.05	0.00	0.05	0.01	0.04
SiO_2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TiO_2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	97,22	98.90	99.47	100.10	99.92	100.11	97.76	98.84	98.60	99.75
$\frac{\Sigma\ \text{Oxides*}}{SnO_2} \times 100$	2.54	1.16	2.58	1.22	1.78	1.41	2.02	1.53	2.24	1.34

Union tin mine

	06377-264 Dark	Light	06377-266 Dark	Light	06377-268 Dark	Light	06377-285 Dark	Light	Mean	
									Dark	Light
Ta_2O_5	0.18	0.28	0.07	0.07	0.05	0.19	0.01	0.08	0.08	0.16
WO_3	0.28	0.30	0.14	0.22	0.03	0.06	0.11	0.14	0.14	0.18
Nb_2O_5	0.00	0.08	0.05	0.00	0.00	0.02	0.00	0.00	0.01	0.03
SnO_2	98.71	99.63	99.64	97.82	97.44	98.81	99.72	99.51	98.88	98.94
FeO	0.77	0.50	0.70	0.48	1.28	0.41	1.64	1.16	1.10	0.64
Sb_2O_3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CuO	0.00	0.00	0.00	0.04	0.05	0.04	0.01	0.02	0.02	0.03
SiO_2	0.00	0.03	0.00	0.03	0.00	0.00	0.15	0.00	0.04	0.02
TiO_2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	99.95	100.82	100.62	98.65	98.85	99.54	101.64	100.91	100.27	100.00
$\frac{\Sigma\ \text{Oxides*}}{SnO_2} \times 100$	1.25	1.19	0.96	0.85	1.45	0.73	1.93	1.41	1.41	1.07

Zaaiplaats tin mine; Bobbejaankop granite

	06377-11 Dark	Light	06377-16 Dark	Light	06377-47 Dark	Light	06377-158 Dark	Light	Mean	
									Dark	Light
Ta_2O_5	0.01	0.04	0.01	0.02	0.16	0.03	0.02	0.05	0.05	0.04
WO_3	0.47	0.00	0.65	0.32	0.11	0.06	0.71	0.01	0.49	0.10
Nb_2O_5	0.18	0.02	0.00	0.03	0.55	0.15	0.00	0.00	0.18	0.07
SnO_2	99.55	100.67	97.98	100.32	96.47	98.71	97.68	98.94	97.92	99.66
FeO	0.44	0.52	0.31	0.56	1.20	0.69	0.36	0.88	0.58	0.66
Sb_2O_3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CuO	0.08	0.00	0.00	0.00	0.00	0.00	0.16	0.09	0.06	0.03
SiO_2	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.03	0.00
TiO_2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	100.72	101.23	98.94	101.24	98.61	99.60	98.79	99.88	99.31	100.42
$\frac{\Sigma\ \text{Oxides*}}{SnO_2} \times 100$	1.18	0.57	0.99	0.93	2.21	0.94	1.28	1.04	1.42	0.90

Zaaiplaats tin mine; Lease granite

	06377-45 Dark	Light	06377-150 Dark	Light	06377-261 Dark	Light	Mean Dark	Mean Light
Ta_2O_5	0.03	0.13	0.18	0.04	0.10	0.16	0.10	0.11
WO_3	0.94	0.00	0.06	0.00	0.40	0.05	0.47	0.02
Nb_2O_5	0.03	0.06	0.01	0.00	0.01	0.02	0.02	0.03
SnO_2	98.93	100.16	100.74	99.08	97.41	100.53	99.03	99.92
FeO	0.55	0.52	1.13	1.47	0.48	0.59	0.72	0.86
Sb_2O_3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CuO	0.00	0.08	0.00	0.03	0.02	0.05	0.01	0.05
SiO_2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TiO_2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	100.49	100.87	102.11	100.62	98.42	101.39	100.35	100.99
$\frac{\Sigma \text{ Oxides*}}{SnO_2} \times 100$	1.57	0.79	1.37	1.55	1.04	0.87	1.33	1.07

