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Metamorphic modifications of the Muremera mafic–ultramafic intrusions, eastern Burundi, and their effect on chromite compositions

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ABSTRACT

The Muremera mafic–ultramafic intrusions were emplaced into metasedimentary rocks of the Karagwe–Ankole Belt in eastern Burundi, as part of the Mesoproterozoic Kibaran tectonomagmatic event. Igneous minerals of the Muremera intrusions have been partly altered to hydrous and carbonated metamorphic assemblages, although in most cases, the original igneous textures are well-preserved. Rounded, subhedral cumulus olivine has been partially and pseudomorphically replaced by lizardite–magnetite mesh-rim and lizardite–brucite mesh-centre assemblages, while anhedral interstitial plagioclase has been replaced by chlorite–tremolite. A later and localized event results in prograde alteration to antigorite–magnetite–chlorite–talc–carbonate and talc–carbonate–chlorite assemblages. The rocks are inferred to have undergone at least three separate metamorphic/alteration events resulting in: AS1 – an early alteration assemblage (mesh-rim lizardite–magnetite) characterized by very low fluid/rock ratios and widespread distribution; AS2 – a later, widespread low-temperature retrogressive (mesh-centre lizardite–brucite) assemblage associated with abundant close-spaced parallel veins; AS3 – later, prograde (antigorite–magnetite) and AT4 (talc–chlorite–carbonate) assemblages associated with more localized shearing and higher fluid/rock ratios. The AS1 assemblage most likely represents deuteric alteration that occurred soon after intrusion and cooling. The AS2 assemblage may relate to a continuation of this cooling, or may be correlated with the regional upright D2 folding event, while the AS3 and AT4 alteration assemblages are most likely correlated with the N–S oriented D3 faulting episode linked to the distal East African Orogeny. Euhedral to subhedral chromite grains are essentially unaltered where enclosed in primary unaltered olivine, pyroxene or plagioclase, as well as in AS1 lizardite–magnetite and AS2 lizardite–brucite altered olivine or pyroxene. In samples which show alteration to AS3 antigorite–magnetite and AT4 talc–carbonate–chlorite assemblages, the chromite grains are zoned to Mg–Al-poor ferritchromite rims. The width and the composition of these alteration rims are related to the degree of alteration of the silicate assemblages. However, it is concluded that chromite found in rocks that have avoided late/localized AS3–AT4 alteration preserve their magmatic to late-magmatic chemical and textural characteristics, and can therefore be used in regional geological studies and exploration.

1. Introduction

The Kibaran belt (*sensu latu*) has long been proposed as a key tectono-stratigraphic domain in the Precambrian geological evolution of central Africa (Cahen et al., 1984; Clifford, 1970), and particularly that of the proto-Congo craton (de Waele et al., 2008). Recent geological investigations in the north-east part of this belt (the Karagwe–Ankole Belt or KAB) have focussed on its stratigraphy and structure (Fernandez-Alonso et al., 2012), its igneous activity (Buchwaldt et al., 2008; Duchesne et al., 2004; Tack et al., 2010) or its metallogeny (Deblond and Tack, 1999; Dewaele et al., 2010; Maier and Barnes, 2010; Maier et al., 2010; Pohl et al., 2013). These studies have tended to confirm the intraplate setting for orogeny and igneous activity as originally proposed by Klerkx et al. (1987) and Tack et al. (1994), as opposed to the convergent margin setting proposed by Rumvegeri (1991) and Kokonyangi et al. (2006), at least in the KAB.

However, a better understanding of the metamorphic history of the KAB is needed to complement the early structural studies and in order to place the proto-Congo craton in the context of plate reconstructions of Precambrian supercontinents (Pisarevsky et al., 2014). Relatively few studies of the metamorphism of the KAB have been carried out since the regional mapping work in Burundi (Sintubin, 1989; Tack and Deblond, 1990). These earlier studies

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concentrated on the initial high grade peak of metamorphism in the KAB, whereas the more recent work by Dewaele et al. (2010, 2011) has examined the later phases of metamorphism in the context of hydrothermal mineralization. There is thus a need for further detailed studies of the full metamorphic evolution within structurally well-constrained rock units within the KAB.

Ultramafic rocks are highly sensitive to metamorphic conditions when a fluid is present and they tend to preserve textural evidence from different generations of fluid ingress (Evans, 1977; Wicks et al., 1977). This fluid may have originated either from within the crystallizing rock itself (residual hydrous melt), or from outside, gaining access to the rock via through-going fractures (veins and shears) and/or by grain boundary infiltration. Wicks et al. (1977) and Wicks and Whittaker (1977) have proposed a textural and compositional framework for the interpretation of serpentine alteration of ultramafic rocks. In particular, they draw attention to the probable timing relationship of the alteration of olivine along its margins and its internal cooling cracks (which they term mesh-rim serpentinization) and alteration of the remaining olivine between these mesh-rims (mesh-centre serpentinization). By careful study of these textures and of the serpentine polymorphs involved in the hydration reactions, the metamorphic evolution of the ultramafic rocks can be reliably deduced. For example, Beard et al. (2009) have been able to distinguish two different generations of serpentinization in partly altered troctolites of the oceanic crust, the first formed in a rock-dominated system at $T > 300$ °C, the second in a fluid-dominated system at $T < 300$ °C.

