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The four Neoproterozoic glaciations of southern Namibia and their detrital zircon record: The fingerprints of four crustal growth events during two supercontinent cycles

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ABSTRACT

The transition from supercontinent Rodinia to Gondwana took place in the Neoproterozoic. The western margin of the Kalahari Craton in southern Namibia underwent rifting at c. 750 Ma, caused by the break-up of Rodinia, followed by drift-events and ongoing sedimentation throughout the Cryogenian (at least from 750 to 630 Ma) in Namibia. These sediments comprise at least three different deposits of glacio-marine diamictites (Kaigas at c. 750–720 Ma, Sturtian at c. 716 Ma and Marinoan at c. 635 Ma). The Ediacaran is characterised by collision during the assembly of Gondwana and includes a fourth glacial deposit (post-Gaskiers Vingerbreek glaciation at c. 547 Ma). This study presents more than 1050 single zircon grain U–Pb analyses of different diamictite horizons from southern Namibia and discusses their correlation. For all samples from sediments related to the Kaigas, Sturtian and Marinoan glacial events, the youngest obtained zircon ages were at c. 1.0 Ga, making differentiation by the maximum age of sedimentation impossible. But a correlation was still possible by using the complete detrital zircon U–Pb age patterns, with a significant change in the relative abundance of concordant Mesoproterozoic to Paleoproterozoic zircons. This P/M ratio seems to be a good tool to distinguish the Cryogenian diamictites (Marinoan: $P/M < 0.4$, Sturtian: $0.4 < P/M < 10$, Kaigas: $P/M > 10$). Although all the observed ages from the detrital zircons can be explained by derivation of local material, none of our samples correspond to the Cryogenian rifting events in southern Namibia. Therefore the source area cannot be local and more probably is located in the east of the studied areas. The constancy of the main U–Pb ages suggests a constant sediment supply direction throughout the Cryogenian. The same age populations occurring in the Ediacaran Aar Member indicate the same sediment transport direction from the east, but with an increased proportion of zircon grains older than 2.2 Ga. This marks a transition to the unconformably overlying Vingerbreek (post-Gaskiers) diamictite horizons, which show a significant change in the age spectra. Probably due to mixed input from the east (Kalahari Craton) and from the west (Gariep Belt), the Vingerbreek diamictites show a wider range of zircon ages with youngest ages at c. 590 Ma. This time is characterised by collision events and the Gondwana formation. The Hf isotope record shows that the only input of juvenile material in our samples occurred in the Mesoproterozoic during the Namaqua Natal Orogeny (formation of the Namaqua Belt). In total, four Archaean to Proterozoic crustal growth events are recognised in the western part of the Kalahari Craton: (1) Meso- to Paleoarchean (c. 3.42–2.8 Ga), (2) lower Paleoproterozoic to Neoarchaean (c. 2.8–2.27 Ga), (3) lower to upper Paleoproterozoic (c. 2.27–1.7 Ga) and (3) Mesoproterozoic (c. 1.6–1.0 Ga).

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1. Introduction

The middle to upper Neoproterozoic is characterised by the break-up of the supercontinent Rodinia and the assembly of Gondwana. This period includes various assumed occurrences of global or near-global glaciations. Of them, the Marinoan Snowball-Earth glaciation at c. 635–630 Ma is the most important and best constrained one (term after Mawson and Sprigg, 1950; originally for glacial sediments in South Australia; exact age for Namibia 635.5 ± 1.2 Ma according to Hoffmann et al., 2004). A second and older glaciation between c. 720 and 660 Ma (Shields-Zhou et al., 2012) is known as the Sturtian glacial event. An exact age was defined in Canada at c. 716.5 Ma according to McDonald et al. (2010a) while the term was originally derived from glacial deposits of the Sturt River Gorge in South Australia.

In addition to them, there is evidence for at least three more glacial events with unknown but possibly global extent: (i) The Kaigas glaciation at c. 750–720 Ma with an indirect age older than 741 ± 6 Ma from Namibia according to Frimmel et al. (1996), (ii) the Gaskiers glaciation at c. 580–582 Ma (exact age of 580 ± 1 Ma has been reported by Bowring et al. (2003) from Newfoundland) which is not known in southern Namibia, and (iii) the post-Gaskiers Vingerbreek glaciation at c. 547 Ma (Germs and Gaucher, 2012). Southern Namibia comprises at least four glacial deposits, although correlations were difficult due to changing stratigraphic columns and formation names.

