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Characterization of enriched lithospheric mantle components in ~2.7 Ga Banded Iron Formations: An example from the Tati Greenstone Belt, Northeastern Botswana

Lasse N. Døssing[a,b,*], Robert Frei[a,b], Henrik Stendal[c], Read B.M. Mapeo[d]

[a] Institute of Geography and Geology, University of Copenhagen, Øster Voldgade 10, DK-1350 Copenhagen K, Denmark
[b] Nordic Center for Earth Evolution (NordCEE), Denmark
[c] Geological Survey of Denmark and Greenland (GEUS), Øster Voldgade 10, DK-1350 Copenhagen K, Denmark
[d] Department of Geology, University of Botswana, Private Bag UB00704, Gaborone, Botswana

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ABSTRACT

Major and trace element, samarium (Sm)–neodymium (Nd) and lead (Pb) isotopic analyses of individual mesobands of five Banded Iron Formations (BIFs) and associated volcanic and sedimentary rocks from the Neoarchean Tati Greenstone Belt (TGB, Northeastern Botswana) were conducted in order to characterize the source(s) and depositional environment(s). Rare earth element (REE)–yttrium (Y) patterns of individual BIF mesobands show features characteristic of other Archean BIFs with LREE depletion relative to MREE and HREE, positive La/La^*_{PAAS}, Eu/Eu^*_{PAAS}, Y/Ho ratios and no Ce/Ce^*_{PAAS} anomalies. The REY patterns are comparable to modern seawater and together with low concentrations of high-field strength elements these features are indicative of an essentially detritus-free precipitation. Elevated Eu anomalies in the TGB BIFs are a general feature observed in ~2.7 Ga BIFs worldwide and possibly result from widespread magmatic activity and associated high-temperature fluid fluxes to the oceans at around this time.

Uranogenic Pb isotope data for the BIFs define correlation lines with slopes corresponding to apparent ages of ~2.7 Ga which brackets the depositional timeframe. Pb isotope data on sulfides and Pb-stepwise leaching (PbSL) data on garnets define a correlation line with an apparent age of 1976 ± 88 Ma. This age is similar to tectono-metamorphic events within the adjacent Limpopo belt. Elevated $^{207}Pb/^{204}Pb$ relative to $^{206}Pb/^{204}Pb$ ratios of BIFs are indicative of a high-μ ($^{238}U/^{204}Pb$) prehistory of their source materials which can best be modeled by a 3.0–3.2 Ga extraction of these sources from an older Archean mantle reservoir.

The TGB BIFs show evidence of two periodically interacting water masses during the deposition. The first is characterized by elevated Sm/Nd ratios and a negative inferred ε_{Nd}(2.7 Ga) value of −2.5 and is associated with high Fe fluxes. The second source, associated with high Si fluxes, is characterized by lower Sm/Nd ratios and a less negative inferred ε_{Nd}(2.7 Ga) value of −0.4. While the association of high Fe concentrations and elevated Sm–Nd in BIF mesobands is characteristic of hydrothermal seawater input, the Sm–Nd isotopic characterization of this source, unlike other Archean BIFs, points to a significantly LREE enriched mantle source. This finding is compatible with the potential existence of a sub-continental lithospheric mantle reservoir beneath the Zimbabwe and Kaapvaal craton. The old (up to ~3.5 Ga) Nd (T_{DM}) model ages, particularly of iron-rich mesobands of the TGB BIFs, support such a scenario. In contrast, Si-rich solutes were likely derived from weathering of mafic continental crust.

1. Introduction

Banded Iron Formations (BIFs) are thought to represent marine chemical sedimentary rocks that were abundant in the Archean and early Proterozoic (Alibert and McCulloch, 1993; Derry and Jacobsen, 1990; Frei and Polat, 2007). BIFs provide insight to long-term changes in the Earth's evolution, particularly with respect to the chemical composition and oxidation state of ancient seawater and indirectly also to atmospheric changes on land. The chemistry of seawater partly reflects the mixed input from different sources. BIFs are, therefore, useful tracers for some of the main processes controlling the terrestrial Precambrian atmosphere–hydrosphere–lithosphere system (Bau and Möller,

* Corresponding author at: Institute of Geography and Geology, University of Copenhagen, Øster Voldgade 10, DK-1350 Copenhagen K, Denmark.
E-mail address: lnd@geo.ku.dk (L.N. Døssing).

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1993; Derry and Jacobsen, 1990). Periodic shifts between silica- and iron-rich mesobands in BIFs are thought to record a balance between submarine hydrothermally versus continentally derived inputs (Hamade et al., 2003; Morris, 1993). Whether these periodic shifts are primary signatures or secondary replacements are a matter of debate (Chown et al., 2000; Mueller and Mortensen, 2002). Major and trace elemental compositions as well as isotopic signatures of individual mesobands and detailed field observations are needed to determine the origin.

