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Zircon U–Pb–Hf evidence for subduction related crustal growth and reworking of Archaean crust within the Palaeoproterozoic Birimian terrane, West African Craton, SE Ghana

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ABSTRACT

Zircon Lu–Hf isotopic data from granites of southern and northwestern Ghana have been used to investigate the contribution of reworked Archaean bedrock to the Birimian crust of Ghana, West African Craton. Zircon from seven localities in southern Ghana and one locality in western Ghana were analysed. Combined U–Pb and Lu–Hf isotope data suggest juvenile crustal addition between 2.3 and 2.1 Ga, with a short period of reworking of Archaean crust. Until now, evidence for reworking of Archaean basement during Birimian magmatism in Ghana has hinged on whole-rock Nd model-ages of the Winneba pluton, and sparse inherited zircon grains from mainly northwestern Ghana. Our data suggest that reworking of Archaean crust is greater than previously inferred, but was limited to between ~2.14 and 2.13 Ga. This period of reworking of older crustal components was preceded and succeeded by juvenile crustal addition.

Coupled isotopic data suggest an eastward, mainly retreating arc system with a shorter pulse of accretion between ~2.18 and 2.13 Ga and a rapid return to slab retreat during the growth of the Birimian terrane. The accretionary phase initiated melting of sub-continental lithospheric mantle and the overlying Archaean crust, generating magma with sub-chondritic Hf signatures. Subsequent slab retreat led to trench-ward movement of the magmatic activity and the mixture of juvenile and Archaean crust was replaced by uncontaminated juvenile magma. The 2.23 Ga age of the West Accra granodiorite (PK105) demonstrates the emplacement of felsic rocks during the Eoeburnean and pre-dates the suggested plume related rocks, contradicting suggested plume initiated subduction.

1. Introduction

The formation of the Birimian terranes in West Africa (Fig. 1a–c) occurs towards the end of a period sometimes assumed to be associated with global magmatic quiescence (Condie et al., 2009). Yet, the formation of the Birimian crust has been cited as an example of rapid crustal growth, as large volumes of juvenile continental material were emplaced during a short time-span (Abouchami et al., 1990). Crystallisation ages from the Birimian bedrock of Ghana range between ~2.31 and 2.06 Ga, with a predominance of ages between 2.21 and 2.06 Ga (e.g. Gasquet et al., 2003; de Kock et al., 2011). These rocks have largely juvenile Nd isotope signatures (Abouchami et al., 1990; Liégeois et al., 1991; Boher et al., 1992; Ama-Salah et al., 1996; Hirdes et al., 1996; Doumbia et al., 1998; Gasquet et al., 2003; Pawlig et al., 2006; Klein et al., 2008; Tapsoba et al., 2013) with the exception of the Winneba pluton from southeastern Ghana, which has a $\varepsilon Nd_{(2.173\,Ga)} = -5.3$ and a depleted mantle model age of ~2.6 Ga, indicating the involvement of Archaean crust (Taylor et al., 1992; Leube et al., 1990). Based on trace element geochemistry of mafic metavolcanic rocks, it has been proposed (Abouchami et al., 1990) that the Birmian crust formed rapidly and in response to mantle plume activity. Although alternative views such as arc accretion and convergent magmatism have been proposed (e.g. Sylvester and Attoh, 1992; Feybesse and Milési, 1994; Ama-Salah et al., 1996; Pouclet et al., 2006; Baratoux et al., 2011; de Kock et al., 2012), the Birimian terranes are still widely promoted as a prime example of mantle plume-related crust formation (c.f. Arndt, 2013). Feybesse et al. (2006) propose that

