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Mineralogical characterization of cassiterite concentrates from quartz vein and pegmatite mineralization of the Karagwe-Ankole and Kibara Belts, Central Africa

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ABSTRACT. The Mesoproterozoic Kibara belt (KIB) and the Karagwe-Ankole Belt (KAB) in Central Africa are characterized by the presence of numerous rare metal mineralized Sn-(Nb-Ta) pegmatites and Sn-W mineralised quartz veins that are related to a S-type granite generation formed at 986 ± 10 Ma. Cassiterite concentrates have been studied by different petrographic and mineralogical techniques. The concentrates have been collected from the rock and mineral collection of the Royal Museum for Central Africa (RMCA) and originate from historical exploitations of eluvial and alluvial cassiterite deposits. No quantitative study of the concentrates has been envisaged since no information is available about the history of the samples prior to sampling. Microscopic investigation revealed the presence of cassiterite crystals with metallic and non-metallic luster, of which the latter show growth zoning. The color from the cassiterite crystals can vary from transparent colorless to black non-transparent. The variation in color in a single grain can be as varied as the color variation between grains for an entire concentrate. The mineralogical composition of the cassiterite concentrates contains minerals that are typical gangue and accessory minerals in the primary mineralization and that were liberated during weathering. In addition, minerals can be found that result from the weathering from the metasedimentary and doleritic host-rocks of the primary mineralization. Except the occasional presence of a certain mineral or a special color for a certain cassiterite, no systematic variation can be observed between the concentrates from the different locations. Often, the mineral and color variation in one concentrate can be as large as for concentrates found from different locations.

KEY WORDS. Karagwe-Ankole belt, Kibara belt, cassiterite concentrates, microscopy, XRD, SEM-EDX

1. Introduction

The Kibara belt (KIB) and the Karagwe-Ankole belt (KAB) of Central Africa consist of Mesoproterozoic supracrustal units, mostly metasedimentary rocks with minor metavolcanic rocks, intruded by voluminous Mesoproterozoic S-type granitoid massifs and subordinate mafic bodies (Cahen et al., 1984 and references therein). The KIB and KAB together host a large metallogenic province that contains numerous granite-related ore deposits, with the typical metal association of Sn-W-Ta. The metals are present in different styles of mineralization. They occur as primary mineralization in quartz veins and pegmatites, but also as secondary mineralization in alluvial or eluvial deposits. Many historical mineralogical and general geological studies have dealt with the mineralization in the KIB and KAB (e.g. Agassiz, 1954; Safiannikoff, 1955; Varlamoff, 1952; 1954; 1969), and recently the study of the granite-related mineralization in the KIB and KAB has been restarted by using more modern techniques (Pohl & Günther, 1991; Dewaele et al., 2010, 2011; De Clercq, 2012).

A politically-driven project on the establishment of a mineralogical and geochemical fingerprint for Ta-Nb mineral concentrates ("coltan") was initiated in 2006 by the BGR (Melcher et al., 2008a, b), with scientific cooperation of the Royal Museum for Central Africa (RMCA). A vast dataset from Nb-Ta samples from more than 30 rare-element granite and pegmatite districts worldwide has been created comprising mineralogical, geochemical and textural characteristics as well as age determinations using the U-Pb method (Melcher et al., 2008a; 2008b; 2009; Graupner et al., 2010; Gäbler et al., 2011; Melcher et al., submitted). Based on their immense datasets, the geologists of the BGR concluded that the combined mineralogical, geochemical and textural data provide important information on regional and local differences ("signatures") and allowed to fingerprint the concentrates (Melcher et al., 2009; Savu-Krohn et al., 2011). The application of these different high-tech techniques (e.g. X-ray fluorescence spectroscopy, electron microprobe analysis, laser ablation inductively coupled mass spectrometry, fully automated electron microscopy or mineral liberation analysis, thermal ionisation mass spectrometry) is, however, very expensive and, therefore not applicable for many African research institutes. In 2009, a research project (i.e. the GECO-project, Geology for an ECOnomic sustainable development) started between the Royal Museum for Central Africa and the Royal Belgian Institute for Natural Sciences, sponsored by the Belgian Ministry of Foreign Affairs, with the aim to study mineral deposits in Central Africa. One of the activities was to characterize the Sn mineralization present in the Great Lakes area. To avoid the high laboratory costs, it was tested if by using rather basic microscopic and mineralogical techniques that are present at most research institutes (standard microscopy, XRD, SEM-EDS), it was possible to characterize different concentrates from different geological environments.

2. Geology of the Karagwe-Ankole belt and the Kibara belt

The Karagwe-Ankole belt (KAB) and the Kibara belt (KIB) (Tack et al., 2010) of Central Africa formed and evolved between two pre-Mesoproterozoic domains: the Archaean-Palaeoproterozoic Congo Craton to the west and north, and the Archaean Tanzania craton to the east and Bangweulu Block to the south (Fig. 1). The two separate - but coeval - belts are separated in the Democratic Republic of the Congo (DRC) by the northwestern extension of the Palaeoproterozoic Ubende belt (SW Tanzania) across Lake Tanganyika: the Rusizian basement. The Northeastern segment or Karagwe-Ankole belt is situated in Rwanda, Burundi and the, Maniema and Kivu provinces in the DRC. The southern segment or Kibara belt is located in the Katanga province in the DRC (Tack et al., 2010).

The Mesoproterozoic metasedimentary rocks of the KAB and KIB consist mainly of monotonous siliciclastic pelite and arenite sequences, interpreted as shallow-water turbidite deposits. Carbonate rocks are rare and occur as thin lenticular deposits (Cahen et al., 1984; Baudet et al., 1988; Kokonyangi, 2006). Vitroclastic tuffs and breccias suggest nearby felsic explosive volcanic activity. At various localities in the western part of Rwanda, the presence of Rusizian basement (Palaeoproterozoic age) has been identified on reconnaissance geochronological data, on structural and/or metamorphic characteristics (Cahen et al., 1984 and references therein; Lavreau, 1985; Baudet et al., 1988; Theunissen et al., 1991) and by using geophysical and geochemical data (Fernandez-Alonso & Theunissen, 1998).

The KIB and KAB have been intruded by different generations of granitoid massifs and subordinate mafic bodies (Cahen et al., 1984 and references therein). Tack et al. (2010) and Fernandez-Alonso et al. (2012) suggest that for the KAB the first main granite generation is related to a thermodynamic "tectono-magmatic" event at ~ 1375 Ma during the time of prominent bimodal magmatism and extensional tectonics, while the orogeny occurred during Rodinia amalgamation at ~ 1000 Ma