The precipitating mechanism for Archean BIFs remains highly debated. Different models have been proposed to explain the oxidation of Fe^{2+} to the less soluble Fe^{3+} and its subsequent precipitation as ferric oxyhydroxides. These include abiotic photochemical oxidation, inorganic reactions using photosynthetically generated O_2, temperature fluctuations in the ocean photic zone and primitive O_2-producing photosynthetic bacteria (Beukes, 2004; Frei and Polat, 2007; Kappler et al., 2005; Konhauser et al., 2002; Posth et al., 2008).

The objectives of this article are: (1) to present isotopic, major- and trace-element data of BIFs and of associated volcanic and sedimentary rocks from the Neoarchean Tati Greenstone Belt (TGB) in order to evaluate the regional geological framework of the TGB; (2) to elaborate on the origin and nature of source materials of the BIFs and to make inferences about the seawater from which these chemical sediments were precipitated. Geochemical data help to distinguish between the two most likely sources—submarine hydrothermal and continental. The results of this article are important because they provide important constraints regarding the TGB, which is important regarding source region characteristics of the surrounding Zimbabwe craton and the adjacent Limpopo Mobile Belt.

2. Geological setting

Southern Africa is largely composed of the Archean Zimbabwe and Kaapvaal cratons (Fig. 1A and B), which are separated by

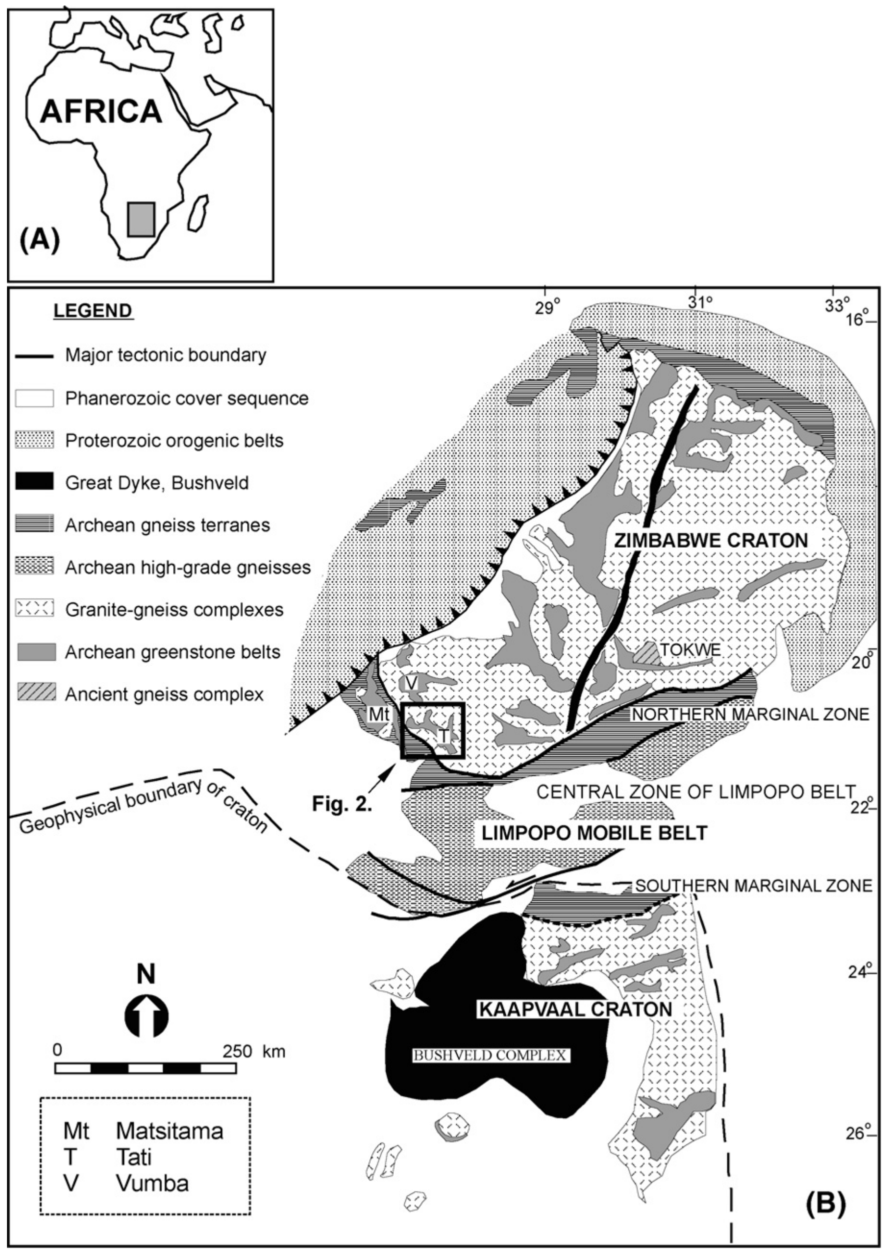

Fig. 1. (A) Sketch map of Africa with inset showing the location of the study area. (B) Simplified geological map of southern Africa; inset depicts the study area enlarged in Fig. 2 (modified after Bagai et al., 2002).