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Upper Permian magnetic stratigraphy of the lower Beaufort Group, Karoo Basin

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ABSTRACT

We carried out a magnetostratigraphic and geochronological study of late Permian sediments in the Karoo Basin of the Western Cape Province, South Africa. A continuous, ~700 m thick section of deltaic sediments of the upper Waterford Formation (uppermost Ecca Group) and the fluvial sediments of the Abrahamskraal Formation (lowermost Beaufort Group) were sampled at the meter scale. U–Pb dating of zircons from interbedded volcanic ash beds by ion microprobe (SHRIMP) provided absolute age constraints on the age of the sedimentary rocks. Paleomagnetic analysis reveals a partial overprint of the Natural Remanent Magnetization (NRM) that is tentatively ascribed to the emplacement of the Karoo Large Igneous Province in the Western Cape region during the middle Jurassic. A stable component of the NRM was found at temperatures higher than 450 °C and was interpreted as a Characteristic Remanent Magnetization (ChRM) acquired during deposition, supported by a positive reversals test for this dual polarity ChRM. The virtual geomagnetic pole position for the Waterford and Abrahamskraal Formations computed from the average ChRM direction is in general agreement with the late Permian directions for stable Gondwana. A significantly different average inclination, and thus paleomagnetic pole position, is obtained by correcting the inclination shallowing error by the Elongation–Inclination method (Tauxe and Kent, 2004). The presence of both normal and reversed polarity zones indicate deposition after the end of the Kiaman Superchron, moreover the polarity sequence is in good agreement with the Illawarra sequence of Steiner (2006). Our results indicate a Capitanian (late Guadalupian) age for the Abrahamskraal Fm., in agreement with the Late Permian age, based on presence of *Glossopteris* flora and *Dicynodont* fauna, traditionally assigned to the fluvial-lacustrine sediments of the Beaufort Group. However, the U–Pb zircon ages of ca. 264–268 Ma suggest an age of 269 Ma for the top of the Kiaman superchron.

1. Introduction

The Kiaman superchron, also known as the Permo-Carboniferous Reverse Superchron, marks a long, 40–50 Ma period in which the geomagnetic field was stuck in a reversed polarity, first noted by Irving and Parry (1963) in samples near the town of Kiama in New South Wales, Australia. Opdyke et al. (2001) established the base of the Kiaman interval as 319 Ma. The return to a geodynamo with aperiodic but regular reversals was observed in late Permian sedimentary rocks from the Illwara region in the Sydney Basin of eastern Australia, so this post-Kiaman series of short, normal and reverse magnetozones is known as the Illawaran series. The age of this series is not well-established, generally due to the lack of integration between geochronological and palemagnetic studies of sedimentary rocks. At present, the best estimate for the age of the base of the Illawaran series is ca. 265 Ma (Glenister et al., 1999), based on zircon age data reported in Bowring et al. (1998) from the Guadalupe Mts. of west Texas.

Unlike the highly precise chronology of the latest Permian (Lopingian) to early Triassic, which has been established from integration of biostratigraphy and U–Pb geochronology (Bowring et al., 1998; Mundil et al., 2004; Shen et al., 2011), as well as carbon isotope chemostratigraphy (e.g., Korte and Kozur, 2010) from multiple sections worldwide, magnetostratigraphy provides no such consensus for the preceding late Middle Permian (Guadalupian) times. Like the end-Permian mass extinction, the end-Guadalupian epoch is also marked by a dramatic decrease in biodiversity (Stanley and Yang, 1994; Sahney and Benton, 2008), so establishing a global chronological reference frame is important for correlation purposes. The Karoo Basin is the site of one of the

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thickest and best-exposed records of sedimentary deposition through late Paleozoic and early Mesozoic times, and it is abundantly endowed with the vertebrate fauna that define the continental record of the late Permian and early Triassic (Smith and Ward, 2001; Rubidge et al., 2013). Our study will address the viability of magnetostratigraphy in the Karoo Basin, as well as establish the Guadalupian age of the Beaufort Group, in contrast with the Permo-Triassic age suggested recently by Fildani et al. (2009).

1.1. Geological setting

The Karoo Basin of South Africa records a long history of sedimentation throughout the Paleozoic to middle Mesozoic with the accumulated deposits reaching up to 5500 m in thickness (Tankard et al., 2009). The Karoo Basin formed on African continental lithosphere, 1000–1500 km removed from the Panthalassan (i.e. palaeo-Pacific) plate margin, with both deposition and erosional intervals that can be broadly correlated with the other Gondwanan cratons. By late Cambrian times, following the stabilization of southern Gondwana, sedimentation along the Panthalassan margin initiated with deposition of the Table Mountain Group, a thick package of Cambro-Ordovician quartz arenites, that are overlain by Devonian-Carboniferous rocks of the Witteberg Group. The Permo-Carboniferous glaciation of southern Gondwana is recorded by the Dwyka Group diamictites, which is superseded by Ecca Group slope and delta deposits.

