Ta-Nb-Sn-W-Au mineralization in the Mesoproterozoic metasediments of the Karagwe-Ankole belt (Rwanda, DRC) and its relation to early Neoproterozoic orogeny and magmatism

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Abstract. A recent renewal of interest and research into Nb, Ta, Sn, W, Li and Au deposits of the Central African Mesoproterozoic Karagwe-Ankole belt (KAB) has led to new insights regarding its metallogenesis. This study provides an overview of the geodynamic framework of the KAB, including its magmatism and mineralization. During compressional deformation, barren quartz veins are intensely folded. A second quartz vein generation developed inside the fold hinges. Reverse faults occur in the hinge zone of such folds. After compression, but still during tectonism, Neoproterozoic granite intrusions (G4) are emplaced. Hydrothermal W-rich quartz veins with a mixed magmatic and metamorphic origin formed after folding and cleavage development. Highly fractionated and often metasomatized pegmatites are enriched in Ta-Nb and Sn. Extensional tectonism is evidenced by boudinaged pegmatites, which post-date vein-type W mineralization. Sigmoidal quartz veins and shear zones are an expression of late tectonic shearing. Gold mineralization at Byumba (Rwanda) could be related to this shear phase, but a hydrothermal magmatic source for this deposit cannot be excluded. Sn mineralization is associated with greisenization of pegmatites and with quartz veins. These Sn deposits originate from magmatic fluids, exolved from pegmatitic melt and post-date folding and faulting.

1 Introduction

The Mesoproterozoic Karagwe-Ankole belt (KAB) stretches from the Kivu-Maniema region in the DR Congo in the south over Burundi and Rwanda to southwest Uganda in the north. It hosts important Nb, Ta, Sn, W, Li and Au mineralization, which occurs associated with lithium-tantalum-cesium family, rare-element pegmatites (Hulsbosch et al. 2014; Melcher et al. 2015), while quartz veins (Dewaele et al. 2016; Pohl and Günther 1991) host Au, Sn and W. After many geological studies carried out in the 1960s, renewed interest in the ore deposits in this part of Central Africa boosted the application of new analytical techniques to gain insights in their metallogenesis (e.g. Hulsbosch et al. 2016; Pohl et al. 2013). These data resulted in a profound knowledge of the ore-forming processes leading to the formation of the Ta-Nb, Sn, W, Li and Au deposits. The studies constrained the origin and age of the deposits, the source of the metals and fluids, and the lithological and structural control on the ore deposits. Although most deposits have been related to a specific stage in the evolution of early-Neoproterozoic granitic intrusions (see reviews in Hulsbosch in press; Pohl et al. 2013), the relationship with the tectonic evolution, although sometimes determined on a local scale (Hulsbosch et al. 2017; Pohl et al. 2013), has not been fully resolved. The aim of this study is to provide a first overview of the relationship between tectonism, granite intrusion and mineralization in the Karagwe-Ankole belt based on the current stage of knowledge.

2 Geochronology

Two main periods of granite intrusion have been identified in the KAB. The first period, which took place between 1400 and 1370 Ma, comprises a large bimodal magmatic event, i.e. the so-called Kibaran event (Tack et al. 2010), and culminated in the intrusion of (1) mafic to ultramafic rocks which have been dated at 1403 ± 14 Ma (SHRIMP U-Pb; Maier et al. 2007) and 1374 ± 14 Ma (SHRIMP U-Pb; Tack et al. 2010); and (2) large volumes of peraluminous S-type granites and accompanying subordinate mafic rocks, which have been dated between 1383 ± 17 Ma and 1371 ± 7 Ma (SHRIMP U-Pb; Tack et al. 2010). The S-type granites are the historically defined G1-G3 generation (i.e. for Rwanda; Gérards and Ledent 1970).

