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Where is my sink? Reconstruction of landscape development in southwestern Africa since the Late Jurassic

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ABSTRACT

Quantifying the rates and timing of landscape denudation provides a means to constrain sediment flux through time to offshore sedimentary basins. The Late Mesozoic evolution of drainage basins in southern Africa is poorly constrained despite the presence of several onshore and offshore sedimentary basins. A novel approach has been developed to calculate the volume of material eroded since the Late Jurassic at different time steps by constructing structural cross-sections and extrapolating thicknesses of eroded material. Using different assumptions, the calculated volumes of material eroded from southwestern Africa range from 2.52×10^6 km^3 (11.3 km of vertical thickness removed) to 8.87×10^5 km^3 (4.0 km of vertical thickness removed). For the southward draining systems alone, the calculated removal of 7.81×10^5–2.60×10^5 km^3 of material is far greater than the volumes of sediment recorded in offshore sedimentary basins (268 500 km^3). Reconstruction of the drainage systems using geomorphic indicators and clast provenance of the Uitenhage Group, as well as extrapolated surface exposure ages, indicate the southern draining systems were active from the Late Jurassic with coeval activity in axial and transverse drainage systems. The calculated volumes are tied to published apatite fission track (AFT) dates to constrain the changes in exhumation rate through time (using multiple scenarios), which indicate a significant amount of Early Cretaceous exhumation (up to 1.26×10^6 km^3, equivalent to 5.70 km of vertical thickness). For the first time, this has permitted long-term landscape evolution to be used to support the interpretation that some of the ‘missing’ sediment was deposited in sedimentary basins on the Falkland Plateau as it moved past southern Africa during the Early Cretaceous. This implies that in this instance, the sinks are separated from their source areas by ~6000 km.

1. Introduction

Reconstructing onshore routeing patterns and landscape development is an important stage in the analysis of ancient source-to-sink configurations (e.g., Clift et al., 2006; Romans et al., 2009; Covault et al., 2011; Macgregor, 2012; Sømme and Jackson, 2013; Helland-Hansen et al., 2016). This relationship can be challenging to constrain and quantify when assessing configurations in deep-time (i.e., Cretaceous and older) and close to active plate boundaries (Romans et al., 2009; Romans and Graham, 2013). Quantitative dating techniques such as *in situ* cosmogenic dating (e.g., Gosse and Phillips, 2001; von Blanckenburg and Willenbring, 2014), apatite fission track (AFT) (e.g., Gleadow et al., 1983, 1986; Gallagher et al., 1998), and (U-Th)/He thermochronology (Flowers and Schoene, 2010; Stanley et al., 2013) can place constraints on the timing and rate of erosion and exhumation. These approaches provide a means to understand onshore drainage basin configurations through time more accurately (e.g., Bierman, 1994; Gallagher and Brown, 1999; Cockburn et al., 2000) and when combined with remote sensing techniques, can aid offshore analysis by linking catchments areas to drainage evolution (McCauley et al., 1986; McHugh et al., 1988; Ramasamy et al., 1991; Blumberg et al., 2004; Gupta et al., 2004; Griffin, 2006; Youssef, 2009; Abdelkareem and El-Baz, 2015; Breeze et al., 2015).

South Africa is a passive margin (e.g., King, 1944; Fleming et al., 1999; Kounov et al., 2009), and comprises an interior plateau of low relief and high elevation, separated by the Great Escarpment from the coastal region of high relief and low average elevation. Large-scale river systems dominate the area to the north of the Great Escarpment such as the Orange River. Three large catchments control the area to the south of the escarpment: the Olifants, Breede and Gouritz catchments. The Great Escarpment forms the main drainage divide between the southward and westward draining systems.

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Offshore southern South Africa there are several sedimentary basins (including the Bredasdorp, Pletmos (Infantaya Embayment), Gamtoos and Algoa basins) (McMillan et al., 1997). Despite the presence of these sedimentary basins, the onshore drainage development of river catchments south of the Great Escarpment has been under investigated (Rogers, 1903; Partridge and Maud, 1987). Landscape evolution research of South Africa has often focussed on the development and retreat of the Great Escarpment (e.g., King, 1953; Partridge and Maud, 1987; Fleming et al., 1999; Brown et al., 2002; Moore and Blenkinsop, 2006) and large-scale drainage systems such as the Orange River (e.g., Dingle and Hendry, 1984; Rust and Summerfield, 1990; de Wit et al., 2000).

During the Cretaceous, there was large-scale exhumation of southern South Africa, recorded by AFT data (Brown et al., 1990; Tinker et al., 2008a). At the same time, large rift basins developed onshore and offshore during the fragmentation of Gondwana and opening of the southern Atlantic Ocean (Macdonald et al., 2003). Tinker et al. (2008a) reported 6.0–7.5 km of exhumation using AFT data, if the whole Karoo Supergroup succession was present, and identified two pulses of exhumation in the Early- and Mid-Late-Cretaceous, respectively. The Uitenhage Group represents the only onshore depositional representation of the Jurassic-Cretaceous exhumation event (Shone, 2006), although the age is contentious due to poor chronostratigraphic control, as discussed below. Previously, however, drainage reconstructions have not fully integrated information on the geomorphic evolution of the region or sedimentology of the Uitenhage Group to constrain the timing, routeing, and volume of sediment flux from onshore drainage basins to offshore sedimentary basins.

