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A record of 0.5 Ga of evolution of the continental crust along the northern edge of the Kaapvaal Craton, South Africa: Consequences for the understanding of Archean geodynamic processes

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ABSTRACT

Geodynamics of crustal growth and evolution consist in one of the thorniest questions of the early Earth. In order to solve it, Archean cratons are intensively studied through geophysical, geochemical and geochronological investigations. However, timing and mechanisms leading to accretion and stabilization of crustal blocks are still under question. In this study, new information on the evolution of Archean cratons is provided through complementary approaches applied to the northern margin of the Archean Kaapvaal craton (KC). The study area comprises the Pietersburg Block (PB) and the terrane immediately adjacent to the North: the Southern Marginal Zone of the Limpopo Complex (SMZ). We present a comprehensive petro-metamorphic study coupled with LA-ICP-MS U-Pb isotope examination of both Na- and K-rich granitoids from the two areas. This dataset points toward a new interpretation of the northern KC (PB + SMZ). Two significant magmatic events are newly recognized: (i) a *ca.* 3.2 Ga event, and (ii) a protracted magmatic event between *ca.* 2.95–2.75 Ga. These events affected in both investigated areas and are unrelated to the *ca.* 2.7 Ga-old event usually attributed to the SMZ. More importantly, phase equilibrium modelling of several lithologies from the SMZ basement points to middle-amphibolite facies conditions of equilibration instead of granulite-facies conditions historically assumed.

This study has both important regional and global implications. Firstly, the presence of a continuous basement from the Thabazimbi-Murchison Lineament to the Palala Shear Zone, different than Central Zone of the Limpopo Complex basement, implies a complete reviewing of the whole Limpopo Complex concept. Secondly, the geometry observed in the northern Kaapvaal craton is assumed to testify for a complete accretionary orogenic sequence with formation of both mafic and TTG lithologies through arc-back arc geodynamic. This was followed by a long-lived lateral compression triggering partial melting of the lower continental crust and emplacement of Bt-granitoids bodies that stabilizes the continental crust. Lastly, partial melting of the underlying enriched mantle stabilized the entire lithosphere allowing long-term preservation of the crustal block.

1. Introduction

Archean terranes presently account for only 7% of the exposed crust (Goodwin, 1996). Geological investigations of Archean terranes lead to the view that substantial volume of continental crust has existed by the end of the Archean (e.g. de Wit et al., 1992c). This view is supported by recent compilations of worldwide U-Pb/Lu-Hf/δ^{18}O isotope analyses on detrital zircon grains suggesting that up to 70% of the present-day volume of continental crust might have been in existence by the end of the Archean (Belousova et al., 2010; Dhuime et al., 2012). Moreover, Kusky and Polat (1999) have demonstrated that margins of the Archean crustal nuclei are key locations of both growth and stabilisation of stable shields. Therefore, Archean terranes provide a unique opportunity to decipher the geodynamic processes which shaped the evolution of the young Earth.

Based on field investigations and geophysical/geochemical modelling, Archean tectonics has been described through two end-members: vertical tectonics versus horizontal tectonics. Growth and recycling of the continental crust through vertical tectonics is proposed for a few Archean terranes: the East Pilbara Granite-Greenstone terrane in

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Western Australia (Collins, 1989; Van Kranendonk et al., 2004), the Superior Province in Canada (Bédard et al., 2003), the Dharwar craton in India (Chardon et al., 1996); or at local scale on other terranes (Jaguin et al., 2012). Conversely, lateral plate tectonics is proposed to drive crustal growth and recycling in most other investigated Archean terranes (de Wit, 1998; Block et al., 2013; Zeh et al., 2013; Dhuime et al., 2015). The consensus is however not reach for most of investigated terranes, and both geodynamics are often proposed (e.g. Cagnard et al., 2011; Van Kranendonk, 2011). The view that vertical and horizontal tectonic processes are exclusive to Archean geology is somehow naive, as it is common in the better preserved Phanerozoic rock record to find evidence for crustal thickening by lateral tectonic processes, with a strong component of relative vertical motion of rock masses during orogenic collapse (Burg and Vanderhaeghe, 1993; Vanderhaeghe, 1999). Moreover, Chardon et al. (2009) outlined the fact that "collision" systems may actually be very diverse and result in a large range of deformational processes and relative motions of rock masses. Finally, Cawood et al. (2009) highlight the fact that "Wilsonian" continental collisions are not the only option available to account for crustal thickening (even within the plate tectonics paradigm) and that the role of alternative settings such as accretionary orogens has been underestimated during Earth history as major sites for formation and reworking of the continental crust. Accretionary orogens are defined as plate margin environments in which continuous subduction of oceanic crust and accretion of volcanic arcs lead to metamorphism and both crustal growth and differentiation (Cawood et al., 2009).

Resolving the relative importance of accretionary orogenic processes for Archean crustal reworking is a crucial step toward a better understanding of the tectonic evolution of the young Earth. Here, we address this issue through a thorough investigation of the northern part of the Archean Kaapvaal craton (KC) and the adjacent southern part of the Limpopo Complex (Fig. 1). This southern part, locally called Southern Marginal Zone (SMZ), is proposed to record an Archean collisional orogeny (van Reenen et al., 1987; Roering et al., 1992b; van Reenen et al., 2011).