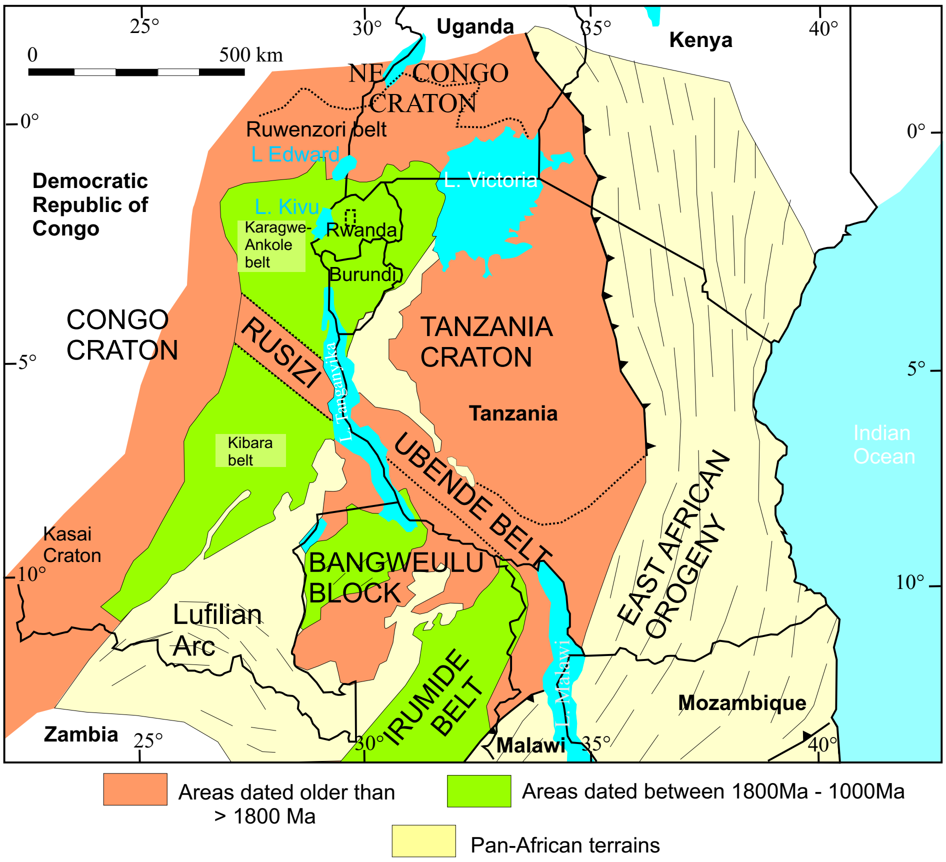

Figure 1. Regional geological setting of the Central African area (modified after Brinckmann et al. 2001 and Dewaele et al. 2011).

(Fernandez-Alonso et al., 2012). The granite generation formed during the latter event is associated with Sn-Nb-Ta mineralized pegmatites and Sn-W mineralized quartz veins. The belts have been reactivated during different more recent periods - from Neoproterozoic orogenic deformation at ~550 Ma until present-day development of the Western Rift -, which has an effect on the morphology and the presence of the mineralization in reworked surface deposits.

3. Cassiterite mineralization in the KIB and KAB

The KIB and KAB together host a large metallogenic province that contains numerous granite-related ore deposits, with the metal association of Sn-W-Ta-Li-Be. The metals are present in different styles of mineralization. They occur as primary mineralization in quartz veins and pegmatites that have intruded metasedimentary and doleritic rocks, but also as secondary mineralization in alluvial or eluvial deposits.

3.1. Primary mineralization in quartz veins and pegmatites

The mineralized quartz veins of the KIB and KAB are dominantly hosted by metasedimentary rocks that have been submitted to regional low-grade greenschist metamorphism (Baudet et al., 1988; Fernandez et al., 2012; Gérards, 1965; Kokonyangi et al., 2004; 2006). The cassiterite mineralized quartz veins show a very similar morphology throughout the entire KIB and KAB (Pohl, 1994; Pohl & Günther, 1991, Dewaele et al., 2007b; 2009). The quartz veins are bordered with a dark rim of tourmaline, which passes into more disseminated tourmaline and muscovite further away from the vein. This alteration of the host-rock is caused by sericitization, silicification, tourmalinization and muscovitization (Dewaele et al., 2007a; 2009; 2010; De Clercq, 2012) (Plate 1B). The host-rocks often show a slight foliation development. The quartz veins with associated alteration crosscut the foliation and are therefore interpreted to have formed syn-to post-cleavage development.

The paragenetic sequence of the quartz vein type cassiterite mineralization has been studied by numerous authors (Dewaele et al., 2007b; 2009, 2010; De Clercq, 2012). In addition to quartz, cassiterite, scheelite, rutile, topaz, muscovite, ferberite/wolframite and different sulphides can be found as primary mineral assemblage (Plate 1A + 1C + 1D). Recent weathering resulted in the formation of hematite, goethite, kaolinite and varlamoffite (Antun, 1960). In general, no columbite-tantalite can be found.

Just as for the quartz vein mineralization, the cassiterite mineralized pegmatites show a very similar appearance throughout the KIB and KAB (Pohl, 1994; Pohl & Günther, 1991; Dewaele et al., 2007b; 2008; 2011). Cassiterite and columbite-tantalite mineralization can be found in the more evolved pegmatites, pegmatites of the LCT-type (Lithium Caesium Tantalum)-type according the paragenetic-geochemical classification scheme of Cerny (1991). A zonal development from the margin towards the center with later metasomatic overprint can be observed in these pegmatites (Dewaele et al., 2008; 2011). The main minerals that can be found in the mineralized pegmatites are K-feldspar, muscovite, sericite, quartz, albite, columbite-tantalite, cassiterite, spodumene, apatite, beryl and some pyrite (Plate 1E + 1F). Some more exotic minerals have been described for different pegmatites in the KIB and KAB, like an extended phosphate mineralogy (eg. Fransolet, 1975). Quantitative Scanning Electron Microscopy/Mineral Liberation Analysis indicated that only a small proportion of the cassiterite is clearly of pegmatite origin (Dewaele et al. 2011),

3.2 Secondary alluvial and eluvial mineralization

Mineralogical and geological information on the characteristics of the secondary deposits is available in the unpublished mining archives of the RMCA and in publications of Varlamoff (1952; 1969). Alteration and erosion was very efficient due to the tropical climate in Central Africa as well as the morphology of the terrain and the abundance of water. The weathering can reach a depth of 15 to 30m and sometimes even more (Varlamoff, 1969). The weathering is particularly developed beneath the old peneplains above granitic rocks. The decomposition of the rocks penetrates until a depth of 5 to 10 meters in schists, while erosion is even less developed in quartzitic and doleritic rocks.

Weathering of cassiterite mineralized quartz veins resulted in little chemical change, mechanical processes dominate. In pegmatites, superficial kaolinitization largely affects the primary mineral assemblage. In both cases, throughout weathering and erosive processes, cassiterite remains unaltered and is partly concentrated in eluvial and river gravels. During continuing mechanical transport the grain size of cassiterite is further reduced.

Varlamoff (1952) has made a systematic study of the eluvial and alluvial cassiterite deposits in the Kalima area. In general, he states that the eluvial deposits inherited their characteristics of the primary deposits. Eluvial deposits immediately above granite bodies typically consist of a gravel layer up to 5 m thick that is mostly composed of quartz boulders. The grain size of the cassiterite is very coarse. Since the sulphides are oxidized and removed during weathering, the mineralized gravel is mostly pure and contains minerals like wolframite/ferberite, columbite-tantalite, in addition to cassiterite. If the eluvial deposit is situated in contact with metasedimentary of doleritic rocks, the gravel becomes more clay-rich. In general, the thickness of the gravel layer is not so developed and only reaches a thickness of 1 to 2m. The grade of the eluvial gravel varies between 0.2 kg/m³ to 5 kg/m³. The average grade of an exploitation varied between 500g/m³ and 1500 g/m³.

The distribution of the alluvial deposits is largely dependent of the type of primary deposit and the morphology of the river network. Varlamoff (1952) noted that for the Kalima area, economic alluvial cassiterite placers (grades above 500g/m³) were only found until 1 to 2 km of the granite contact with primary mineralization. The morphology and the tonnage of the mineralized flat are determined by the shape of the river basin. The gravel of the rivers can contain more than 50 % of quartz. In general, the grain size of the cassiterite is quite uniform. Columbite-tantalite behaves in the same way as cassiterite, but wolframite/ferberite occurs until 100 to 200m of the primary deposit. There is, however, an important contribution of heavy minerals from the surrounding metasedimentary and doleritic rocks in the river basin, which has an influence on the purity of the concentrates.