Leeuwpoort tin mine

	06377-1 Dark	Light	06377-3 Dark	Light	06377-5 Dark	Light	06377-236 Dark	Light
Ta_2O_5	0.11	0.06	0.07	0.00	0.06	0.15	0.01	0.01
WO_3	1.09	0.02	0.51	0.01	0.00	0.08	0.43	0.10
Nb_2O_5	0.00	0.00	0.00	0.19	0.01	0.00	0.05	0.05
SnO_2	96.70	98.57	98.52	99.48	96.22	98.41	100.03	96.67
FeO	1.12	0.51	0.68	0.23	0.27	0.21	0.37	1.66
Sb_2O_3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CuO	0.03	0.00	0.04	0.00	0.01	0.00	0.06	0.09
SiO_2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30
TiO_2	0.00	0.00	0.17	0.23	0.60	0.28	0.31	0.00
TOTAL	99.05	99.16	99.99	100.16	97.18	99.12	101.24	98.87
$\frac{\Sigma \text{ Oxides*}}{SnO_2} \times 100$	2.43	0.60	1.49	0.66	0.99	0.73	1.23	2.29

	06377-239 Dark	Light	06377-289 Dark	Light	06377-259 Dark	Light	16802 Dark	Light	Mean Dark	Mean Light
Ta_2O_5	0.15	0.09	0.06	0.16	0.01	0.16	0.03	0.10	0.06	0.09
WO_3	0.88	0.03	0.42	0.55	0.73	0.00	0.52	0.05	0.58	0.11
Nb_2O_5	0.07	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.02	0.03
SnO_2	99.00	99.18	97.05	98.49	97.17	99.28	99.21	100.03	97.99	98.64
FeO	0.90	1.55	1.03	0.61	0.32	0.55	0.58	0.63	0.66	0.74
Sb_2O_3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CuO	0.05	0.00	0.02	0.03	0.04	0.02	0.00	0.02	0.03	0.02
SiO_2	0.06	0.00	0.00	0.02	0.13	0.00	0.00	0.00	0.02	0.04
TiO_2	0.00	0.02	0.00	0.00	0.00	0.00	0.05	0.00	0.14	0.11
TOTAL	101.11	100.87	98.59	99.85	98.41	100.01	100.40	100.83	99.50	99.78
$\frac{\Sigma \text{ Oxides*}}{SnO_2} \times 100$	2.13	1.70	1.58	1.40	1.27	0.74	1.20	0.80	1.54	1.16

* Σ Oxides = $Ta_2O_5 + WO_3 + Nb_2O_5 + FeO + Sb_2O_3 + CuO + SiO_2 + TiO_2$

are much higher in their average tungsten contents (about 0.5 % WO_3; see Table 1) than the light ones (less than 0.11 % WO_3 in Zaaiplaats and Leeuwpoort tin mine cassiterites, and less than 0.37 % WO_3 in Rooiberg tin mine cassiterites). The only exceptions in the distribution of tungsten in favour of the dark colour zones were those in the Union tin-mine cassiterites, the dark zones being slightly poorer (mean value 0.14 % WO_3) in tungsten than the light ones (mean value 0.18 % WO_3).

The niobium contents of the cassiterites are also very low (average Nb_2O_5 content less than 0.07 %) with the exception of the dark cassiterite portions in the Bobbejaankop granite specimens average Nb_2O_5 content 0.18 %). Consistent with the tantalum contents the niobium distribution cannot be ascribed to the differences between the various colour fractions in cassiterite.

The highest iron content, given as FeO, was found in the dark cassiterite zones of the Rooiberg tin mine specimens (mean FeO content 1.45 %), the light zones of the same crystals having about half that amount of iron (0.81 % FeO). Microprobe analyses did not reveal any pronounced differences in iron contents between the light and dark colour fractions of the analysed cassiterites. The average iron contents in the Zaaiplaats and Leeuwpoort tin mine cassiterites vary between 0.58 % and 0.86 % FeO; whereas the Union tin mine cassiterites are slightly higher in iron, *i.e.,* between 0.64 % and 1.10 % FeO. From the other analysed oxides, only very low CuO contents could be detected by the microprobe techniques (between 0.01 % and 0.06 % CuO). Titanium oxide could only be detected in the cassiterites from the Leeuwpoort tin mine, and SiO_2 impurities never exceed 0.04 % in the mean values as indicated in Table 1.