The chromite occurring in ultramafic rocks is also potentially useful as an indicator of both igneous and metallogenetic processes (Averill, 2011; Irvine, 1965), but only if its modification by subsequent metamorphism and alteration is well understood (Abzalov, 1998; Barnes, 2000; Merlini et al., 2009). There have been many studies on the effects of metamorphism on primary igneous chromite (Abzalov, 1998; Barnes, 2000; Burkhard, 1993; Kimball, 1990; Wylie et al., 1987) and its involvement in metamorphic reactions within ultramafic rocks (Evans and Frost, 1975). It has generally been observed that igneous chromite is only weakly affected by metamorphism up to the lower to mid-greenschist facies, but that it is generally strongly altered in upper greenschist facies and above. To a great extent, the degree of alteration of the chromite, especially at lower temperatures is controlled by the fluid to rock volume and by the type of immediately adjacent minerals. For example, chromite within continental layered intrusions that have undergone greenschist facies or lower conditions of metamorphism with relatively low water–rock ratios are relatively unaffected by metamorphism (Abzalov, 1998; Cameron, 1975; Wilson, 1982), whereas chromite within layered intrusions of oceanic affinity that have been subject to pervasive sea floor alteration at greenschist facies with high water–rock ratios can be significantly modified (Kimball, 1990; Merlini et al., 2009). Those spinels adjacent to or involved with reactions with Al-bearing alteration phases (e.g. hornblende and chlorite) may experience significant changes of their Cr/(Cr + Al) ratio, whereas those spinels that are only surrounded by serpentine experience only changes of Mg/(Mg + Fe^{2+}) ratio (Kimball, 1990). The access of CO_2-bearing fluids resulting in talc–carbonate assemblages is also cited as resulting in greater compositional change to chromite (Barnes, 2000; Burkhard, 1993).

The most obvious change to igneous chromite during metamorphism is the development of ferritchromite rims replacing the outer zone of the original grain (Spangenberg, 1943; Merlini et al., 2009). The progressive alteration of chromite with prograde metamorphism is thought to commence with overgrowth of secondary magnetite rims on the igneous grain during low-temperature serpentinization (Abzalov, 1998; Barnes, 2000). This is followed at higher temperature by commencement of a dissolution–precipitation reaction, initially at the interface between chromite and magnetite and progressing inwards, involving loss of Al and Mg to surrounding Al-bearing silicates, and their replacement by Fe^{3+} and Fe^{2+} (Barnes, 2000; Wylie et al., 1987). Merlini et al. (2009) propose that ferritchromite forms in two stages; first with the retrograde serpentinization of adjacent olivine, followed by prograde reaction of the aluminous chromite and adjacent serpentine in the presence of water and oxygen to form ferritchromite (replacing the spinel) and chromian chlorite (replacing serpentine). In any case, the result is usually a zoned crystal with an aluminous core and iron-rich rim, or in the case of complete reaction to an equilibrium assemblage, a homogeneous Al-depleted spinel grain. The composition of the equilibrium textured spinel (ferritchromite or chromian magnetite) or of the outer margin of the ferritchromite rim against magnetite in zoned grains can indicate the temperature conditions of the metamorphism (Barnes, 2000; Evans and Frost, 1975).

This study investigates the effects of deformation and metamorphism on the relict igneous minerals (chromite in particular) in small mafic–ultramafic intrusive bodies of the KAB in eastern Burundi. The results of this study are of relevance for the understanding of regional deformation and metamorphic events on the proto-Congo craton, and will be of practical use in regional metal exploration using chromite as an indicator mineral.

2. Regional geology

The KAB is a Palæo- to Mesoproterozoic tectonostratigraphic domain that covers most of Burundi, Rwanda, and parts of northwest Tanzania, southwest Uganda, the north and south Kivu provinces of the Democratic Republic of Congo (Tack et al., 2010). It comprises two main superposed elements: 1 – an underlying Archaean to Palæoproterozoic metamorphic basement making up part of the proto-Congo craton, which is overlain by 2 – a siliciclastic, shallow marine to epicontinental sedimentary sequence (Baudet et al., 1988; Fernandez-Alonso et al., 2012). Based on U–Pb dating of both volcanic and detrital zircons in the sedimentary sequence, sedimentation occurred between 1780 Ma and 1400 Ma (Fernandez-Alonso et al., 2012). The KAB sedimentary sequence has been deformed by three main tectonic events: an early bedding-parallel extensional D1 event characterized by mylonitic zones, a compressional D2 event resulting in open, upright folding (F2), and a late N–S oriented transpressional faulting event (D3) that has reactivated older structures (Fernandez-Alonso et al., 2012; Klerkx et al., 1987; Tack, 1990).

The D1 mylonitic extension is closely associated with the Kibaran tectonomagmatic event, which comprises widespread within-plate igneous activity on the broader proto-Congo craton in central Africa between 1400 Ma and 1350 Ma (Klerkx et al., 1987; Tack et al., 2010). The D2 compressional episode (D2a event of Klerkx et al., 1987) has been demonstrated to post-date the Kibaran intrusive event (Evans et al., 2000) and it is now assumed to be caused by the distal effects of the Irumide orogeny at the southern margin of the proto-Congo craton between about 1050 and 1000 Ma (Fernandez-Alonso et al., 2012). These authors and Dewaele et al. (2011) suggest that the late transpressional D3 event (D2b event of Klerkx et al. (1987)) is related to far-field effects within the proto-Congo craton of the East African orogeny to the east at around 590–550 Ma. Note, however, that recent detailed structural observations in the Nyakahura-Biharamulo area of Tanzania and their synthesis by Koegelenberg and Kisters (2014) suggest that all three deformation events may have their origin in a southeasterly-verging fold-thrust belt that records overall convergent tectonics between the Congo and Tanzania cratons. Evidently, further structural and metamorphic studies are needed in the KAB.