4. Methodology

Cassiterite concentrate samples have been collected from the mineral and rock collection of the RMCA (Royal Museum for Central Africa). These different concentrates originate from historical exploitations during colonial times, from different mining companies and different periods. Information about the geological context of these historical exploitations is available in the mining archives of the colonial mining companies, in the RMCA. However, no information is available about any "processing" that the samples have probably been submitted to prior to sampling. Some of the samples have probably been submitted to some mechanized concentration (crushing, sieving, jigs and washing tables; unpublished archives RMCA), while other samples are the result of simple panning. Since this lack of information about the "history" of the samples, the comparison of the mineralogical results between samples from different locations should be carried out with care and quantitative comparison is, therefore, not envisaged in this study.

Samples have been selected from cassiterite deposits that originate from both the KIB (Katanga) and KAB (Maniema, Kivus and Rwanda) (Figure 2, Table 1). Attention has been spent during sample selection to have a good regional distribution of the sampling locations, but also to have different samples from the same area. This could help to illustrate the regional variability in concentrate composition. Most concentrates originate from the exploitation of alluvial and eluvial deposits that originate from the weathering and erosion of primary quartz vein and pegmatite mineralization.

Thin and polished sections have been prepared for optical investigation of the concentrates. Transmitted and reflected light microscopy was carried out to characterize the color, luster, mineralogy and the morphology of the different minerals present. Thin sections were especially prepared for the cassiterite concentrates to identify internal features, eg. mineral inclusions, zonation and growth or deformation structures. The mineralogical composition of additional mineral components of the concentrates has been identified by scanning electron microscopy equipped with energy dispersive spectrometry (SEM-EDS), X-ray diffraction and laser Raman spectrometry. For XRD, the sample has been sieved and the fraction smaller than 1 mm has been crushed and analysed. The fraction larger than 1 mm has been checked microscopically and consisted of pure cassiterite. The mineralogical composition of different minerals was determined by XRD-analysis on a Philips PW3710 diffractometer with Cu-tube. The working conditions were 45kV, 30mA, rotating sample holder, secondary monochromator with divergence and receiving slit of respectively 1° and 0.1°, and with a stepsize of 0.05° 2q. For SEM-EDS and laser Raman analysis, analysis has been carried out on polished sections.

	Sample n° RMCA	Location	Territory	Country	coX	coY	Sample type	Type of primary mineralisation	Host-rock
SD02	RG 12676	D16 Lowa,Kima	Lubutu	DRC	26.72	-1.43	alluvial	Q vein	Metasediments
SD03		Mususa	Kailo	DRC	26.13	-2.60	eluvial	Q vein	Metasediments / granite
SD04	RG 1476	Mokama	Kailo	DRC	26.08	-2.60	eluvial	Q vein	Metasediments / granite
SD05	RG 114	Kailo	Kailo	DRC	26.11	-2.63	eluvial	Q vein	Metasediments / granite
SD06	RG 183	Kabunga	Masisi	DRC	28.16	-1.64	alluvial	Q vein/pegmatite	Metasediments
SD07	RG 1923	Kisheke	Masisi	DRC	27.97	-1.63	alluvial	Q vein/pegmatite	Metasediments
SD08	RG 1928	Sasa	Kabare	DRC	28.20	-3.12	alluvial	Q vein/pegmatite	Metasediments
SD09	RG 1919	Matale	Kabare	DRC	28.33	-2.66	alluvial	Q vein/pegmatite	Metasediments
SD10	RG 135	Kabambare – Yungwe	Fizi	DRC	27.72	-4.67	alluvial	Q vein/pegmatite	Metasediments / granite
SD11	RG 172	Punia	Punia	DRC	26.47	-1.45	eluvial	Q vein	Metasediments / granite
SD12	RG 2014	Kasese	Shabunda	DRC	27.34	-2.69	eluvial	Q vein	Metasediments / granite
SD13		Nyangulube	Kampene	DRC	26.67	-3.59	eluvial	Q vein	Metasediments
SD14	RG 165	Muana	Mwenga	DRC	28.43	-3.13	eluvial	pegmatite	Metasediments
SD15	RG 188	Nzombe	Mwenga	DRC	28.54	-3.14	eluvial	Q vein	granite
SD16	RG 34776	Ngussa W	Mwenga	DRC	28.67	-3.28	eluvial	Q vein	Metasediments
SD17	RG 1926	Bilembo	Mwenga	DRC	28.36	-3.01	alluvial	Q vein	Metasediments / granite
SD18	RG 12762	Miki	Mwenga	DRC	28.67	-3.36	alluvial	Q vein	Metasediments / granite
SD19	RG 211	Misobo	Pangi	DRC	26.54	-2.64	eluvial	Q vein	Metasediments / granite
SD20	RG 209	Atondo	Pangi	DRC	26.83	-2.72	eluvial	Q vein	granite
SD21	RG 203	Salukwango	Pangi	DRC	26.60	-2.63	eluvial	Q vein	Metasediments / granite
SD22	RG 1541	Moga	Pangi	DRC	26.80	-2.33	eluvial	Q vein	Metasediments / granite
SD23	RG 192	Nzalu	Pangi	DRC	26.71	-2.58	eluvial	Q vein	Metasediments / granite
SD24	RG 2377	Nakenge	Pangi	DRC	26.67	-2.58	eluvial	Q vein	Metasediments / granite
SD25	RG 12686	Kindi	Pangi	DRC	27.69	-3.00	eluvial	Q vein	Metasediments / granite
SD26	RG 320	Kianzo-Kasese	Pangi	DRC	27.11	-1.64	alluvial	Q vein	granite
SD27	RG 1806	Mitwaba	Katanga	DRC	27.35	-8.60	eluvial	Q vein	Metasediments
SD28	RG 3554	Manono	Katanga	DRC	27.42	-7.25	eluvial	pegmatite	Metasediments
SD29	RG 711	Muika	Katanga	DRC	28.07	-7.37	eluvial	pegmatite	Metasediments
SD30	UMHK	Busanga	Katanga	DRC	25.40	-10.22	eluvial	Q vein	Metasediments
SD31		Kalanda	Katanga	DRC	25.99	-5.85	eluvial	Q vein	Metasediments
SD32		Bisesero		Rwanda	29.19	-2.16	eluvial	Q vein	Metasediments
SD33		Filon Migera, Rwinkwavu		Rwanda	30.59	-1.98	eluvial	Q vein	Metasediments
SD34	RG 8600	Lemera		Rwanda	29.54	-2.23	eluvial	pegmatite	Metasediments
SD35	RG 13272	Musha		Rwanda	30.35	-1.93	eluvial	Q vein/pegmatite	Metasediments
SD36	RG 9127	Lutsiro		Rwanda	29.44	-1.88	eluvial	Q vein/pegmatite	Metasediments
SD37	RG 10677	Mwaka		Rwanda	29.65	-2.13	eluvial	pegmatite	Metasediments
SD38		Rutongo		Rwanda	30.05	-1.81	eluvial	Q vein	Metasediments
SD39		Gatumba S		Rwanda	29.65	-1.94	eluvial	pegmatite	Metasediments
SD40		Bugalula		Rwanda	29.44	-2.02	eluvial	Q vein	Metasediments
SD41	RG 1532	Moga, g4D68	Pangi	DRC	26.80	-2.33	alluvial	?	Metasediments / granite
SD42	RG 1534	Moga, D64 amont 1	Pangi	DRC	26.80	-2.33	alluvial	?	Metasediments / granite
SD43	RG 1539	Moga, Musoke 1	Pangi	DRC	26.80	-2.33	alluvial	?	Metasediments / granite
SD44	RG 1541	Moga, D68 n°1	Pangi	DRC	26.80	-2.33	alluvial	?	Metasediments / granite
SD45	RG 1542	Moga, Musoke 2	Pangi	DRC	26.80	-2.33	alluvial	?	Metasediments / granite

Table 1. List of samples with geographic coordinates, the sample number in the rock and mineral collection of the RMCA, territory, country (DRC:Democratic Republic of Congo), type of exploitation and geological context (Q vein: quartz vein).

