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Just another drip: Re-analysis of a proposed Mesoarchean suture from the Barberton Mountain Land, South Africa

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ABSTRACT

Structural analysis of a proposed Mesoarchean suture located immediately to the southwest of the Barberton Greenstone Belt, South Africa – known as the Inyoni Shear Zone (ISZ) – reveals that the main, steeply dipping, NNE-striking fabric is distributed across only 1 km width, is late (D3), and clearly overprints two earlier sets of fabric elements (D1, D2) that were originally oriented at right angles to the direction of proposed collision. Dating of a S2 foliated meta-trondhjemite is interpreted to indicate that D2 deformation was at, or younger than, 3238.2 ± 0.9 Ma. The D3 high strain fabric of the ISZ is localised around tightly folded, kilometre-scale supracrustal rafts, but dissipates in all directions away from the rafts, along and across strike. The kinematic asymmetry of S3 shear foliations changes across opposing limbs of tight, upright F3 folds of supracrustal rocks in the ISZ, indicative of simple shear related to buckle folding of more competent supracrustal rocks in a matrix of less competent granitic gneisses. F3 buckle folding was highly non-cylindrical on steep to subvertical axes that plunge to the south in the northern part of the zone and to the north in the southern part of the zone, with nests of vertically plunging sheath folds along amphibolite/metagranite contacts in the central area. High-pressure (HP), garnet-bearing amphibolites are restricted to close association with the vertical D3 sheath folds and do not extend along strike.

Combined, the data indicate that the ISZ is not the product of west-directed subduction, as previously suggested. Rather, the strain and kinematic data indicate that the ISZ is just another drip of relatively cool, relatively rigid greenstones into hot, ductile granitic gneisses, formed during partial convective overturn of the upper (greenstone) and middle (granitic) crust. Uplift of the HP rocks was along a late (D4), brittle–ductile mylonite zone associated with emplacement of the c. 3.1 Ga Kees Zyn Doorns syenite.

1. Introduction

Starkly contrasting models exist for the formation of the Barberton Greenstone Belt (BGB) and surrounding areas of predominantly granitoid rocks that together form the eastern part of the Kaapvaal Craton in southern Africa (Fig. 1).

One model of evolution – here referred to as the allochthonous, or arc-accretion model – suggests that the BGB represents a stack of thrusted ophiolite complexes that were juxtaposed against a 3.29–3.23 Ga arc terrane to the northwest during 3.26–3.23 Ga subduction and collisional orogeny (Fig. 2a: de Wit, 1982; de Wit et al., 1983, 1987a, 1987b, 1992, 2011; Kamo and Davis, 1994; de Ronde and Kamo, 2000; Moyen et al., 2006; Kisters et al., 2010; Furnes et al., 2012, 2013). In this model, older granitoid rocks and greenstones along the southwestern margin of the belt (Stolzburg

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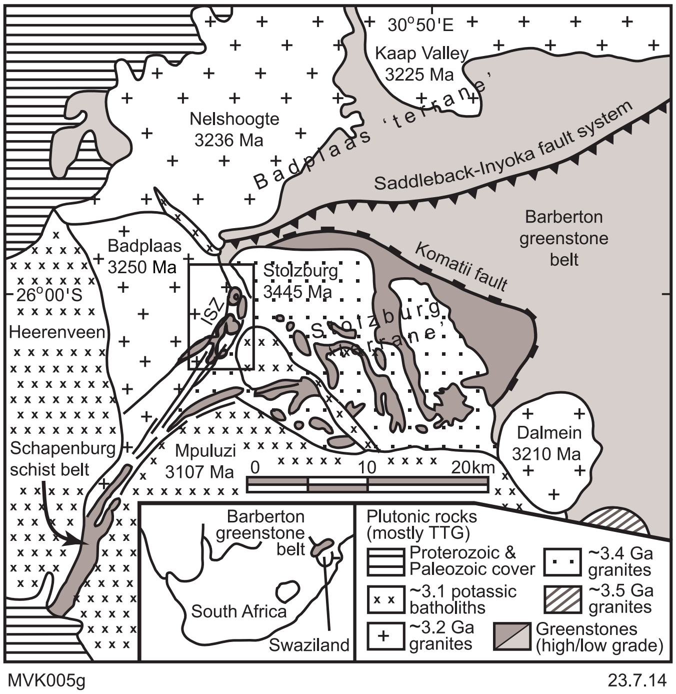

Fig. 1. Regional geological map of the southwestern Barberton Granitoid-Greenstone Terrain, showing the location of the Inyoni Shear Zone (ISZ) and study area (rectangle = location of Fig. 3). KZD = Kees Zyn Doorns syenite. Badplaas 'terrane' is across the top left side of the figure, and includes the Kaap Valley, Nelshoogte, and Badplaas 'plutons', as well as part of the Barberton Greenstone Belt to the northwest of the Saddleback-Inyoka Fault System (SIFS). Stolzburg 'terrane' includes rocks to the southwest of the Komati fault and southeast of the ISZ.

