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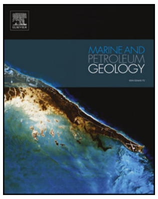

Research paper

Post-rift stratigraphic evolution of the Atlantic margin of Namibia and South Africa: Implications for the vertical movements of the margin and the uplift history of the South African Plateau

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ABSTRACT

The aim of this study is to constrain the post-rift deformations of the Atlantic passive margin of Namibia and South Africa using an extensive industrial 2D reflection seismic dataset calibrated by wells and onshore outcrops that have been revaluated in age (biostratigraphy) in order to discuss the evolution of the South African Plateau uplift. The first-order evolution of the margin is tectonically driven and can be divided into three principal phases. The first (131–93.5 Ma) comprises an overall retrogradational trend that results from a rate of accommodation, created by the thermal flexure of the margin, that is higher than the sediment supply. The second (93.5–66 Ma) comprises an overall aggradational-progradational trend that results from a relative increase in sediment supply due to an uplift and subsequent erosion of the margin and the inland domain. The third (66–0 Ma) is retrogradational again in response to a decrease in sediment supply induced by a relative stability of the margin and climate conditions. This study demonstrates that the present-day configuration of the margin is acquired during the Late Cretaceous (from 81 to 66 Ma) with a strike, long-wavelength and seaward tilt of the margin which could be related to the growth of the onshore main escarpment. We also characterize a regional Oligocene unconformity marked by a significant downward shift of the shoreline which suggests a moderate uplift of the inland domain and could be associated with a reactivation of the relic late Cretaceous relief.

1. Introduction

The emerged relief of the Earth is composed of three main types of forms, besides large volcanoes: (1) mountain belts and associated orogenic plateaus, (2) rift shoulders and (3) anorogenic plateaus and plains. This latter type, plateaus and plains, is the specific relief for most of the interior of the continents (e.g. southern Africa, southeastern continental margin of Australia, Brazil, eastern parts of both South and North America, northern part of Eurasia and southern India). The kinematic and causes of the topograhic growth of these reliefs are poorly understood.

The South African Plateau is characterized by an average elevation of ~1000 m for a size of several hundreds of kilometres, which is often regarded as the expression of the surface upwelling caused by flow in the underlying mantle associated with the African superplume, a low-seismic velocity anomaly in the lower mantle (e.g. Nyblade and Robinson, 1994).

However the timing, spatial pattern and causes of this uplift are highly debated. Many authors suggest a Mesozoic origin based on thermochronologic data interpretations (e.g. Brown et al., 2002; Van der Beek et al., 2002; Kounov et al., 2009; Stanley et al., 2015; Wildman et al., 2017) and sedimentary flux estimates (e.g. Guillocheau et al., 2012; Tinker et al., 2008; Braun et al., 2014). Others interpret it as a Cenozoic feature, < 30 Ma, based mostly on planation surface correlations across the plateau (e.g. Partridge and Maud, 1987; Burke and Gunnell, 2008).

Here, we focus on the continental margin of Namibia and South Africa. The objective is to constrain the uplift history of the South African Plateau based on an analysis of the stratigraphic record of the adjacent divergent passive Atlantic margin, from Walvis Ridge to the north to the Cape Peninsula to the south. This study is based on a sequence stratigraphic analysis using industrial 2D reflection seismic data

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and offshore industrial wells.

At the scale of the margin, we provide a second-order stratigraphic framework (seismic units covering > 10 Myr) revaluated in age and regional thickness maps. The purpose is to characterize the post-rift deformations of the margin, the evidence for alterations in the drainage patterns of the continent and to discuss their implications for the Cretaceous and Cenozoic uplifts of the South African Plateau.

2. Geological setting

2.1. The continental margin of Namibia and South Africa

2.1.1. Structural setting

The continental margin of southern Africa is a classic example of an extensive volcanic passive margin (e.g. Gladczenko et al., 1997, 1998; Bauer et al., 2000; Corner et al., 2002; Maystrenko et al., 2013) characterized by a thick (> 3 km) sequence of seaward-dipping reflectors (SDRs) that results from subaerial basaltic flows at time of the breakup of the continent. The basement of the inner margin is Neoproterozoic to Early Cambrian in age and structured at the time of the Pan-African Orogeny (see Frimmel et al., 2011 for a review). The subsidence distribution is controlled by the different segments of this orogenic belt (Clemson et al., 1997; Corner et al., 2002), from north to south: (1) the Kaoko Belt, (2) the Damara Belt, oblique-to-coast, (3) the Gariep Belt and (4) the Saldanha Belt (Fig. 1B). The onset of rifting is poorly constrained. By analogy with the Outeniqua Basin (e.g. Dingle et al., 1983) it is likely that rifting starts during the Middle-Late Jurassic (~ 160 Ma). Several half-grabens and grabens are distributed along the inner margin partly overlain by the SDRs located seaward (Clemson et al., 1997). The ages of these rifts are debated, some of them might be Triassic at the time of the Karoo extension (Clemson et al., 1999). The SDRs are time equivalent to the Parana-Etendeka Large Igneous Province (138–128 Ma) (Koopmann et al., 2016, 2014; Marsh et al., 2001). It is generally acknowledged that the magnetic anomaly M3 (~ 130 Ma - Gradstein et al., 2012) marks the onset of the conventional seafloor spreading that led to the South Atlantic Ocean (Collier et al., 2017). Chron M9 (~ 133 Ma - Gradstein et al., 2012) has been suggested as the oldest determinable magnetic anomaly in the southern portion of the Orange Basin (e.g. Koopmann et al., 2014). The South Atlantic opened from south to north in a zipper-like succession.