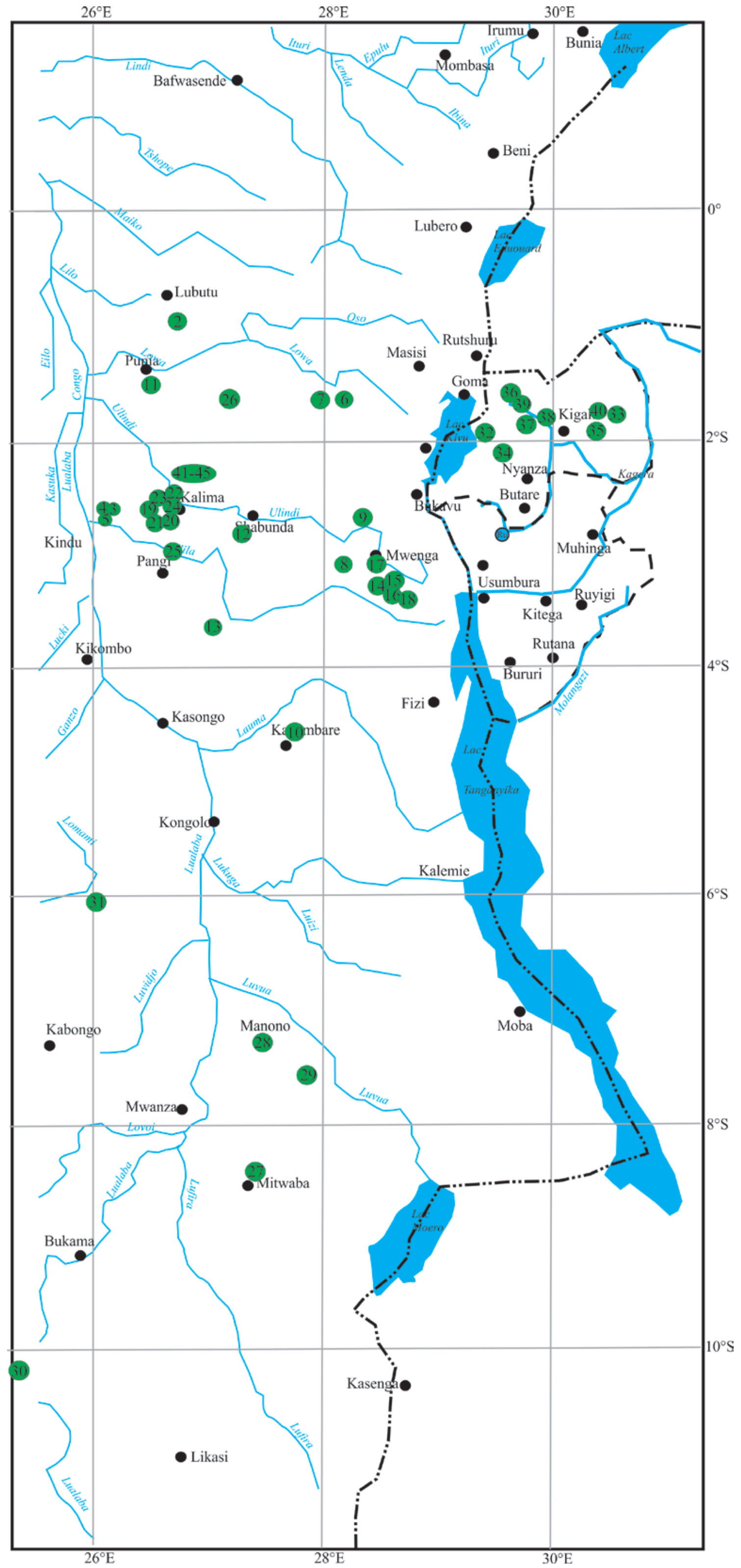

Figure 2. Schematic map of the Great Lakes Area in Central Africa, showing the different locations of the samples studied. Numbers in green cercles correspond to the sample list in Table 1.

5. Mineralogical characterization

Microscopic characterization

The morphology of the grains and the grain size have not been investigated in detail, since no information is known about any processing that the concentrates have been submitted to prior to sampling. The grain size of the different concentrates seems, however, to be quite uniform in the different samples, which could indicate a similar processing. Most cassiterite grains are not nicely rounded indicating that the grains have not been submitted to any long transport and associated physical erosion.

The luster of different cassiterite crystals in the concentrates has been investigated (Table 2). Cassiterite with a metallic and non-metallic luster can be identified. The cassiterite with a (sub-)metallic luster is quite opaque to transmitted light. The cassiterites with non-metallic luster are in general light-colored and transmit light. The non-metallic luster can be described further and a distinction can be made between cassiterite with a greasy or adamantine luster. It should be noted that the grains of some of the concentrates have a quite homogeneous luster (eg SD03), while other concentrates show a mixture of grains ranging from a (sub-)metallic to a non-metallic luster. It is striking that single cassiterite crystals can be identified were a non-transparent zone with (sub-)metallic luster is in direct contact with a transparent zone with a greasy luster. Therefore variation in the luster (and transparency) in other cassiterite concentrates should not necessarily be accredited to contamination and mixing.

Growth zones in cassiterite grains have mostly not been observed in the grains with a (sub-)metallic luster, but is omnipresent in the cassiterites with a non-metallic luster (Table 2).

	Location	Grain size	Banding	Luster	Zoning	Colour
SD02	D16 Iowa, Kima	mean some 300 μ quite uniform	none	semi-metallic	few	dull grey-white
SD03	Mususa	mean some 300 μ quite uniform	none	metallic	some	black-dark brown
SD04	Mokama	mean some 250 μ quite uniform	few	metallic	/	black-dark brown
SD05	Kailo	mean some 200 μ quite uniform	few	semi-metallic	zoning	black-dark brown
SD06	Kabingo	mean some 200 μ quite uniform	none	semi-metallic	some	dark brown to black
SD07	Kisheke	300 -400 μ quite uniform	/	translucent	rare brown	beige
SD08	Sasa	/	/	translucent to metallic	/	beige,dark brown to black
SD09	Matale	mean some 200 μ variable		/	rare dark brown	colourless to light brown
SD10	Kabambare - Yungwe	200 -400 μ quite variable	none	(semi-)metallic	/	dark brown to black
SD11	Punia	150 -400 μ quite variable	rare	(semi-)metallic	few	pale yellow, dark brown to black
SD12	Kasese	/	/	/	some dark brown	colourless to light brown (smoked)
SD13	Nyangulube	200 -350 μ quite variable	rare	/		amber brown
SD14	Muana	25 -200 μ quite variable	rare	adamantine to metallic	zoned	pale yellow , amber, brown, black
SD15	Nzombe	mean some 300 μ quite uniform	none	(semi-)metallic	irregular	dark (light) brown
SD16	Ngussa W	mean some 200 μ quite uniform	rare	(semi-)metallic	irregular	beige translucent, brown, black
SD17	Bilembo	200-500 μ variable	none	adamantine	some dark zones	beige roze translucent
SD18	Miki	150-450 μ variable	rare	adamantine	some brown zones	colourless transparant to beige lightly smoked
SD19	Misobo	50-500 μ very variable	banding	(semi-)metallic	dark zones	colourless transparant, beige translucent, brown to black
SD20	Atondo	mean 250 μ quite uniform	banded	metallic	zoned	dull dark brown to black
SD21	Salukwango	mean 150 μ	none	(semi-)metallic	zoned	light to dark brown and black
SD22	Moga		none	adamantine to metallic		dull grey-white, beige, brown
SD23	Nzalu	mean 200 - 350 μ	none	semi-metallic	zoned	brown to black
SD24	Nakenge	mean 150 μ quite uniform	none	semi-metallic	none	black
SD25	Kindi	150 -250 μ quite variable	none	semi-metallic	none	black
SD26	Kianzo - Kasese	mean 200 μ quite uniform	none	semi-metallic to metallic	rare	pale grey-brown dark brown to black
SD27	Mitwaba	50 -350 μ very variable	some	adamantine to semi-metallic	some	colourless, light to dark brown
SD28	Manono	25 -500 μ very variable	none	semi-metallic to metallic	some	brown, mostly black
SD29	Muika	mean 250 μ quite uniform	no	semi-metallic to metallic	some	dark brown, mostly black
SD30	Busanga	mean 350 μ quite uniform	none	adamantine to semi-metallic	rare	grey, licht brown (some dark & black)
SD31	Kalanda	mean 200 μ quite uniform	none	semi-metallic	some	light to dark brown & black
SD32	Bisesero	50 -200 μ variable	some	adamantine to semi-metallic	frequenty zoned	grey, licht brown to dark brown & black)
SD33	filon Migera, Rwinkwavu	150 - 350 μ variable	rare	(adamantine) semi-metallic	some	licht brown to dark brown & black)
SD34	Lemera	100 - 500 μ variable	none	semi-metallic	none	black
SD35	Musha	150 - 400 μ variable	light	semi-metallic	zoned	licht brown (some dark)
SD36	Lutsiro	150 - 450 μ variable	frequently	adamantine to metallic	frequently	colourless transparant over all shades of brown to black
SD37	Mwaka	10 - 500 μ extremely variable	none	semi-metallic	none	light brown black
SD38	Rutongo	150 - 400 μ variable	some	adamantine to semi-metallic	zoned	grey light to dark brown