Following the deposition of the Ecca Group turbidites and deltaic sandstones and mudstones, a transition to a continental setting is inferred from the fluvial sediments of the Adelaide Subgroup of the lowermost Beaufort Group. These rocks are typical of a meandering river systems, with fine grained mud- and siltstones beds, 1–5 m thick, interbedded with coarser grained, 5–10 m thick channel fill fine-grained sandstones. The upper sedimentary units of the Beaufort Group are known as the Tarkastad Subgroup, which includes predominantly thick sandstones (>10 m beds) of the Katberg Fm. These rocks are considered to mark a transition to faster-flowing rivers with braided geometries, possibly linked to either faster erosion of a denuded continental surface (Smith and Ward, 2001) or runoff from the tectonically-uplifted Cape Fold Belt. During the Jurassic, continental flood basalts with concomitant dyke and sill intrusions (ca. 180 Ma, Duncan et al., 1997; Jourdan et al., 2007) and extensional tectonics resulted in the termination of Karoo Basin sedimentation (Tankard et al., 2009).

1.2. Previous results

The late Paleozoic and early Mesozoic sedimentary sequences of the Karoo Basin represent an attractive target for paleomagnetic studies. Many early paleomagnetic studies of the Beaufort Group report pervasive remagnetization, which was generally ascribed to the thermal effects of the emplacement of the Karoo Large Igneous Province during the Jurassic. For example, Ballard et al. (1986) carried out a study of the Lower Beaufort Group using standard paleomagnetic techniques that included chemical demagnetization. Their samples were thermally demagnetized up to a temperature of 450 °C and alternating-field demagnetized at a maximum field of 90 mT, showing single component NRM with an average direction 340°E and inclination −58°, which was interpreted as secondary magnetization after a negative fold test. Unreliable paleomagnetic results were also reported from unpublished studies in the Upper Beaufort Group red beds exposed in the eastern part of the Karoo Basin (Graham, 1961; Graham and

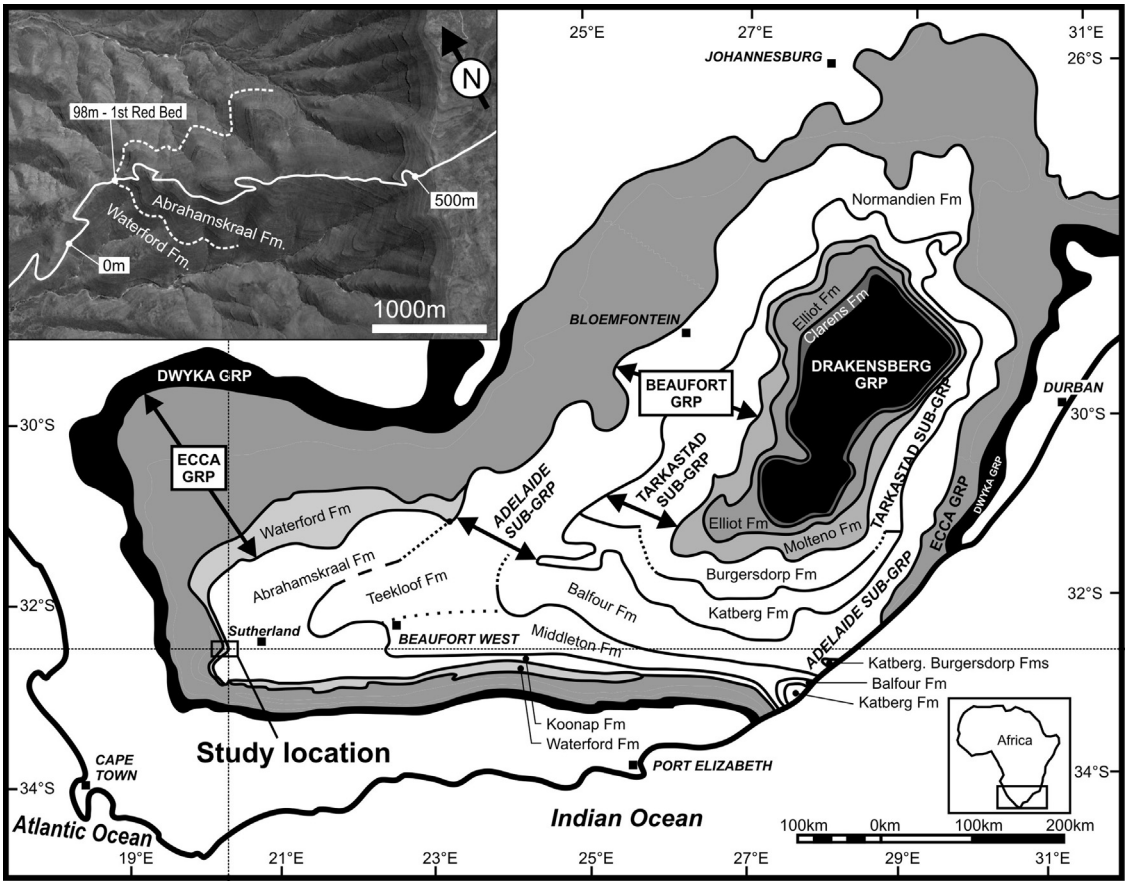

Fig. 1. Map of the studied area. Geological map after Johnson et al. (1997).