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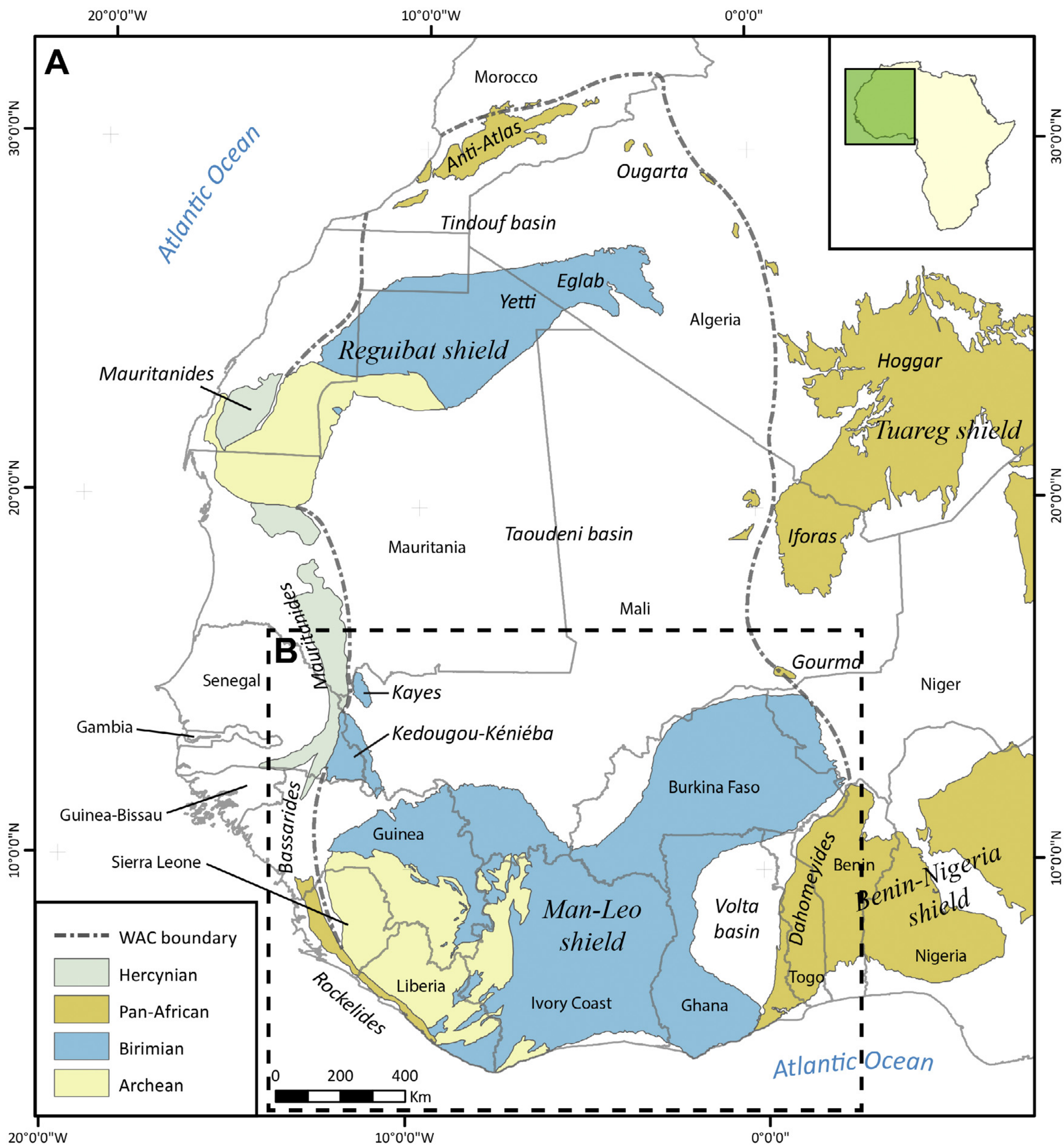

Fig. 1. (a) Simplified tectonic map of the West African Craton and adjacent Pan-African-Hercynian fold and thrust belts. Mesoproterozoic to recent sedimentary rocks are not depicted. The map has been compiled from the following sources; Man-Leo shield, Kedougou-Kéniéba, Kayes (Egal et al., 2002; Baratoux et al., 2011), Reguibat shield (Peucat et al., 2005; Schofield et al., 2012), Pan-African belts (Persits et al., 2002; Baratoux et al., 2011) and Hercynian belt (Abouchami et al., 1990; Schofield et al., 2012). WAC boundaries after Ennih and Liégeois (2008). Redrawn after Grenholm (2014). (b) Schematic geological map of Birimian rocks of the Man-Leo shield redrawn after Baratoux et al. (2011) with modifications by Egal et al. (2002), Agyei Duodu et al. (2009) and Grenholm (2014). Key to inherited zircon: 1: Gondo granite gneiss, EC1074A, 2.876 Ga and 2.499 Ga, Thomas et al. (2009). 2: Ifantayire granite gneiss, SC1011, 2.386 Ga and 2.258 Ga, Siegfried et al. (2009). 3: Dabakala tonalitic gneiss, s8-32, 2.312 Ga, Gasquet et al. (2003). 4: Gomoa Fetteh hornblende biotite granite, PK103, 2.460 Ga, this study. (c) Geological map of Ghana showing sample locations, basins, belts and main rock units. Initial version of the map was compiled by Watts, Griffit and McQuat Ltd., Lakewood Colorado, USA.

the onset of continental crust growth within the Birimian terrane started at the end of the Eoeburnean (c. 2.35–2.15 Ga) phase, with the intrusion of abundant monzogranites between 2.16 and 2.15 Ga. Reworked Palaeoproterozoic to Archaean crust within the Birimian terrane is, apart from the Winneba pluton in southeastern Ghana (i.e. near the SE margin of currently exposed Birimian crust), only known through the presence of 2.26–2.88 Ga xenocrystic and commonly discordant zircon from rocks in the Bolé-Navrongo belt in northwestern Ghana e.g. the Gondo orthogneiss and the Ifantayire granite gneiss (Thomas et al., 2009; Siegfried et al., 2009; de Kock et al., 2011, Fig. 1c). Available geochronological data for the Birimian terrane, whole rock Lu–Hf and Sm–Nd isochrons for basalts (Blichert-Toft et al., 1999) and zircon U–Pb of granites (Hirdes et al., 1996) are coeval within error, i.e. they formed at 2.15 ± 0.05 Ga. Following a similar approach as Næraa et al. (2012), we explore coupled shifts in zircon U–Pb–Lu–Hf isotopes to explore crustal growth and reworking of older crust within an accretionary orogen. Detrital zircon $\delta^{18}O$ from five rivers draining Birimian bedrock in Ghana yield a weighted mean of 6.7 ± 0.2 (MSWD = 5; Kristinsdóttir et al., 2013), which might indicate a significant reworked supracrustal component (c.f. Dhuime et al., 2012). Such an inference is in stark contrast with current models for the Birimian continental crust growth, which imply that the entire mass of juvenile crust formed around 2.15 Ga with the exception of the 2.173 +0.107/−0.115 Ga Winneba pluton (Taylor et al., 1988; Leube et al., 1990; Taylor et al., 1992).