Table 2. Table indicating the different color and luster identified for the different cassiterite concentrates

	Code RMCA	Location	Minerals identified in addition to cassiterite	Primary Mineralisation	Host-rock
SD02	RG 12676	D16 Iowa, Kima	Tourmaline	Q vein	Metasediments
SD03		Mususa	Quartz, topaz, Albite	Q vein	Metasediments / granite
SD04	RG 1476	Mokama	Quartz, Nb-Ta, Albite	Q vein	Metasediments / granite
SD05	RG 114	Kailo	Quartz	Q vein	Metasediments / granite
SD06	RG 183	Kabingo	Nb-Ta	Q vein/pegmatite	Metasediments
SD07	RG 1923	Kisheke	/	Q vein/pegmatite	Metasediments
SD08	RG 1928	Sasa	Quartz	Q vein/pegmatite	Metasediments
SD09	RG 1919	Matale	/	Q vein/pegmatite	Metasediments
SD10	RG 135	Kabambare - Yungwe	Nb-Ta, Hematite	Q vein/pegmatite	Metasediments / granite
SD11	RG 172	Punia	Nb-Ta, Ilmenite	Q vein	Metasediments / granite
SD12	RG 2014	Kasese	/	Q vein	Metasediments / granite
SD13		Nyangulube	Quartz, Tourmaline	Q vein	Metasediments
SD14	RG 165	Muana	Ilmenite, Quartz	pegmatite	Metasediments
SD15	RG 188	Nzombe	Muscovite, Tourmaline	Q vein	granite
SD16	RG 34776	Ngussa W	Quartz, Muscovite, Goethite	Q vein	Metasediments
SD17	RG 1926	Bilembo	/	Q vein	Metasediments / granite
SD18	RG 12762	Miki	/	Q vein	Metasediments / granite
SD19	RG 211	Misobo	Quartz	Q vein	Metasediments / granite
SD20	RG 209	Atondo	Albite, Muscovite	Q vein	granite
SD21	RG 203	Salukwango	Quartz, Muscovite	Q vein	Metasediments / granite
SD22	RG 1541	Moga	Quartz	Q vein	Metasediments / granite
SD23	RG 192	Nzalu	Quartz	Q vein	Metasediments / granite
SD24	RG 2377	Nakenge	Muscovite	Q vein	Metasediments / granite
SD25	RG 12686	Kindi	Nb-Ta	Q vein	Metasediments / granite
SD26	RG 320	Kianzo - Kasese	Muscovite, Quartz, Wolframite	Q vein	granite
SD32		Bisesero	Quartz	Q vein	Metasediments
SD33		filon Migera, Rwinkwavu	Quartz	Q vein	Metasediments
SD34	RG 8600	Lemera	/	pegmatite	Metasediments
SD35	RG 13272	Musha	Muscovite, Quartz	Q vein/pegmatite	Metasediments
SD36	RG 9127	Lutsiro	Quartz	Q vein/pegmatite	Metasediments
SD37	RG 10677	Mwaka	/	pegmatite	Metasediments
SD38		Rutongo	Quartz	Q vein	Metasediments
SD39		Gatumba S	Quartz	pegmatite	Metasediments
SD40		Bugalula	Muscovite, Quartz	Q vein	Metasediments
SD41	RG 1532	Moga, g4D68	Quartz, Calcite, ilmenite	?	Metasediments / granite
SD42	RG 1534	Moga,D64 amont 1	Quartz	?	Metasediments / granite
SD43	RG 1539	Moga, Musoke 1	Quartz, Ilmenite, Magnetite	?	Metasediments / granite
SD44	RG 1541	Moga, D68	Quartz, Ilmenite	?	Metasediments / granite
SD45	RG 1542	Moga, Musoke 2	Quartz	?	Metasediments / granite

Table 3. Table indicating the minerals found by XRD analysis in addition to cassiterite. Nb-Ta = columbite -tantalite

A color variation can be observed going from transparent to dark brown in a single crystal. The color of the individual grains with (sub-)metallic luster can have a dark-grey to dark-brown color. The grains with a non-metallic luster can be transparent, beige and light to dark-brown. As different colors can be identified in a single grain, color variation in a cassiterite concentrate does not necessary imply the mixing of cassiterite from different sources. Some of the grains show an exceptional color. The grains of the Bilembo (SD17) concentrate for example show beige rose translucent color.

X-Ray Diffraction

XRD analyses on the different cassiterite concentrates show that the concentrates originating from the weathering of mineralized quartz veins contain feldspars, iron oxides and hydroxides, muscovite, tourmaline, topaz, quartz, wolframite and columbite-tantalite in addition to cassiterite (Table 3). Pegmatite cassiterite concentrates show the presence of columbite-tantalite, ilmenite, iron oxides and hydroxides, muscovite and quartz (Table 3).

XRD investigation show that only limited minerals can be identified in addition to cassiterite (Table 3) in the cassiterite concentrates. This indicates that the cassiterite concentrates are quite pure, which has been illustrated by the results of Mineral Liberation Analysis (BGR, unpublished data) performed on some of the samples. Except the different alluvial concentrates of the Moga river (SD41-45), most of the cassiterite concentrates consists for more than 95% out of cassiterite. By comparing these results with the mineral liberation analysis (MLA), it becomes clear that only components that make more than ~0.5% of the concentrates have been identified by XRD analyses. Since only a very limited amount of minerals can be identified in addition to cassiterite, it is not possible to make a comparison between the different concentrates.

SEM-EDS characterization

The mineralogical composition of the different cassiterite concentrates has been investigated by SEM-EDS (Table 4). Typical gangue and alteration minerals of the primary mineralization have been identified: quartz (25 concentrates), tourmaline (8 concentrates), feldspar (11 concentrates), muscovite (12 concentrates) and an unidentified Fe-K-Al-silicate (12 concentrates). Also accessory minerals typical of the primary mineralization have been determined: columbite-tantalite (6 concentrates), wolframite (5 concentrates), topaz (6 concentrates), fluorite (2 concentrates) and sulphides (6 concentrates). Since the concentrates investigated have an eluvial or alluvial origin, Fe-oxydes and hydroxides (14 concentrates) are abundant. It should be noted that different heavy minerals that do not occur in the primary mineralization have been found, i.e. staurolite (4 concentrates), ilmenite (8 concentrates), rutile (7 concentrates), anatase (1 concentrates), xenotime (3 concentrates) and zircon (2 concentrates). These minerals are typically present in the host-rock of the primary mineralization. The presence of these minerals can be explained by the weathering and erosion of the host-rocks of the primary mineralization. Some minerals have been identified from at a limited number of locations, eg Pb-rich tungstate (1 concentrates) at Mokama, Al-Pb-Bi-phosphate (3 concentrates) at Mokama, Ngussa W and Salukwango and zinwaldite (1 concentrates) at Moga.