The minor oxide contents of the analysed cassiterites do not show any clear correlation between each other or between the colour zones. As an example, Fig. 3 shows the WO_3-Ta_2O_5 and WO_3-FeO plots for the cassiterites. On the contrary, the ratios of all other oxides divided by tin oxide

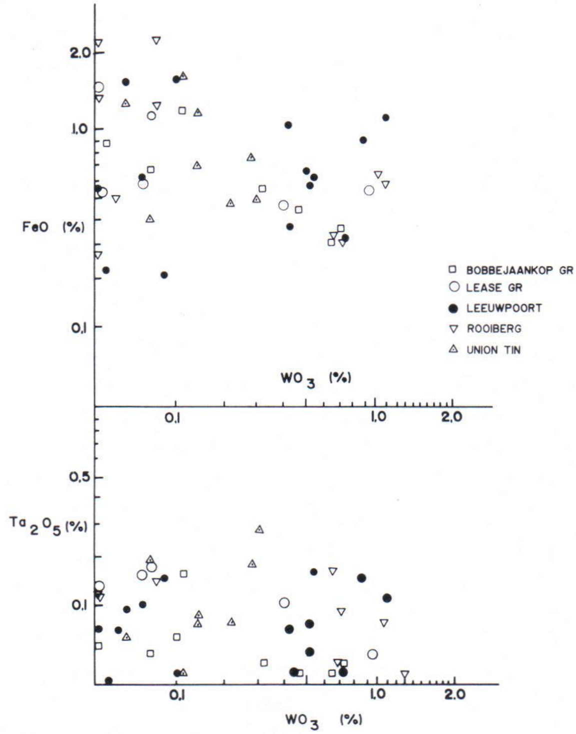

Fig. 3. FeO—WO_3 and Ta_2O_5—WO_3 plot of the analysed cassiterites including both dark and light colour zones.

(in Table 1, multiplied by 100) are always higher in dark zones than in light zones. Only two crystals, *i.e.,* 06377—261 in the Lease granite and 06377—236 at the Leeuwpoort tin mine, are exceptions to this rule. Thus far, the dark zones of the Bushveld Complex cassiterites accommodate higher amounts of other cations in the crystal lattices than the light zones, finding may provide the explanation of the colour zoning itself.

The homogeneity of the analysed crystals was studied by a scanning electron microscope equipped with a semi-quantitative energy dispersive X-ray (SEM-EDAX) analyser. Generally, all the analysed crystals contained only very small amounts of mineral inclusions as impurities. Ankerite occurs as inclusions in some Union tin mine cassiterites whereas some dark zones of cassiterites from Zaaiplaats have inclusions of sphene and/or scheelite.

Discussion

Grubb and Hannaford (1966) argued that essentially three varieties of cassiterite can be recognized:

(i) A purplish-grey or black, strongly pleochroic, non-magnetic variety that has slightly higher proportions of copper and nickel and that is most commonly associated with sulphide or tourmaline-rich ore bodies.

(ii) A reddish-brown cassiterite that is strongly pleochroic in the Nigerian tin-fields, but generally only weakly so. This fraction is usually the most magnetic and has a high Fe^{2+}/Fe^{3+} ratio, and sometimes some tantalum and niobium.

(iii) Colourless cassiterite that is ubiquitous in tin deposits but is more common in lodes rich in sulphide components.

Hosking (1970) suggested that the strong red/green pleochroism of cassiterite in vein deposits of Thailand and Malaysia is due to appreciable tantalum and/or niobium in the lattice. Polished sections of such cassiterite are characterized by the presence of small exsolution bodies that have not been identified with certainty but are probably members of the columbite/tantalite series of minerals. Such niobiferous/tantaliferous cassiterite occurs in pegmatites. That tantalum/niobium may be confined to certain zones in a cassiterite crystal has been demonstrated by means of the electron probe.

