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Geochemistry of a komatiitic, boninitic, and tholeiitic basalt association in the Mesoarchean Koolyanobbing greenstone belt, Southern Cross Domain, Yilgarn craton: Implications for mantle sources and geodynamic setting of banded iron formation

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ABSTRACT

Komatiite–basalt magmatism and Algoma-type banded iron formation (BIF) of Archean greenstone terranes have common time series, but there are few constraints on the geodynamic setting in which BIF were precipitated. The ~3.0 Ga Koolyanobbing greenstone belt (KGB), Southern Cross Domain, Yilgarn craton, exhibits an greenschist to lower amphibolite facies metamorphosed lithostratigraphic series, including four predominantly mafic to ultramafic volcanic sequences (S1–S4) with prominent BIF horizons (and local basal pyrite-dominated massive sulfide lenses) in between. Petrography, XRD, high-precision major, trace high field strength, and REE element chemistry of representative ultramafic and mafic rocks from S1, S2, and S3 are consistent with a komatiitic, boninitic, and tholeiitic basalt association. Komatiites are Al-depleted and Al-undepleted (Al_2O_3/TiO_2 12–28 and $(Gd/Yb)_N$, ≥1) endorsing a zoned plume and/or melting over a range of depths. The boninite-series rocks (Al_2O_3/TiO_2 28–45 and $(Gd/Yb)_N$, <1) preserve characteristic U-shaped REE patterns and positive Zr–Hf/MREE anomalies. Komatiites include uncontaminated members and counterparts contaminated by metasomatized continental mantle lithosphere, suggesting eruption proximal to a rifted arc setting, whereas boninite-series were erupted at an intraoceanic arc, collectively consistent with plume eruption into a convergent margin. Al-depleted and Al-undepleted komatiites plot close together to the mantle array on the Th/Yb versus Nb/Yb discrimination plot of Pearce (2008), implying a depleted, mildly heterogeneous, source for the mantle plume from which komatiites erupted. Boninites lie parallel to and above the mantle array, in the field of intraoceanic arcs, in keeping with their inferred oceanic convergent margin setting. Ratios of Nb/Yb extend to lower and higher values than komatiites implying a more heterogeneous upper mantle source of the subarc wedge.

The KGB exhibits the first reported boninite-suite rocks in the Southern Cross Domain, Yilgarn craton. Conclusively, the komatiitic, boninitic, and tholeiitic basalt association suggests that BIF and basal massive pyrite lenses of the Koolyanobbing greenstone belt were precipitated from low-temperature submarine discharge of a seawater-dominated hydrothermal system driven by magmatic systems of a mantle plume erupting in a forearc convergent margin suprasubduction ophiolite.

1. Introduction and scope

Ultramafic (komatiitic) to mafic (basaltic) volcanic rocks (typically distinguished by a MgO content of higher and lower 18 wt.%, respectively), interlayered with banded iron formation (BIF) and/or cherts, are a major recorded constituent of the Archean supracrust defining the typical lithostratigraphy of greenstone belts. Archean volcanic rocks and volcanogenic seafloor sedimentary rocks such as BIF are crucial to our understanding of early Earth formation, including chemical and thermal development of the mantle, geodynamic processes, crustal growth, and the evolution of the atmosphere and life (Bekker et al., 2010). Furthermore, this greenstone belt lithological assemblage is amongst the most fertile settings for gold, nickel and iron ore metallogeny of Archean age (Groves et al., 2005; Goldfarb et al., 2010).

The geodynamic setting in which nickel, VMS, and gold deposits formed in Archean greenstone terranes is relatively well constrained. Nickel deposits are associated with mantle plume-derived komatiite flows and mafic–ultramafic intrusions; VMS deposits accumulated in convergent margins, specifically backarc basins;

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and orogenic gold deposits are sited proximal to terrane boundary structures of accretionary orogens (Kerrich and Wyman, 1990; Feng and Kerrich, 1992; Franklin et al., 2005; Groves et al., 2005; Kerrich et al., 2005; Goldfarb et al., 2010; Huston et al., 2010; Naldrett, 2010; and references therein). However, there are few constraints on the geodynamic setting of Archean banded iron formations, host to the largest low- to high-grade iron ore systems, worldwide: Isley and Abbott (1999) identified a common time series of iron formations and mantle plume events, but the functional relationship between the two is not known. Bekker et al. (2010) document the association of Algoma-type iron formations in greenstone terranes with volcanic sequences, and with some VMS deposits, but there is little information on the composition, and therefore geodynamic setting, of the volcanic hosts to Archean BIF. This paper sets out to characterize the geochemistry of volcanic host rocks to banded iron formation in the Koolyanobbing greenstone belt in order to constrain the geodynamic setting in which iron sedimentation occurred.

From the Yilgarn craton perspective, the focus of understanding the geology, including lithostratigraphy and tectonic setting of the Archean crust, was until recently mostly restricted to the Neoarchean Eastern Goldfields Superterrane (Myers, 1997; Barley et al., 2003, 2008; Krapez, 2006; Blewett et al., 2010; Czarnota et al., 2010; Said and Kerrich, 2010a,b). Consequently, there is a dearth of knowledge about the specific nature of the older greenstones and associated sedimentary sequences in the Youanmi Terrane. Only few studies deal with lithostratigraphy and tectonic setting of supracrustal rocks from the Southern Cross Domain (Perring et al., 1996; Chen et al., 2003, 2005; Morris et al., 2007) and from the Murchison Domain (Van Kranendonk, 2008; Van Kranendonk and Ivanic, 2009). This paper attempts to distinguish lithostratigraphic sequences of metamorphosed volcanic and volcanogenic rocks hosted in the Koolyanobbing greenstone belt in the central Southern Cross Domain of the Yilgarn craton.