Present day Namibia contains parts of the Kalahari Craton (S) and the Congo Craton (N). The first one comprises two units of Archaean crust: the Zimbabwe Craton (N) and the Kaapvaal Craton (S) with the Archaean to Paleoproterozoic Limpopo Belt in between (Fig. 1). This belt is interpreted as an exotic crustal block that probably got caught between the Zimbabwe and Kaapvaal Cratons during a 2.7–2.6 Ga collision (Begg et al., 2009). Both of the latter mentioned Archaean to Paleoproterozoic cores grew mainly along their NW margins (present day coordinates) in the Paleoproterozoic. This Mesoproterozoic "Proto-Kalahari Craton" (marked by the red dashed line in Fig. 1) was influenced by intense tectonic activity along all margins forming the Kalahari Craton as in its present extent (Jacobs et al., 2008). The southern and eastern margins of this craton are more or less equal to the Namaqua-Natal Belt. This major continuous belt of mainly high-grade rocks is a continental arc that evolved during accretion prior to continent-continent collision at c. 1.2–1.0 Ga and is associated with the formation of supercontinent Rodinia. According to Evans (2009), Jacobs et al. (2008) and others the Namaqua-Natal Belt comprises the remnants of a collision orogen evolved from the Kalahari-Australia/Mawsonland continent-continent collision. Simultaneously to this collision the Kalahari Craton was influenced by intra-plate magmatism, represented by the ca 1.11 Ga Umkondo-Borg Large Igneous Province (Jacobs et al., 2008).

In general, the Kalahari Craton is surrounded by a series of Neoproterozoic to Early Paleozoic (650–450 Ma) orogenic mobile belts ("Pan-African" in the broadest sense), such as Zambezi, Saldania, Gariep and Damara Belts (Fig. 1), which evolved through different phases of intra-continental rifting, continental break-up, spreading, plate motion reversal, subduction and finally continental collision (Frimmel et al., 2011; Jacobs et al., 2008). Parts of the Kalahari Craton were involved in at least two supercontinental cycles that resulted in the formation and dispersion of Rodinia and Gondwana. According to Jacobs et al. (2008) parts of the Kalahari Craton are also exposed in East- and West-Antarctica, in the Falkland Islands and possibly in South America, with all of them reflecting collision events with adjacent cratons.

As a supercontinent formation is not a stable construct, first rift-related structures in the western Kalahari Craton occurred already in the early Cryogenian at 800–750 Ma (Gaucher et al., 2010),

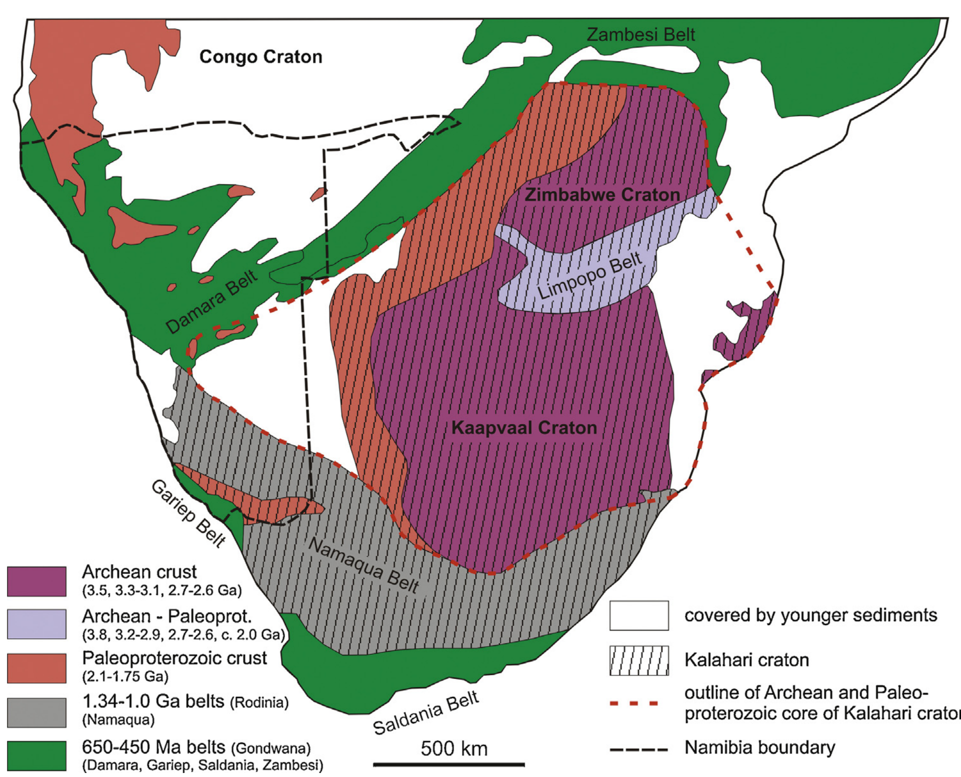

Fig. 1. Constitution of the Kalahari Craton and surrounding areas in southern Africa (from Hofmann et al., 2013; simplified after Jacobs et al., 2008). The Archaean to Paleoproterozoic core of the craton is completely surrounded by upper Neoproterozoic to lower Paleoproterozoic mobile belts, such as the Damara, Gariep and Saldania Belt. The Namaqua Belt is a result of the assembly of Rodinia supercontinent. Younger mobile belts are related to the assembly of Gondwana. Ages based on Jacobs et al. (2008) and Trompette (1994).