Appreciable proportions of the cassiterite from South-East Asia are, in addition, magnetic, and two different types of magnetic cassiterite are found there. The ferromagnetic type, whose magnetic property is destroyed by heating, occurs in areas in which cassiterite is closely associated with iron ores (Hosking 1970).

Liebenberg (1945) suggested that pleochroism might originate through the presence of niobium and tantalum, whereas Ramdohr (1933) attributed the existence of pleochroic haloes to radioactive mineral inclusions.

The reasons for colour variation within cassiterite are poorly understood. Tangential studies have prompted many suggestions usually involving specific or combinations of trace impurities (Taylor 1979).

The colour zoning of cassiterites has been attributed to compositional differences (Leube and Stumpfl 1963) or variation in the Fe^{2+}/Fe^{3+} ratio (Grubb and Hannaford 1966). However, Banerjee *et al.* (1970) disagreed with these conclusions.

According to Taylor (1979, *op.cit.*), Goncharov and Filatov (1971) noted that the cell parameters changed with colour, the lattice contracting anisotropically on moving from a pale to a darker zone, and that the strength of the colour is not a consequence of the total quantity of trace components in the SnO_2. These components may be divided into two groups. Some of them (especially Ti) cause the SnO_2 lattice to contract isotropically but do not colour the crystal. Others (Fe, W, Ba, Sc, Be, Mn) show regular increases in content from the pale varieties to the dark ones. Some of these elements appear to cause anisotropic lattice deformation and to produce brown colours.

Dudykina (1959, *in* Taylor 1979, *op.cit.*) concluded that both Nb and Ta concentrations were at a maximum in cassiterites from pegmatitic environments and that particularly tantalum may be used to characterize conditions of formation. He also found that up to 2 per cent Ta was present in cassiterites from pegmatite veins and was also found in high-temperature quartz-feldspar veins and greisens. Levels of Ta in quartz-cassiterite veins were low (150 ppm) and none was found in quartz-cassiterite veins or sulphide-cassiterite type.

The observed differences in chemical composition between granite cassiterite (Nb_2O_5, Ta_2O_5, FeO and TiO_2 = 10.5—6.4 wt %), pegmatite cassiterite (= 5.0—3.7 %) and greisen cassiterite (= 1.1—0.8 %), and other properties of the cassiterites from different types of occurrences in the Eurajoki area indicate differences in the physicochemical conditions of their formation, and also that the granite cassiterite crystallized at a slightly higher temperature than the pegmatite cassiterite and at a much higher temperature than the greisen cassiterite (Haapala 1977).

Both the niobium and tantalum concentrations in the analysed Bushveld cassiterites are very low compared with the values reported in the literature. The highest average niobium value (0.13 % Nb_2O_5) is found in the granite cassiterites (in unaltered Bobbejaankop granite) that apparently had the highest original crystallization temperature of all the tin deposits under consideration.

The present data are insufficient to permit to draw clear conclusions about the physicochemical crystallization conditions in the tin deposits studied.

Conclusion

The present investigation has verified that minor amounts of tantalum, niobium, tungsten and iron are incorporated in the crystal structures of cassiterites in different types of tin deposits within the acid phase of the Bushveld Complex.

The only exception is tungsten that can, at least partially, occur as tiny mineral inclusions of sphene or scheelite in Zaaiplaats cassiterites and iron as ankerite in Union tin mine cassiterites.

The very low minor and trace element concentration in the Bushveld cassiterites is apparently due to their exceptional purity from mineral inclusions in microscopic and/or submicroscopic scales.

According to this study, the most plausible explanation for the colour zoning in the Bushveld Complex cassiterites is that the dark zones of cassiterites incorporate higher total amounts of tantalum, niobium, tungsten and iron oxides than the light ones.

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