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Depositional environments of the lower Permian Dwyka diamictite and Prince Albert shale inferred from the geochemistry of early diagenetic concretions, southwest Karoo Basin, South Africa

C.T. Herbert *, J.S. Compton

Department of Geological Sciences, University of Cape Town, Rondebosch 7700, South Africa

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Abstract

The upper Dwyka and lower Ecca Groups in the Karoo Basin of South Africa document the climatic and palaeoenvironmental changes associated with the final Permo-Carboniferous deglaciation of the Gondwana supercontinent. The depositional environments of these groups have, until recently, been interpreted on the basis of sedimentological and palaeontological evidence. Here we use the geochemistry of early diagenetic concretions – septarian calcite concretions from the upper Dwyka Group and phosphatic chert concretions and beds from the lower Ecca Group – to infer the depositional environment of these rocks in the southwestern Karoo Basin. $\delta^{18}O$ values (7.8 to 8.9‰ SMOW) suggest that the calcite concretions precipitated from a mixture of meteoric and glacial melt waters rather than Permian seawater. $\delta^{13}C$ values (−15 to −3‰ PDB) indicate that the carbon was derived from a mixture of craton-derived calcareous material and organic matter, bacterially degraded in the lower sulphate-reduction to upper methanogenesis zones during early burial diagenesis. The rare-earth element (REE) patterns, Sr concentrations and $^{87}Sr/^{86}Sr$ ratios (0.716–0.737) significantly greater than Permian seawater (0.708), together also support the interpretation that calcite and phosphatic concretions formed in glacial, fresh water sediments.

Keywords: Permo-Carboniferous; Ice age; Rare earth elements; Stable isotopes; Sr isotopes; Gondwana; Concretions; Phosphorite; Karoo Basin

1. Introduction

The Late Palaeozoic was a time of major climatic change as the Gondwana ice sheets began their final retreat. At the peak of glaciation, the South Pole was located in southern Africa (Opdyke et al., 2001; Bumby and Guiraud, 2005) and ice sheets spread across approximately 70 million km^2 of southern Gondwana (Visser, 1993). Widespread Permo-Carboniferous glacial deposits in South America, Africa and Antarctica provide important evidence for the palaeoenvironments of Gondwana during the Late Palaeozoic. Of particular interest is the transition from full glacial to non-glacial conditions, preserved in the sediments of the upper Dwyka to lower Ecca Groups in the Karoo Basin of southern Africa (Catuneanu et al., 1998).

Depositional environments varied geographically in the Karoo Basin and ranged from marine to lacustrine for the Dwyka to lower Ecca Groups of southern Africa. Fossils from the Dwyka Group in the Warmbad Basin in southern Namibia (Fig. 1) indicate a marine depositional

* Corresponding author. Fax: +27 21 650 3783.
E-mail address: cherbert@geology.uct.ac.za (C.T. Herbert).

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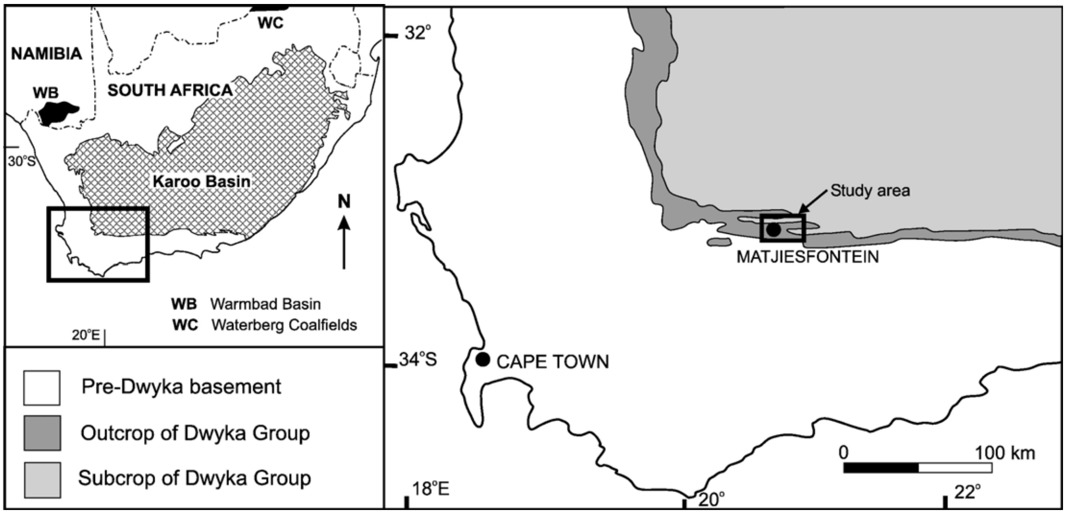