We present a comprehensive geochronological and petrological database for the largely unknown felsic gneisses of the SMZ, which is then compared to their counterparts from the northern KC (Poujol et al., 1996; Poujol and Robb, 1999; Passeraub et al., 1999; Henderson et al., 2000; Kröner et al., 2000; Poujol, 2001; Anhaeusser and Poujol, 2004; Zeh et al., 2009; Zeh and Gerdes, 2012; Jaguin et al., 2013; Block et al., 2013; Laurent et al., 2013; Zeh et al., 2013; Kramers et al., 2014; Laurent and Zeh, 2015). These felsic gneisses form the majority of the exposed crust and have long been recognized as fundamental for the development of continental nuclei (Barker and Arth, 1976). Investigations of felsic gneisses, combined with previously published radiochronometric datasets, draw new terrane outlines of the northern KC (northern part of the Archean KC + SMZ) and call for a reappraisal of the geodynamic evolution of this area as well as a reappraisal of the extent of accretionary orogen settings in building early Earth continental crust.

2. Geological setting

The Kaapvaal craton represents a large Archean block mostly present in South Africa and partly covered by younger sedimentary sequences in its central and western parts (Fig. 1). Based on a compilation of geochronological and structural data, the KC has been divided into several cratonic sub-blocks (Fig. 1): the Kimberley Block, Witwatersrand Block, Swaziland Block and the Pietersburg Block (Eglington and Armstrong, 2004; Anhaeusser, 2006). The northernmost Pietersburg Block (PB further in the text) is juxtaposed along its northern edge to the SMZ belonging to the Limpopo Complex (see Figs. 1 and 2 for geographical localization). The southern edge of the PB is flanked of the Rooiwater-Rubbervale magmatic complex and the adjacent Murchison Greenstone Belt (Vearncombe et al., 1987; Vearncombe, 1988, 1991; Poujol et al., 1996; Poujol, 2001; Jaguin et al., 2012; Block et al., 2013; Zeh et al., 2013). This area is bounded by the Thabazimbi-Murchison Lineament, delineating the PB and the Witwatersrand Block (see Good and de Wit (1997), de Wit and Tinker (2004) and Fig. 1). This contribution focuses on the basement exposed in both the PB and the SMZ. Regarding the various nomenclatures attributed to these areas, it is necessary to define the terms used here.

2.1. Nomenclature of geological units

This contribution will use the followings: the term "PB" (Pietersburg Block) will be used to mean the geological area between the Letaba Shear Zone and the Hout River Shear Zone while the term "SMZ" (Southern Marginal Zone of the Limpopo complex) will be used to mean the geological area comprised between the Hout River Shear Zone and the Palala Shear Zone (see Fig. 2 for localization of the above mentioned tectonic breaks). It is noteworthy that the PB extends toward the West up to the Makoppa Dome (Fig. 1) which is petrologically and geochronologically akin to the Eastern part of the PB (Anhaeusser and Poujol, 2004; Laurent et al., 2014b; Laurent and Zeh, 2015). The term "northern KC" will be used to mean merging of the PB and the retrogressed sub-zone of the SMZ (see following sections for geological context). The Central Zone of the Limpopo Complex will not be dealt with in this contribution since previous petro-metamorphic and geochronological investigations have demonstrated distinct geological histories between the Southern Marginal Zone and the Central Zone of the Limpopo Complex (Holzer et al., 1998, 1999; Schaller et al., 1999; Barton et al., 2006).

2.2. Distinction between the Pietersburg block and the Southern Marginal Zone of the Limpopo complex

The distinction between the PB and the SMZ is based on two considerations, the crustal architecture and the metamorphic record. On the large scale, structural and seismic investigations suggest the presence of northward dipping reflectors at the PB–SMZ interface (e.g. De Beer and Stettler, 1992; Durrheim et al., 1992; McCourt and van Reenen, 1992; McCourt and Vearncombe, 1992; Smit et al., 1992; de Wit et al., 1992a) interpreted as a thrust system (Roering et al., 1992a,b). This interface has been identified on the field as the Hout River Shear Zone (HRSZ, see Fig. 2).

Secondly, the supracrustal lithologies record contrasting metamorphic paragenesis across the HRSZ. Supracrustal lithologies are represented within the SMZ by the Bandelierkop Formation (BF, black lenses on the Fig. 2) and by three greenstone belt units (Giyani, Pietersburg and Rhenosterkoppies, see Fig. 2) within the PB. The dismembered BF supracrustals have collectively been interpreted to reflect reworked greenstone belt units (van Reenen, 1978; Du Toit et al., 1983; van Reenen, 1983; van Reenen et al., 1988, 1990).

The metasedimentary members of the SMZ underwent granulite facies metamorphism along with significant partial melting (Taylor et al., 2014; Nicoli et al., 2015). The mineral assemblage of Opx + Grt + Pl + Qz + Bt ± Crd (abbreviations after Whitney and Evans, 2010) provide evidence for peak metamorphism of *ca.* 850 °C and 11 kbar at *ca.* 2.71 Ga (Taylor et al., 2014; Nicoli et al., 2015). The granulite facies assemblage is partly retrogressed to amphibolite facies within a narrow (*ca.* 25 km) WSW–ENE trending area, the so-called retrogressed sub-zone (Fig. 2). Conversely the three greenstone belts of the PB lack any evidence for granulite facies paragenesis. These supracrustals preserve greenschist to lower-amphibolite facies mineral assemblages (de Wit et al., 1992a,b; van Schalkwyk et al., 1993; Passeraub et al., 1999).

Differences between pressure and temperature of metamorphism experienced by metasedimentary terms of the SMZ supracrustals in comparison with amphibolite facies rocks just to the South of the HRSZ (e.g. McCourt and van Reenen, 1992; Passeraub et al., 1999; Kramers