The concentrates originating from the weathering of quartz vein deposits contain quartz (13 concentrates), tourmaline (3 concentrates), feldspar (3 concentrates), muscovite (10 concentrates), Fe-K-Al-silicate (10 concentrates), Pb-rich tungstate (1 concentrates), Al-Pb-Bi-phosphate (3 concentrates), zinwaldite (1 concentrates), wolframite (3 concentrates), topaz (2 concentrates), fluorite (1 concentrate), sulphides (2 concentrates), carbonates (1 concentrate), staurolite (3 concentrates), ilmenite

	Code RMCA	Location	Minerals identified in addition to cassiterite
SD02	RG 12676	D16 Iowa, Kima	Fe-ox
SD03		Mususa	Wolf, Topaz, Fe-K-Al silicate
SD04	RG 1476	Mokama	Fe-ox, Wolf, Pb-rich tungstate, Al-Pb-Bi-phosphate
SD05	RG 114	Kailo	/
SD06	RG 183	Kabingo	Musc, Q, Zircon
SD07	RG 1923	Kisheke	/
SD08	RG 1928	Sasa	Fe-ox, Tourm, Musc, Q
SD09	RG 1919	Matale	/
SD10	RG 135	Kabambare - Yungwe	Fe-ox, Q, Feldsp
SD11	RG 172	Punia	Q, Staurolite, Ilmenite, Zircon
SD12	RG 2014	Kasese	Fe-K-Al silicate
SD13		Nyangulube	Fe-ox, Tourm, Q
SD14	RG 165	Muana	Q, Feldsp, Ilmenite, Rutile, Anatase, Xenotime
SD15	RG 188	Nzombe	Tourm, Musc, Q, Ilmenite, Rutile
SD16	RG 34776	Ngussa W	Fe-ox, Tourm, Musc, Q
SD17	RG 1926	Bilembo	Al-Pb-Bi-phosphate
SD18	RG 12762	Miki	Q
SD19	RG 211	Misobo	Q, Rutile, Carbonate, Fe-K-Al-silicate
SD20	RG 209	Atondo	Topaz, Musc, Feldsp, Ilmenite, Sulf, Fe-K-Al-silicate
SD21	RG 203	Salukwango	Al-Pb-Bi-phosphate, Musc, Staurolite, Fe-K-Al-silicate
SD22	RG 1541	Moga	Musc, Q, Zinwaldite
SD23	RG 192	Nzalu	Musc, Q, Feldsp, Staurolite
SD24	RG 2377	Nakenge	Fluorite, Fe-K-Al-silicate
SD25	RG 12686	Kindi	
SD26	RG 320	Kianzo - Kasese	Wolf, Muscovite, Q, Feldsp, Fe-K-Al silicate
SD27	RG 1806	Mitwaba	Q
SD28	RG 3554	Manono	Nb-Ta, Q, Fe-K-Al-silicate
SD29	RG 711	Muika	Q
SD30	UMHK	Busanga	/
SD31		Kalanda	Fe-Ox, Musc, Fe-K-Al-silicate
SD32		Bisesero	Fe-Ox, Q, Sulf, Fe-K-Al-silicate
SD33		filon Migera, Rwinkwavu	Musc, Q
SD34	RG 8600	Lemera	Nb-Ta, Q, Fe-K-Al-silicate
SD35	RG 13272	Musha	/
SD36	RG 9127	Lutsiro	/
SD37	RG 10677	Mwaka	Feldsp
SD38		Rutongo	/
SD39		Gatumba S	Fe-Ox, Q, Feldsp
SD40		Bugalula	Musc, Q, Fe-K-Al-silicate
SD41	RG 1532	Moga, g4D68	Nb-Ta, Fe-ox, Wolf, Tourm, Q, feldsp, ilmenite, rutile, xenotime, Sulf
SD42	RG 1534	Moga,D64 amont 1	Nb-Ta, Fe-ox, ilmenite, rutile, Sulf
SD43	RG 1539	Moga, Musoke 1	Nb-Ta, Fe-ox, topaz, fluorite, Tourm, Q, Feldsp, rutile, xenotime, Sulf
SD44	RG 1541	Moga, D68	Fe-ox, topaz, Tourm, Q, feldsp, staurolite, ilmenite, rutile, Sulf
SD45	RG 1542	Moga, Musoke 2	Fe-ox, Wolfr, Topaz, Tourm, Q, Feldsp, Ilmenite

Table 4. Minerals found by SEM-EDS analysis in addition to cassiterite. Q : quartz, Fe-ox: Fe-oxide or hydroxide, Musc : muscovite, Nb-Ta : columbite –tantalite, Feldsp : feldspar mineral, Sulf : sulphides, Wolf : wolframites, Tourm : tourmaline

	Code RMCA	Location	Minerals identified as inclusion in cassiterite
SD02	RG 12676	D16 lowa, Kima	Fe-ox, Tourm
SD03		Mususa	Nb-Ta, Topaz, Fe-K-Al silicate
SD04	RG 1476	Mokama	Fe-ox, Pb-rich tungstate
SD05	RG 114	Kailo	Nb-Ta
SD06	RG 183	Kabingo	Nb-Ta, Musc, Q, Zircon
SD07	RG 1923	Kisheke	Tourm, rutile
SD08	RG 1928	Sasa	Fe-ox, Q
SD09	RG 1919	Matale	/
SD10	RG 135	Kabambare - Yungwe	Nb-Ta, Al-Pb-Bi phosphate, Feldsp, Xenotime, Zircon
SD11	RG 172	Punia	Nb-Ta, Ilmenite, Rutile, Sulf, Zircon
SD12	RG 2014	Kasese	/
SD13		Nyangulube	Rutile
SD14	RG 165	Muana	Nb-Ta, Wolf, Ilmenite, Rutile, Anatase, Monazite, Xenotime, Zircon
SD15	RG 188	Nzombe	/
SD16	RG 34776	Ngussa W	Fe-ox
SD17	RG 1926	Bilembo	/
SD18	RG 12762	Miki	/
SD19	RG 211	Misobo	Wolf
SD20	RG 209	Atondo	Nb-Ta, Rutile, Zircon
SD21	RG 203	Salukwango	/
SD22	RG 1541	Moga	/
SD23	RG 192	Nzalu	Nb-Ta
SD24	RG 2377	Nakenge	/
SD25	RG 12686	Kindi	Wolframite, Ilmenite, Rutile, Zircon
SD26	RG 320	Kianzo - Kasese	/
SD27	RG 1806	Mitwaba	Nb-Ta, Ilmenite, Sulfides
SD28	RG 3554	Manono	Nb-Ta
SD29	RG 711	Muika	/
SD30	UMHK	Busanga	Rutile
SD31		Kalanda	Nb-Ta
SD32		Bisesero	/
SD33		filon Migera, Rwinkwavu	Muscovite, Quartz
SD34	RG 8600	Lemera	Nb-Ta
SD35	RG 13272	Musha	Nb-Ta, Rutile, Zircon
SD36	RG 9127	Lutsiro	/
SD37	RG 10677	Mwaka	/
SD38		Rutongo	Ilmenite, Rutile
SD39		Gatumba S	Nb-Ta, Ilmenite, Rutile
SD40		Bugalula	Nb-Ta
SD41	RG 1532	Moga, g4D68	Scheelite
SD42	RG 1534	Moga,D64 amont 1	Nb-Ta
SD43	RG 1539	Moga, Musoke 1	/
SD44	RG 1541	Moga, D68	/
SD45	RG 1542	Moga, Musoke 2	Al-Pb-Bi phosphate, Sulf

Table 5. Table indicating of the mineral inclusions in cassiterite crystals, identified by SEM-EDS analysis. Fe-ox : Fe-oxide or hydroxide, Nb-Ta : columbite –tantalite, Tourm : tourmaline, Feldsp : feldspar mineral, Sulf : sulphides.