'terrane'[1]) are interpreted as allochthonous and tectonically juxtaposed against a northwestern arc terrane (Badplaas 'terrane') across a suture zone represented by the Inyoni Shear Zone (ISZ), which is located immediately to the southwest of the BGB. The ISZ is linked to its proposed extension along strike to the northeast, the Saddleback-Inyoka Fault System (SIFS), which extends down the length of the BGB (Fig. 1). A key element of the arc-accretion model is the 2 km-wide, north–northeast-striking ISZ, which Moyen et al. (2006) proposed represents "...the mid- to lower-crustal expression of a suture zone...", based on the presence of (1) garnet-albite-bearing amphibolites from which high-P/moderate-T conditions of metamorphism "...similar to those found in recent subduction zones" ($P = 1.2–1.5$ GPa, $T = 600–650$ °C, apparent geothermal gradients of 12–15 °C/km) were reconstructed; (2) high strain shear fabrics; (3) juxtaposition of proposed terranes with inferred distinct geological histories on either side of the zone. The Stolzburg 'terrane' in the southeast was interpreted as having been affected by high-pressure (HP) metamorphism across its full areal extent during west-directed subduction beneath the Badplaas 'terrane' (Diener et al., 2005; Moyen et al., 2006; Kisters et al., 2010). The Badplaas 'terrane' was described as containing NNE-striking foliations and E-plunging mineral elongation lineations that were suggested to have formed through at least three fabric-forming events over the interval 3.46–3.23 Ga (Kisters et al., 2010). The main collisional event was interpreted to have occurred at 3.23 Ga, based on the ages of syn-kinematic tonalites (Stevens et al., 2002; Dziggel et al., 2002).

A competing model – here referred to as the autochthonous, or volcanic plateau model (e.g. Van Kranendonk, 2011; Van Kranendonk et al., 2014) – suggests that the BGB represents the structural remnant of a thick pile of greenstones (3.53–3.3 Ga Onverwacht Group) that were erupted onto older continental basement (Ancient Gneiss Complex; 3.65–3.55 Ga: Kröner, 2007) and/or older mafic crust (Clemens et al., 2006) (Fig. 2b). In this model, predominantly komatiite-basalt eruption was accompanied by periods of felsic volcanism derived from fractionation and crustal contamination, and intruded by syn-volcanic granitoid rocks derived from melting of the mafic lower crust (e.g., Moyen et al., 2007; Kröner et al., 2013). The greenstone-over-granite crustal architecture was then affected by partial convective overturn (PCO), whereby dense greenstones sank down into partially molten granitic middle crust at c. 3.26–3.22 Ga, accompanied by the intrusion of syn-kinematic granitoid rocks and by the deposition of predominantly clastic sedimentary rocks (Fig Tree and Moodies groups) in developing synclines where they were affected by contractional deformation arising from bed-length shortening between developing granitic domes (Viljoen and Viljoen, 1969; Anhaeusser, 1984; Byerly et al., 1996; Van Kranendonk et al., 2009; Van Kranendonk, 2011; Heubeck et al., 2013).

The volcanic plateau model has been criticised for not being able to explain the presence of high strain shear zones within the BGB, the HP metamorphic assemblages and high strain of the ISZ, the presence of the SIFS and strongly deformed rocks within the BGB, nor the juvenile 'arc' rocks of the Badplaas 'terrane'.

Conversely, the arc-accretion model also has a number of weaknesses, as follows. (1) The same range of ages of pre-collisional magmatism in the Badplaas 'terrane' (3300–3290 Ma, 3256 Ma, 3230 Ma 'arc' magmas) has also been recorded in 'terranes' to the east of the ISZ-SIFS; e.g., komatiitic volcanism (3298 ± 3 Ma Mendon Formation, Onverwacht Group) and felsic volcanism (3.26–3.23 Ga Fig Tree Group) (Byerly et al., 1996; Kamo and Davis, 1994; de Ronde and Kamo, 2000). (2) The sedimentary provenance of pre-collisional Fig Tree Group sediments is similar on both sides of the SIFS (Zeh et al., 2013). (3) The c. 3224 Ma Kaap Valley Pluton of the Badplaas 'terrane', which is interpreted as part of the arc suite, is *younger* than the age of proposed collision, which is impossible. (4) A more detailed analysis of the garnet amphibolites from the ISZ has indicated that they formed under conditions less similar to modern subduction zones than initially proposed ($P = 1.1–1.2$ GPa, $T = 720–800$ °C, apparent average geothermal gradients of 17–22 °C/km: Nédélec et al., 2012). Indeed, these conditions are unlike modern subduction zones at all, and not even similar to conditions within normal crust; for example, 800 °C at 12 kbar is unusually hot for subduction zones and in the field of migmatite development. Furthermore, averaging thermal gradients in this manner is inappropriate for such depths, since gradients are expected to decrease with depth. (5) Results from a study of greenstones located 15 km along strike of the HP garnet amphibolites in the ISZ (Schapenburg schist belt; Fig. 1), indicate much lower conditions of peak metamorphism ($P = 0.48 \pm 0.01$ GPa, $T = 640 \pm 40$ °C, apparent geothermal gradient of 40 °C/km: Stevens et al., 2002), casting doubt on a subduction model for this part of what has been interpreted as the same shear zone. (6) It has previously been documented that not all of the Stolzburg 'terrane' has undergone HP metamorphism as proposed by Moyen et al. (2006); for example, undeformed greenstones within the core of the domical Theespruit Pluton have only been metamorphosed to upper greenschist facies ($P = 0.3–0.5$ GPa, $T = 480$ °C: Van Vuren and Cloete, 1995), and greenstones flanking the pluton record maximum conditions of between $P = 0.8–1.1$ GPa, and $T = 650–700$ °C (Dziggel et al., 2002; Diener et al., 2005) and $P < 0.4$ GPa (Van Kranendonk et al., 2009).

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[1] Terrane is used as a genetic term for blocks of crust that have evolved separately and then been juxtaposed across faults in convergent plate margin settings: quotation marks are used to indicate where the use is controversial and domain used to denote geological areas without a tectonic connotation as to origin.