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Sediment supply to the Orange sedimentary system over the last 150 My: An evaluation from sedimentation/denudation balance

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ABSTRACT

The South African plateau is bordered by passive margin basins preserving the terrigeneous sediment produced during onshore erosion. As such, these basins potentially provide a record of the variation in onshore elevation and relief over time. Here we bring new constraints on the uplift and erosion of the Southern African plateau over the last 150 Ma from the perspective of the stratigraphic architecture of these basins. We review published data to quantify the terrigeneous supply eroded in the drainage area and preserved in the basins. The novel aspect of our approach is the integration of the evolution of the whole domain in sedimentation (i.e. not only the platform) as well as the onshore eroding region.

Along the South African and Namibian Atlantic margins, we determined the long-term signal of sedimentary supply (at the 10 Ma scale) from 3D mass balance calculations comparing sedimentary volumes deduced from offshore isopach maps (with a particular attention to associated uncertainties) on one hand and denudation volumes deduced from thermochronology data on the other.

We show that, in this case, the volumes of denudation and of sediments preserved in the basin are consistent both in total and incremental amount. The latter is therefore a reliable estimation of the denudation in the associated continental domain, subject to certain assumptions such as the drainage area over time. The long-term signal of sedimentary supply of the South African and Namibian Atlantic margins shows that the major part of the denudation occurred during the post-rift Lower Cretaceous and the Upper Cretaceous and subsequently decreased. This is not the expected behavior for the simple relaxation of topography acquired during rifting that would show a progressive decrease of the sediment supply over time. This suggests a significant rejuvenation of relief during the Upper Cretaceous, 50 Ma after the rifting event. If erosion is directly linked to elevation or relief variation, this implies 2 generations, the first before break-up (i.e. before 130 Ma; presumably during rifting) and the second during the Upper Cretaceous.

1. Introduction

The apparently anomalous topography above 900 m of southern Africa has attracted a lot of attention in the past decades. The wavelength of this « African Superswell » (×1000 km) described by Nyblade and Robinson (1994) suggests a deep origin, potentially related to a mantle anomaly that has been characterized by seismic tomography below the current position of Southern Africa (e.g. Ritsema et al., 1999; Ni et al., 1999; Nyblade et al., 2000; Ritsema and Van Heijst, 2000; Ni et al., 2002). Various processes have been invoked to explain this topography: thermal effects of a mantle plume (e.g. Nyblade and Sleep, 2003), dynamic topography resulting from vertical motions induced by mantle convection (e.g. Lithgow-Bertelloni and Silver, 1998; Gurnis et al., 2000; Conrad and Gurnis, 2003; Behn et al., 2004), inheritance of an earlier Gondwana topography (Doucoure and De Wit, 2003), isostatic rebound following a slab detachment (Pysklwec and Mitrovica, 1999), magmatic underplating (Cox, 1989) or retreat of a scarp inherited from the rifting of a plateau (e.g. Gilchrist et al., 1994; Van Der Beek et al., 2002). Potential discrimination of these models essentially relies on the wavelength, the amplitude, the timing and the kinematics of the processes invoked (e.g. Nyblade and Sleep, 2003; Walford and White, 2005).

The age of formation and kinematics of the anomalous topography in southern Africa are, however, debated. Several time ranges have been proposed for the age of the plateau: prior to Gondwana

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dispersion (e.g. Gilchrist et al., 1994; Van Der Beek et al., 2002; Pysklwec and Mitrovica, 1999; Doucoure and De Wit, 2003), Upper Cretaceous (≅80 Ma; e.g. Nyblade and Sleep, 2003; Smith, 1982), Oligocene (≅30 Ma; e.g. Burke, 1996), Plio-Pleistocene (since 3 Ma; e.g. Partridge and Maud, 1987), or progressively throughout the Cenozoic (e.g. Gurnis et al., 2000). Among the most useful constraints currently available are thermochronologic data gathered in that area to determine the denudation history (Gallagher and Brown, 1999a, b; Brown et al., 2000; Raab et al., 2002, 2005; Kohn et al., 2005; Tinker et al., 2008a). Along the Namibian and South African margins, theses authors show significant denudation since the Southern Atlantic rifting around 150 Ma (about 5 km in total), this denudation not being limited to the rims of the plateau and showing an acceleration culminating during the Upper Cretaceous (about 80 Ma).

The products of erosion are preserved (often to an unknown extent) in the offshore passive margin basins. These may then provide a record of the variation in elevation and relief over time. The history of the terrigeneous supply and denudation has typically been analyzed quite independently, mostly because, over geological timescales, the interpretation of sediment supply in terms of relief variations in the drainage area is far from straightforward. In that context, a good understanding of sediment flux transfer from the drainage area to the sedimentary basin, at geological time scales (×10 Ma), is critical (e.g. Poag and Sevon, 1989; Rust and Summerfield, 1990; Pazzaglia and Gardner, 1994; Pazzaglia and Brandon, 1996; Jones et al., 2002; Walford and White, 2005).