(3 concentrates), rutile (2 concentrates), zircon (1 concentrate) and Fe-oxydes and hydroxides (6 concentrates). The concentrates originating from the weathering of pegmatites contain quartz (6 concentrates), tourmaline (1 concentrate), feldspar (2 concentrates), Fe-K-Al-silicate (2 concentrates), muscovite (2 concentrates), ilmenite (1 concentrate), Nb-Ta minerals (2 concentrates), rutile (1 concentrate), anatase (1 concentrate), xenotime (1 concentrates), zircon (2 concentrates) and Fe-oxydes and hydroxides (2 concentrates). Although as mentioned above, it is not allowed to make a quantitative comparison between different concentrates, only concentrates with a pegmatitic origin seem to contain anatase, Nb-Ta minerals and xenotime, while only concentrates with a quartz vein origin contain Pb-rich tungstate, Al-Pb-Bi-phosphate, zinwaldite, wolframite, topaz, fluorite, sulphide minerals, carbonate minerals and staurolite. The concentrates from the Moga river basin (SD41 – 45) are not mentioned in this comparison, since the exact origin is not known and probably consist of a mixture of cassiterite from quartz vein and pegmatite deposits.

The presence of different mineral inclusions in the cassiterite crystals has also been investigated with SEM-EDS (Table 5). The majority of the mineral inclusions are formed by columbite-tantalite (17 concentrates), rutile (10 concentrates), zircon (8 concentrates), ilmenite (6 concentrates), Fe oxides and hydroxides (4 concentrates), wolframite (3 concentrates) and sulphides (4 concentrates). Two times the presence of tourmaline, quartz, carbonate inclusions have been found in the cassiterite crystals. Scheelite, Pb-rich tungstate, topaz, Al-Pb-Bi phosphate, muscovite, feldspar, anatase, monazite, Fe-Al-K silicate have only been found once. Due to the tectonic deformation of some of the cassiterite crystals, it is often difficult to distinguish a real mineral inclusion trapped during the growth of the crystals or crystals from a mineral trapped in a healed fracture. If the mineral occurs also as an isolated mineral in the concentrate, it was decided that we were dealing with the latter category. Based on this criterion, it seems that only columbite-tantalite, rutile, zircon and ilmenite can be classified as real inclusions. Cassiterite originating from the weathering of both primary quartz vein as well as pegmatite mineralization seems to contain columbite-tantalite, rutile, ilmenite and zircon as inclusions. Therefore no differentiation is possible based on these inclusions.

6. Discussion

Cassiterite concentrates have been investigated from different locations in the KIB and KAB. The concentrates investigated come from eluvial and alluvial exploitations that originate from the weathering of cassiterite mineralized quartz vein and pegmatite mineralization. The difference in processing history could probably explain why in certain concentrates only cassiterite (eg SD05, SD07, SD09, SD30, SD35, SD36, SD38) has been identified, while other concentrates contain nine different additional minerals (eg. SD41 and SD44). This probably also explains why some concentrates still contain feldspar or muscovite, which can be very easily eliminated during processing of the concentrates (eg. SD08, SD20). Only a qualitative evaluation is envisaged based on the different geological settings of the samples.

Cassiterite concentrates contain cassiterite crystals with different luster and color. The cassiterite crystals with a non-metallic luster are often transparent and show a color zonation. No systematic difference can be observed in color or luster between cassiterites from a quartz vein origin or a pegmatite origin. In general, it can be stated that the color variation in a single cassiterite crystal can be as large as in an entire concentrate. In addition, the variation between grains from the same concentrate is often as large as between cassiterite concentrates from different regions. Some cassiterite crystals, however, show an exceptional colour (eg SD17, Bilembo).

Mineralogical investigation of the concentrates shows that concentrates described to originate from mineralized quartz veins contain iron oxides and hydroxides, feldspars, fluorite, carbonates, Fe-K-Al-silicate, ilmenite, muscovite, Al-Pb-Bi-rich phosphate, quartz, rutile, staurolite, sulphides, topaz, tourmaline, Pb-rich tungstate, wolframite, zinwaldite and zircon. Concentrates originating from the weathering of pegmatites contain anatase, iron oxides and hydroxides, Fe-K-Al-silicate, feldspars, ilmenite, muscovite, quartz, rutile, tourmaline, xenotime, columbite-tantalite and zircon. Except the presence of some individual minerals, there seems no big difference between the mineralogical composition of concentrates originating from the weathering of quartz veins or pegmatites. Fluorite, carbonates, Al-Pb-Bi-rich phosphate, staurolite, sulphides, topaz, Pb-rich tungstate, wolframite and zinwaldite have only been described for concentrates originating from primary quartz vein mineralization. It should, however, be mentioned that fluorite (SD24), carbonates (SD19), Pb-rich tungstate (SD04), wolframite (SD04) and zinwaldite (SD22) have only be described for one sample. Anatase, xenotime and columbite-tantalite have only been found in the concentrates originating from the weathering of pegmatites. This difference in concentrate composition could be explained by the mineralogical composition of the primary mineralization. Columbite-tantalite, anatase and xenotime have been described as typical primary constituents of the cassiterite mineralized pegmatites and topaz, Pb-rich tungstate, wolframite and zinwaldite as primary constituents of the cassiterite mineralized quartz veins in the KIB and KAB. Based on the mineralogical composition of the primary mineralization, it is clear that certain minerals (eg fluorite, Al-Pb-Bi-rich phosphate) that have been described in this study for concentrates from quartz vein mineralization are more likely to originate from the weathering of pegmatites. This could be explained by mixing of material from the weathering of pegmatitic material that probably occurred in the vicinity of the quartz veins. Some minerals seem to occur in both types of primary mineralization (eg. tourmaline, sulphides).

Some minerals found in the cassiterite concentrates have not been described in the primary mineralization (eg. ilmenite, rutile, staurolite, etc). The minerals that occur in cassiterite concentrates are only partly related to the primary mineralization. Their composition is also largely determined by the mineral composition of the host-rock. If the cassiterite concentrate has been recovered from primary mineralization in the main granitic areas, the granites and associated pegmatites are the main sources of the heavy minerals. The mineralogical composition of these granites can largely vary. Granites with muscovite, muscovite-biotite, biotite and amphiboles have been described. Zircon, apatite, monazite, fluorite, ilmenite, magnetite, xenotime and sphene have been found in the granitic massifs in the Maniema area (unpublished data mining archives, RMCA). The main part of the granites is related to bimodal magmatism. The alteration of these related doleritic and amphibolitic rocks can explain the occurrence of titanomagnetite, tourmaline, fluorite and sulphides in the concentrates (unpublished data Mining archives, RMCA). It is described that the weathering and the alteration of these mafic rocks resulted in the formation of large amounts of iron (and manganese) oxides and hydroxides.

The weathering of the metasediments surrounding the primary mineralization can also contribute largely to the composition of the cassiterite concentrates. A distinction can be made between schists and quartzites. Staurolite, garnet, ilmenite, andalusite and corundum occur in the schists surrounding the granitic massifs in the Kalima area. The heavy mineral composition of the schists is influenced by the degree of metamorphism. Higher metamorphosed schists contain andalusite, staurolite and corundum. The contact metamorphism between the granites and the surrounded metasediments resulted in intense tourmalinization at the contact, which can also be identified in the concentrates. The quartzites contain less different minerals. Only zircon, rutile, tourmaline and ilmenite have been described. Amphibolitic quartzites could contribute amphibolite, diopside, epidote, sphene and sulphides (pyrite – pyrrhotite) to the cassiterite concentrates.