The Koolyanobbing greenstone belt is mainly recognized for its wealth of supergene-modified Archean hypogene iron ore (Angerer and Hagemann, 2010; Angerer et al., 2012a). Processes forming hypogene domains of Archean BIF-hosted iron ore systems are not well understood and consequently a matter of debate (Findlay, 1994; Dalstra and Guedes, 2004; Lascelles, 2007; Beukes et al., 2008; Figueiredo e Silva et al., 2008; Angerer et al., 2010, 2012a). It is therefore of concern to understand depositional and physicochemical interaction between greenstone belts and BIF at the geodynamic-, down to the deposit-scale.

Accordingly, new, high precision, whole-rock elemental data from 19 ultramafic to mafic rocks within volcanic rock sequences, hosting BIF, are reported. We address the composition, mantle sources, possible crustal contamination, and the geodynamic context of melt generation over time, and for inter-comparison with the geodynamic settings of other mineral deposits in Archean terranes.

2. Geological setting of the Koolyanobbing greenstone belt

2.1. Overview

The Koolyanobbing greenstone belt (KGB) is located 350 km east of Perth, Western Australia. The ~3.0 Ga belt is part of the Southern Cross Domain in the Youanmi Terrane, Yilgarn craton. The northwestern striking, elongated KGB is exposed for approximately 35 km between the Lake Deborah and Lake Seabrook salt lakes (Fig. 1A). The surrounding rocks of the KGB in the southwest are gneisses of the Ghooli and Lake Deborah Domes (Chin and Smith, 1983), and in the northeast banded gneisses. Almost the entire southwestern boundary of the belt is defined by the northwest trending Koolyanobbing shear zone, which is marked by a 6- to 14-km-wide mylonite zone (Libby et al., 1991). Locally, a mostly undeformed monzogranite, the Lake Seabrook granite, intrudes the Ghooli Dome gneisses, Koolyanobbing shear zone, and Koolyanobbing greenstone belt.

Traditionally, the KGB has been divided into the North and South Ranges (north and south of 6,591,000 m, respectively), where the South Range hosts all of the known high-grade iron ore deposits (Fig. 1A). The spatially closest greenstone terranes are the Marda belt to the north and the Southern Cross belt to the south (Fig. 1B).

2.2. Lithostratigraphy

The Koolyanobbing greenstone belt includes rocks of the lower greenstone succession, which is assumed to be the oldest volcano-sedimentary succession within the Youanmi Terrane (minimum age 3023 ± 10 Ma: Nelson, 1999; Chen et al., 2003; Cassidy et al., 2006). Throughout the Youanmi Terrane, the lower greenstone succession consists of: discontinuous, basal clastic quartzites; followed by thick tholeiitic basalt flows, high-magnesium basalts to komatiitic basalts, minor mafic tuffites and komatiites; several BIF, and minor clastic sedimentary rocks (e.g., Chen et al., 2003; Wyche et al., 2004; Cassidy et al., 2006). The lithostratigraphic column of the KGB assumes a uniform stratigraphic younging of the monoclinal inclined lithostratigraphic units towards the northeast (Fig. 2). The sequences of the lower greenstone succession in the KGB contain lesser felsic to intermediate lithologies than most other greenstone belts in the Yilgarn craton (Chin and Smith, 1983). Griffin (1981) estimated an apparent 6 km thickness of the mafic volcanic sequence in the KGB, however local tectonic thickening or thinning is likely owing the complex deformation history, as summarized in the following section (Angerer and Hagemann, 2010). Ultramafic layers are most abundant in the lowermost and in the upper section of the lithostratigraphic column. Exposed clastic sedimentary rocks of the Koolyanobbing greenstone belt include quartzite and pelites (Griffin, 1981). Three BIF units within the Koolyanobbing greenstone belt strike broadly parallel to the belt and have thicknesses between 50 and 180 m, or locally up to 260 m where tectonically thickened.

A subdivision of mafic volcanic events in the Koolyanobbing greenstone belt into four distinct lithostratigraphic subsequences, termed S1–S4, is proposed (Fig. 2). Owing to the complex deformation of the greenstone belt (see in the following section), true thicknesses estimation of the sequences is impossible. The division into four stratigraphically distinct volcanic sequences is based on the greenstone belt-wide occurrence of three major BIF units, which represent inter-/post-volcanic periods on top of mafic rock packages. The lower part of S1 and the top of S4 are not exposed due to tectonic/magmatic boundaries.

The preserved part of S1 consists predominantly of amphibolites and intercalated ultramafic layers, especially in the direct footwall of the top BIF unit. Minor BIF/chert and metamorphosed sandstone layers are intercalated within the volcanic sequence. Amphibolites with a schistose fabric are typically observed in the footwall of the lower BIF in proximity (several 100 m distance) to the Koolyanobbing shear zone. These relationships suggest a genetic relationship of metamorphic, ductile deformation to the shear zone (Libby et al., 1991). The peridotitic komatiite flows (Nesbitt, 1971) are now strongly altered to carbonate-bearing talc-, chlorite-, actinolite/tremolite-, antigorite-rich schists (Griffin, 1981). Laminated or massive metacherts dominate the top BIF unit.

In the S2 metabasalts and komatiitic metabasalts dominate and ultramafic rocks appear to be absent. Amphibolites dominate in the lower part of S2, and towards the upper part and the top BIF, mafic rocks are typically schistose metabasalts. Strongly deformed chlorite schists are observed in the footwall of the top BIF. This