Our objective in this contribution is to bring new constraints on the uplift and erosion of the Southern African plateau over the last 150 Ma from the perspective of the stratigraphic architecture of its passive margin basins. The novel aspect of our approach is that we aim to integrate the evolution of both the domains in erosion and in sedimentation (Fig. 1), and to review published data to quantify the terrigeneous supply eroded in the drainage area and preserved in the basins. We determine the long-term signal of sedimentary supply (at the 10 Ma scale) along the South African and Namibian Atlantic margins (Orange and Walvis basins) paying particular attention to the uncertainties associated with these 3D mass balance calculations. One objective is to evaluate the conditions under which this simple approach, based on already published data, can be used to infer long-term continental relief variations (the sedimentary archives of the domain in erosion being by definition scarce) and denudation evaluation by thermochronology, which often rely on assumptions concerning palaeo heat flow or temperature gradients.

We present the database developed for the 3D geometry of the Orange sedimentary system, the quantification of the solid volumes of terrigeneous sediments preserved in the basins and the volume of material eroded on the continent determined from cooling histories inferred from thermochronology (Gallagher and Brown, 1999a, b). We then discuss mass balance over the sedimentary system and the implications for the long-term evolution of topography.

2. Geological setting

2.1. The Orange sedimentary system

In order to assess the record of long-term terrigeneous supply preserved in sedimentary basins in terms of relief variation on the continent, we need to identify (1) a sedimentary system from the drainage divide down to the most distal deposits on the oceanic crust (Fig. 1), (2) a domain in sedimentation which covers an area large enough to incorporate redistribution of sediment across and parallel to the margin and (3) a domain in erosion which has been geographically stable over the Meso-Cenozoic (e.g. no major capture).

Given this, the Orange sedimentary system represents an appropriate case study. The studied area includes the basins of the Namibian/South African passive margin located between the Walvis Ridge and the Falkland-Aghulas fracture zone (i.e. the Walvis, Luderitz and Orange basins) and the drainage basins located on the Southern African plateau and its western rim, the larger being the Orange river catchment (Fig. 2).

2.2. Domain in sedimentation: syn-rift and post-rift evolution

The South-West Africa margin basins are filled by a thick sedimentary wedge showing 2 main depocentres (Walvis and Orange basins), locally reaching 8 km in thickness and thinning out seaward over 800–1000 km (Fig. 2).

The onset of the rift that led to the formation of this margin as well as the exact geometry and extent of the syn-rift sequence a not fully constrained. It is generally acknowledged that the rifting propagated northward from the Falklan-Aghulas fracture zone to the Walvis Ridge during the Upper Jurassic (i.e. between 144 and 160 Ma; see review in Jackson et al., 2000). However, in the north of the studied area, along the Namibian margin, rift structures predating the Late Jurassic–Early Cretaceous Atlantic rift have been described (most likely of Karoo age, i.e. Permo-Triassic; Light et al., 1993; Clemson et al., 1997, 1999; Aizawa et al., 2000; Corner et al., 2002). Rift basins are filled by siliciclastic, continental fluvial and deltaic series (Van Der Spuy, 2003). However, evidence from seaward-dipping reflectors (SDRs: subaerial volcanic flow emplaced during rifting) indicates that these syn-rift geometries, along both Namibian and South African margins, might include significant, but unknown, amounts of volcanics (e.g. Gladczenko et al., 1998; Bauer et al., 2000; Jackson et al., 2000; Mohriak et al., 2002; Van Der Spuy, 2003).

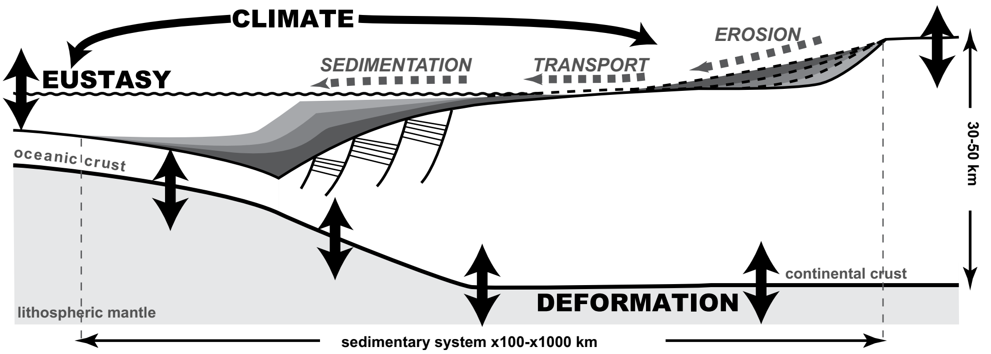

Fig. 1. Sketch of a margin sedimentary system defined from the drainage divide down to the distal most deposits onto the oceanic crust, that is to say including both the areas in erosion and in sedimentation. Parameters influencing the transfer of sediments from on domain to the other are shown: climate (including eustasy) and deformation.