Since most of the mineralized quartz veins and pegmatites occur in the same type of host-rock (lower greenschist schists and quartzites) that have been intruded by granites and associated doleritic intrusions (Baudet, 1988; Gérards, 1965; Fernandez et al., 2012), the mineralogical composition of the concentrates of the quartz veins and the pegmatites are similar. In addition, the pegmatites and quartz veins often occur in each other vicinity, which implies that weathering results in a mixing of heavy minerals from both origins. Except the presence of some typical minerals, no distinction can be made between the mineralogy of the concentrates from the two origins.

7. Conclusion

Different petrographic and mineralogical techniques have been applied on cassiterite concentrates that originate from different locations in the Karagwe-Ankole and the Kibara belt in Central Africa. The cassiterite concentrates have been selected from the minerals and rock collection of the Royal Museum for Central Africa and come from the historical exploitation of eluvial and alluvial deposits. These cassiterite concentrates can originate from the weathering of primary Nb-Ta-Sn mineralized pegmatites or Sn-W mineralized quartz veins. Direct exploitation of primary mineralization has been very limited. Since no exact information is available about the treatment the samples have been submitted to, a quantitative comparison between the different locations is not opportune.

The luster and color of the different cassiterite crystals in the concentrates has been investigated by transmitted and reflected microscopy. Cassiterites with a metallic and non-metallic luster are present. Growth zoning can be identified in the grains with a non-metallic luster. The color varies from transparent to dark brown in a single crystal. This color variation in a single grain is as large as in an entire concentrate. Some of the cassiterite grains show exceptional coloring (eg Bilembo), which could allow fingerprinting. XRD investigation only revealed the presence of minerals that are relatively abundant. Quartz vein cassiterite concentrates contain feldspars, iron oxides and hydroxides, muscovite, tourmaline, topaz, quartz, wolframite and columbite-tantalite in addition to cassiterite, while pegmatite concentrates only contain columbite-tantalite, ilmenite, iron oxides and hydroxides, muscovite and quartz.

SEM-EDS analysis shows the presence of typical gangue and alteration minerals of the primary mineralization in addition to cassiterite. Quartz, tourmaline, feldspar, muscovite and a unidentified Fe-K-Al-silicate, but also accessory minerals present in the primary mineralization have been found, such as columbite-tantalite, wolframite, topaz, fluorite and sulphides. Different heavy minerals that do not occur in the primary mineralization are also present, i.e. staurolite, ilmenite, rutile, anatase, xenotime and zircon. Some minerals have only been identified at a limited number of locations, eg Pb-rich tungstate at Mokama, Al-Pb-Bi-phosphate at Mokama, Ngussa W and Salukwango and zinwaldite at Moga.

Except the occasional presence of a certain mineral or a special color for a certain cassiterite, no systematic variation can be observed between the concentrates from the different locations based on the applied mineralogical techniques in this study. Often, the mineral and color variation in one concentrate can be as large as for concentrates found from different locations.

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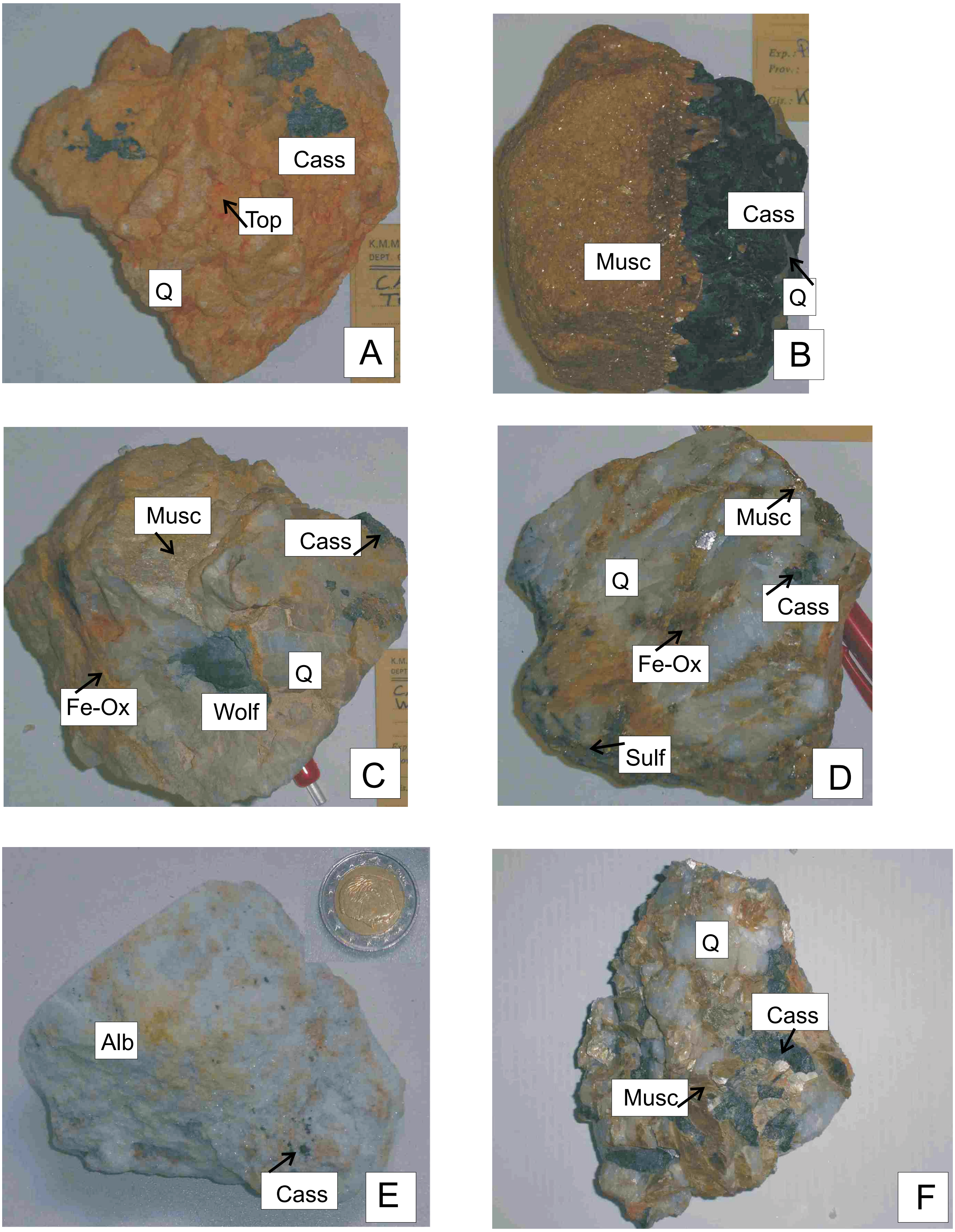

Photo plates

Plate 1. A. Photograph of cassiterite mineralization of Atondo (RG 2407), Cass : cassiterite, Q : quartz, Top : topaz. **B**. Photograph of cassiterite mineralization of Misobo (RG 8386), Cass : cassiterite, Musc : muscovite. **C**. Photograph of cassiterite mineralization of Yubuli (RG 2499), Cass : cassiterite, Q : quartz, Musc : muscovite, wolf : wolframite, Fe-Ox : Fe oxide/hydroxide. **D**. Photograph of cassiterite mineralization of Nzombe (RG 8660), Cass : cassiterite, Q : quartz, Musc : muscovite, Sulf : sulphides, Fe-Ox : Fe oxide/hydroxide. **E**. Photograph of cassiterite mineralization of Manono, Cass : cassiterite, Alb : albite. **F**. Photograph of cassiterite mineralization of Manono, Cass : cassiterite, Q : quartz, Musc : muscovite.