The second period of granite magmatism took place at the beginning of the Neoproterozoic. Their intrusion age has recently been set at 986 ± 10 Ma by SHRIMP U-Pb dating of zircons from the small peraluminous S-type Kasika granite in the Kivu province of DR Congo (Tack et al. 2010). Regionally, they are the so-called G4 generation (i.e. in Rwanda; Gérards and Ledent 1970). Compressional events are reported in the entire “Kibara” region in the early-Neoproterozoic, however the exact timing is debated (Kokonyangi et al. 2004; Tack et al. 2010). This compressional event resulted in upright folding and thrusting of the metasediments of the western part of the KAB (Fernandez-Alonso et al. 2012). Several pegmatite generations have been identified and reflect different stages of fractionation of G4

leucogranites

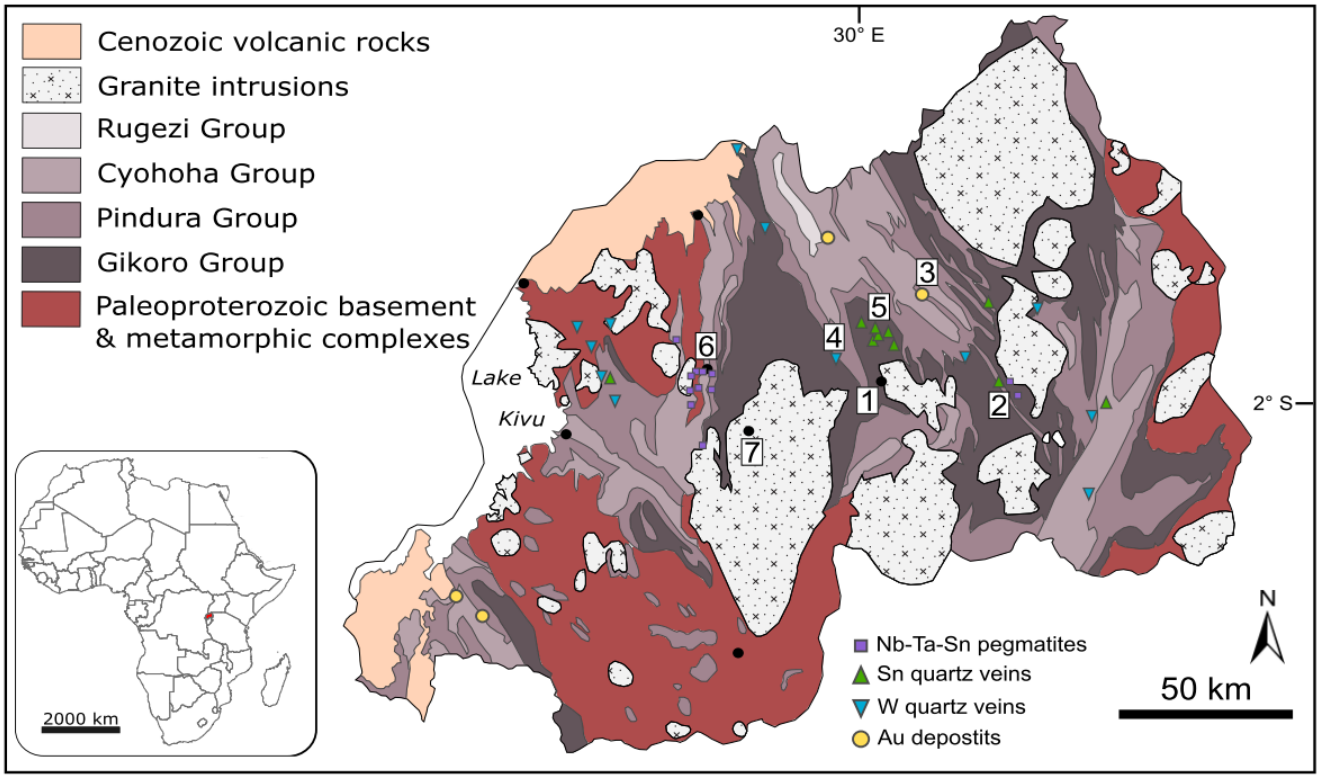

Figure 1. Simplified geological map of Rwanda with indication of the most important Nb-Ta, Sn, W and Au deposits. Geological map after Fernandez-Alonso et al. (2007), location of the ore deposits after Baudin et al. (1982). Locations: 1) Kigali 2) Musha-Ntunga 3) Byumba 4) Nyakabingo 5) Rutongo 6) Gatumba 7) Gitarama.