Fig. 1. Map showing the extent of the Dwyka Group in the southwest Karoo Basin, South Africa, and the location of the study area in the vicinity of Matjiesfontein after Visser and Loock (1987).

environment (Martin and Wilczewski, 1970). In the Main Karoo Basin, lower Ecca Group shales (Prince Albert Formation) are interpreted as marine basin or shelf deposits (Strydom, 1950; Oelofsen, 1986; Buhmann et al., 1989; Visser, 1991, 1994b; MacRae, 1999, p.135). However, in the eastern portion of the Main Karoo Basin, palaeontological evidence (Savage, 1970; Anderson, 1970) suggests a fresh water, periglacial environment for upper Dwyka deposits, and stable isotope analyses from sites along the northern and southern margins of the basin (Faure and Cole, 1999) indicate a brackish to fresh water depositional environment for the lower Ecca Group.

Palaeoenvironmental studies in the southwestern portion of the Main Karoo Basin have relied mainly on sedimentological features because fossil evidence is limited (McLachlan and Anderson, 1973). In contrast to rare fossils, hard, resistant concretions weather conspicuously from outcrops of the upper Dwyka diamictites and Prince Albert Formation in the southwestern Main Karoo Basin. In this paper, the geochemistry of concretions collected from the study area (Fig. 1) across the Dwyka–Ecca boundary is argued to indicate that the concretions formed during early diagenesis in a glacial melt water lake depositional environment.

2. Geological setting

The depositional history of the Main Karoo retro-arc foreland basin, recorded in the Karoo Supergroup, spans from the Late Carboniferous to the Middle Jurassic (Catuneanu et al., 2002). Situated on the craton side of the Cape Fold Belt, a north verging fold and thrust belt created by subduction along the palaeopacific margin (Daly et al., 1992), the Karoo Supergroup attains a maximum thickness of 6–8 km in the south (Rubidge, 1995). Little is known about the degree of metamorphism of the Karoo Supergroup, however rocks of the Cape Fold Belt have undergone, at most, lower greenschist grade (approximately 200 °C) metamorphism (de Swart and Rowsell, 1974).

The glaciogenic Dwyka Group constitutes the oldest rocks of the Karoo Supergroup (Figs. 1 and 2). Glacial sedimentation dominated from the Late Carboniferous to Early Permian (Bangert et al., 1999; Veevers and Powell, 1987; Visser, 1989, 1990, 1993). Visser (1986) divided the Dwyka Group into two facies: a valley-highland facies that consists of a heterolithic sequence of variable thickness, found along the northern margin of the Karoo Basin and in the Kalahari Basin in Namibia; and a shelf facies that consists of massive and stratified diamictites with distantly derived clasts and a more uniform thickness, found in the western and southern Karoo Basin. In the southern Karoo Basin, four deglaciation sequences are identified (DS1–DS4) each consisting of a basal zone of massive diamictite (“c” unit) that, in the younger sequences, is capped by a stratified terminal zone (“f” unit) (Fig. 2) (Theron and Blignault, 1975). The youngest of the Dwyka Group units (DS 4c and f) consist of clast-poor diamictite with subordinate mudstone that is interpreted to be dense proximal rain-out deposits from melting icebergs,