This study aims to reconstruct the drainage history of two large drainage basins (the Gouritz and Breede catchments) in the Western Cape in order to: (1) calculate the maximum volume of material removed and compare relative timings with published AFT data; (2) compare the volume of material removed to the overall offshore sediment volumes during the Mesozoic; (3) examine the geomorphic indicators of river evolution and reconstruct the drainage evolution using geomorphological and sedimentological evidence, and (4) discuss where the 'missing' sediment was deposited during Mesozoic exhumation of southern South Africa.

2. Regional setting

2.1. Study area

The study area encompasses four onshore Mesozoic extensional basins in the Western Cape: the Oudtshoorn (study site - Kruisrivier Valley and N12), De Rust (study site - R341), Worcester (study site – Rooikrans) and Nuy (study site – Nuy Road) basins (Fig. 1). The onshore sedimentary basins are within two large discordant catchments in the Western Cape Province: the Gouritz (Richardson et al., 2016) and the Breede (Fig. 1), which have been developing since the Mesozoic break-up of Gondwana (Moore and Blenkinsop, 2002; Goudie, 2005; Hattingh, 2008).

The Mesozoic sedimentary basins have been deeply exhumed and dissected (Fig. 1; Green et al., 2016). The Oudtshoorn Basin is bounded by the Kango fault and is the largest onshore Mesozoic basin with a length of 80 km across the *E*-W strike and a width up to 21 km (Fig. 1). The Kango fault also bounds the De Rust Basin, which is 37 km in length (E-W strike) and has a maximum width of 8 km. The Worcester and Nuy basins are bounded by the Worcester fault. The Worcester Basin is highly dissected and is approximately 27 km in length and 3 km in width; the Nuy Basin is 15 km in length and 7 km in width. Hereafter, the Worcester and Nuy basins are referred to as the Worcester Basin.

2.2. Geology

The Cape and Karoo supergroups are extensively exposed in southern South Africa, with minor Pre-Cambrian metasediments (the Malmesbury, Kaaimans and Gamtoos groups) and granites (the Cape Granite suite) (Fig. 2). The Cape Supergroup is a siliciclastic succession composed of the Table Mountain, Bokkeveld and Witteberg groups (Broquet, 1992). The quartzitic Table Mountain Group represents

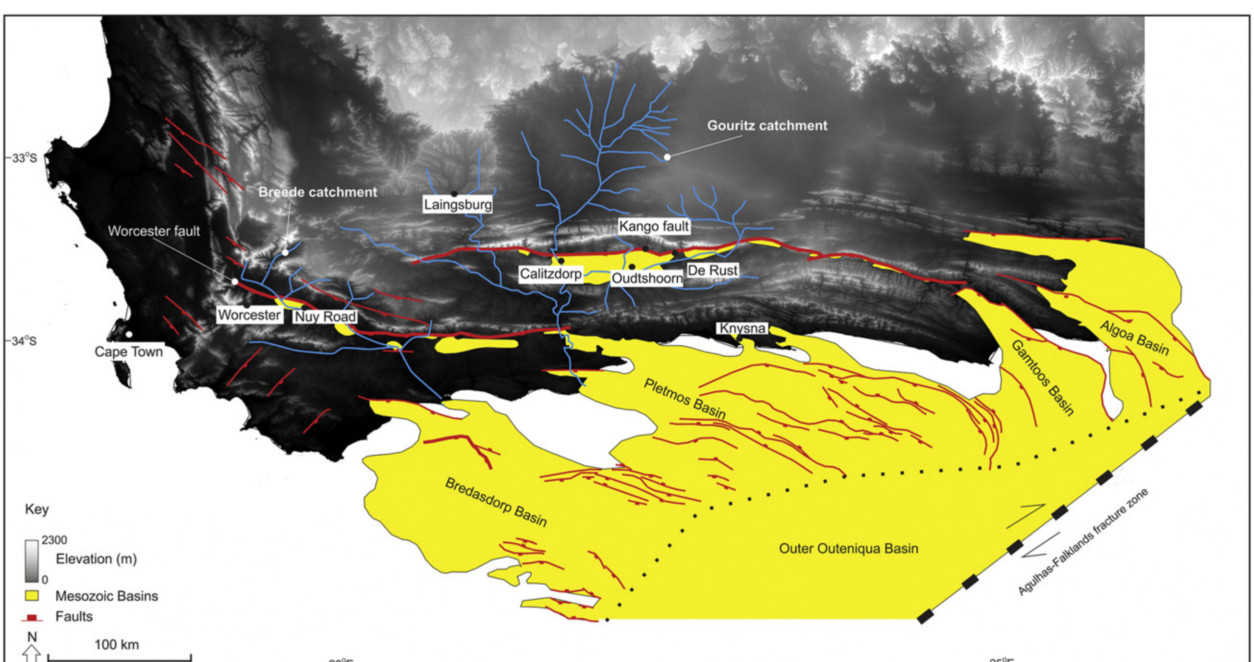

Fig. 1. Location map of study sites and Mesozoic basins of southern South Africa, adapted from McMillan et al. (1997). The current day planforms of the Breede and Gouritz catchments are shown.