(Hulsbosch et al. 2014). U–Pb ages were obtained from TNO (tantalum-niobium oxides) forming the primary mineralization of the pegmatites in the Karagwe Ankole Belt. Columbite data from pegmatites in northern Burundi reveal ages of 963 +9/−5 Ma and 968 +33/−29 Ma (Romer and Lehmann 1995). New TIMS and LA-ICP-MS U-Pb columbite–tantalite ages from the KAB range largely from ca. 920 to 1030 Ma, with a maximum around 960–990 Ma (Melcher et al. 2015). Additional new U-Pb columbite ages from the Gatumba-Gitarama area show also a spread in age between 975 ± 8 Ma and 936 ± 14 Ma (Dewaele et al. 2011).

Tungsten mineralization has been dated by Ar-Ar of muscovites hosted by W-rich quartz veins at 992.4 ± 1.5 Ma (Dewaele et al. 2016). This age overlaps with the emplacement of the G4 granites and is slightly older than the ages obtained for pegmatites and associated columbite-tantalite mineralization in Rwanda (Dewaele et al. 2011, 2016). This age is in agreement with the metallogenic model, which relates the W-mineralization to an early fractionation and expulsion of an aqueous fluid from the leucogranites (Hulsbosch et al. 2016).

Cassiterite-rich quartz veins in Burundi (Mulehe) have been dated at 951 ± 18 Ma (Rb-Sr muscovite-tourmaline; Brinckmann et al. 1994) and 936 ± 82 Ma (Rb-Sr muscovite; Brinckmann 1988). Sn-mineralised quartz veins from the Rutongo area in Rwanda have been dated at 965 ± 29 Ma (Rb-Sr muscovite; Monteye-Poulaert et al. 1962) and 916 ± 50 Ma (Pb-Pb galena; Monteye-Poulaert et al. 1962).

Central African orogenic gold mineralization has been related to fold-and-thrust belt formation (Brinckman et al. 1994; Koegelenberg et al. 2016). The exact timing of gold mineralization and this deformation is however still highly debated. Two periods of gold mineralization have been proposed for the Western Domain of the KAB, although they are not well constrained. Firstly, sulfide vein assemblages with gold, dated at 908 ± 21 Ma (Rb-Sr muscovite-tourmaline; Brinckmann et al. 1994), are interpreted to be genetically related to the early-Neoproterozoic G4-granite magmatism. Secondly, ferruginous breccia zones with gold dated at 640 ± 28 Ma are interpreted to be related to Pan-African events (Rb-Sr muscovite-tourmaline; Brinckmann et al. 1994). Also muscovite from quartz-sulfide-gold saddle reefs of the Twangiza deposit (Kivu, DR Congo) gave an age of 522 ± 15 Ma (Ar-Ar; Walemba 2001). Alternatively, Pohl and Günther (1991) proposed that Au mineralization is due to deep crustal metamorphism and not related to the G4 magmatism. Timing of metamorphism would be associated with crustal thickening immediately preceding the granitoid magmatism and the metallogenic climax.

3 Tectonic evolution and veining

The Mesoproterozoic strata have been intensely folded often resulting in tight folds. Cleavage is well developed and often almost parallel to the steep bedding. Two cleavage sets can be identified based on their

orientation. Both cleavage sets are parallel to the axial plane of the folds, i.e. represent an axial planar cleavage. Occasionally, crenulation cleavage is observed in mica-rich schists. Reverse faults developed in steep to overturned limbs of folds are therefore developed at the end of the folding. Several meter-thick shear zones developed after folding and are characterized by the occurrence of C-type shear bands. These shear zones are heavily chloritized and host several deformed quartz veins which are parallel to the foliation. Barren and mineralized pegmatites developed dominantly parallel to the bedding, cleavage, bedding-parallel and strike-parallel joints and strike-slip fractures, which developed in relation to the folding (cross-fold joints, e.g. in the Musha-Ntunga-Rwamagana area). Pegmatites and quartz veins, which developed parallel to the bedding, have been boudinaged, reflecting layer-parallel extension.

Several dominant quartz vein generations developed in relation to the tectonic evolution of the rocks and allow construction of (1) a relative timing of quartz veining and (2) a more detailed paragenetic sequence including the mineralization phases. Quartz veins, which developed parallel to the bedding, have been intensely folded and thus predate tectonic deformation. A second generation of massive quartz veins occurs in the hinge zones of folds where it can be associated with massive pyrite, e.g. Byumba area. In addition, smaller, irregular veins may be present in these hinge zones, but they are more widespread in the metasedimentary rocks. Quartz veins of the 3rd generation occur in fractures related to faulting or along the faults themselves. A fourth generation of quartz veins developed parallel to the cleavage, especially in shales and at the contact between shales and sandstones. In the Byumba area, in cm-thick sandstone layers, these quartz veins do not follow the bedding but crosscut the sandstones at an angle of 45°-60°. The cleavage parallel nature of the veins in the shales and the crosscutting structure in the sandstones gives a sigmoidal or S-shape geometry of the quartz veins. This geometry indicates the veins formed due to shearing along the cleavage. A prominent characteristic is that these veins are also boudinaged, i.e. stretched parallel to the cleavage, which is often sub-parallel or at a small angle to the bedding. Massive quartz veins crosscut the folds and cleavage and all former quartz generations.

4 Paragenetic sequence of veining and mineralization in relation to deformation

The first vein generation observed is parallel to the bedding, has been intensely folded, is not mineralized and crosscut by W-mineralized quartz veins at the Nyakabingo mine. The second vein generation observed are related to the folding and the third vein generation to faulting, often present in the hinge zone of faults. The fourth quartz generation developed parallel to the cleavage and is mineralized in tungsten at the Nyakabingo mine. The Sn-mineralized quartz veins developed as extension veins between boudinaged sandstone layers at Rutongo. An important part of the Sn-mineralized quartz veins developed after pegmatite intrusions and during layer parallel extension.

5 Discussion and conclusion

The paragenetic sequence of the veining and mineralization in relation to deformation can be further integrated within the geodynamic framework, including magmatism. Compressional deformation caused the folding and the development of an axial planar cleavage. Reverse faulting is intimately associated with this folding and occurs close to the fold hinges and in the steep to overturned limbs of the folds, e.g. as observed in the Gitarama-Gatumba section. Existing barren quartz veins became intensely folded and new quartz veins developed in the hinge zones of the folds. Granite intrusions crosscut the folds and are younger (986 ± 10 Ma; SHRIMP U-Pb zircon; Tack et al. 2010). Tungsten-rich quartz veins formed after folding and cleavage development, tungsten had a magmatic source and the hydrothermal fluid had a mixed magmatic and metamorphic origin (Dewaele et al. 2016; Hulsbosch et al. 2016). Tungsten mineralization formed during an early stage of the fractionation of the granitic magma (Hulsbosch et al. 2016). The quartz veins developed along the bedding and cleavage planes, but also along large fractures, which crosscut the folds. The lack of foliated G4 granites further indicate that magmatic activity occurred after the main period of compression but still during late stage tectonism (Hulsbosch et al. 2017). Pegmatites can be boudinaged indicating subsequent extensional tectonism. Tantalum and tin mineralization occur in highly fractionated, often metasomatized pegmatites (Hulsbosch et al. 2014, 2017). Taking into account the former evidence, Ta-Nb and Sn mineralization post-date vein-type W mineralization, and is in agreement with the geochronology of both phases.

A distinct phase of shearing post-dates folding and cleavage development as expressed by sigmoidal veins and shear zones. Silicification as well as intense chloritization is associated with this shearing. Preliminary results suggest that gold mineralization at Byumba could have been formed during this phase. Since this late tectonic stage could well coincide with granite magmatism, a hydrothermal magmatic source of the gold and fluids cannot be excluded and further research is needed.

The main Sn mineralization phase is associated with greisenization of pegmatites and with Sn quartz veins, which post-date folding and faulting as indicated by the structural analysis and geochronology (Pohl et al. 2013). Moreover, these Sn-rich quartz veins are present as inter-boudin veins and are thus related to bedding-parallel stretching of the metasandstone layers in which they preferentially occur at Rutongo. Sn mineralization in quartz veins has a largely magmatic origin, i.e. fluids exsolved from pegmatitic melt.

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