2.1.2. Post-rift basin infilling

2.1.2.1. Offshore domain. The post-rift infilling consists of thick siliciclastic sedimentary wedges (4–7 km) (Aizawa et al., 2000) distributed along three main basins: Orange, Lüderitz and Walvis (Fig. 1A). The post-rift infilling has been extensively studied in South Africa and Namibia (e.g. Emery et al., 1975; Dingle et al., 1983; Light et al., 1993; Brown et al., 1995; Aizawa et al., 2000; Holtar and Forsberg, 2000; Paton et al., 2008). Using seismic stratigraphic concepts, Brown et al. (1995) recognized 33 third-order sequences for the Cretaceous post-rift history of the Orange Basin. More recently, Paton et al. (2008) defined four megasequences: one syn-rift, one transitional (Late Hauterivian-Aptian) and two during the drift period (Aptian-uppermost Cretaceous and Cenozoic). Several authors (e.g. Aizawa et al., 2000; Paton et al., 2008; Kuhlmann et al., 2010; Hartwig et al., 2012) have recognized a major seaward tilting of the Orange Basin during the Late Campanian coeval with large slumping and gravity collapse structures (see de Vera et al., 2010; Dalton et al., 2016 for a review).

2.1.2.2. Onshore domain. The onshore outcropping sediments are mainly Cenozoic in age with the notable exception of the marine Turonian sediments of Wanderfeld IV (Sperrgebiet, south Namibia). Cenozoic sediments extend from the south (Saldanha Peninsula, Cape) to the north (Skeleton Coast, northern Namibia). The most extensive succession is located in southern Namibia (Sperrgebiet area, Pickford, 2015) with the following succession: (1) weatherings of the basement (laterite), (2) silcretes (Pomona Fm) and lacustrine carbonates (Ystervak Fm of Lutetian to Bartonian age), (3) Priabonian (Siesser and Miles, 1979) marine deposits (Langental/Buntfeldschuh Fm), (4) fluvial incisions filled by (5) Early Miocene (Elisabeth Bay Fm) and Late Miocene (Gembokstal Fm) continental deposits and (6) aeolian deposits of the Namib desert (Late Miocene to Pleistocene).

The downstream part of the Orange Valley is filled by alluvial terraces dated (Pickford and Senut, 2003) at 18–19 Ma (uppermost Early Miocene), 6 Ma (uppermost Late Miocene) and 2–3 Ma (Pliocene-Pleistocene transition). Along the Atlantic Coast of South Africa (Pether, 1986; Roberts et al., 2011), the coastal plain is filled by (1) alluvial deposits of Middle to Late Miocene age, (2) a marine flooding of Late Miocene age and (3) Pliocene coastal plain sediments.

2.2. South African Plateau: physiography and uplift history

The onshore relief of the margin (Fig. 1A) is organized in three domains: (1) a low relief and high average elevation interior plateau bounded by (2) a prominent Main (or Great) Escarpment, separating, on the seaward side, (3) a dissected coastal region in which some marine sediments are preserved (see above). The drainage pattern reflects this geomorphological contrast between the interior and exterior domains. The Orange River flows westward into the Atlantic Ocean, draining a large portion of the plateau interior, whereas the coastal region is characterized by small catchments, bounded by the Main Escarpment, with short parallel rivers oriented perpendicular to the coastline.

Permian marine sediments preserved on the top of the plateau indicate that it was at sea level at 290–270 Ma (Catuneanu et al., 2005). It has likely been terrestrial since that time but the timing and mechanisms of its topographic development are still debated. It is classically regarded as the expression of the surface upwelling caused by flow in the underlying mantle associated with the African Superplume (Gurnis et al., 2000; Nyblade and Robinson, 1994; Nyblade and Sleep, 2003).

2.2.1. Uplift: thermochronometry approach

Low temperature thermochronometry studies (Apatite Fission Track (AFT) and (U- Th)/He on apatite) performed along the western coastal domain of southern Africa (Gallagher and Brown, 1999a, b; Raab et al., 2002, 2005; Kounov et al., 2009; Brown et al., 2014; Wildman et al., 2015, 2016) and in the plateau interior (Stanley et al., 2013, 2015; Wildman et al., 2017) were in agreement for two punctuated episodes of exhumation during the Early Cretaceous (~ 140–120 Ma) and the Late Cretaceous (~ 100–70 Ma). These two denudation pulses had been linked offshore with an increase in sedimentary flux along the margin (Guillocheau et al., 2012; Rouby et al., 2009).

2.2.2. Uplift: geomorphological approach

The South African Plateau is characterized by stepped planation surfaces. Following Du Toit (1933) and his famous “Crustal movement as a factor in the geographical evolution of South Africa”, L.C. King tried to use these planation surfaces as a record of uplift, although these surfaces have not been dated directly. King developed a polycyclic model for the growth of the South African Plateau (e.g. King, 1948, 1949, 1982) defining three main stepped pediplains, from the highest to the lowest, (1) the Gondwana Surface considered to be of Jurassic age, (2) the African Surface of Late Cretaceous to Eocene age and (3) the Post-African Surface of late Cenozoic age. Each pediplain is supposed to be related to pulses of tectonic uplift.

Partridge and Maud (1987) modified King's original model and recognized three major planation surfaces: (1) the African Surface of Early Cretaceous to Miocene age, (2) the post-African I Surface initiated during the Miocene and (3) the post-African II Surface initiated during the Pliocene. The African Surface is interpreted as a remnant relief initiated during the continental breakup of Gondwana and is supposed to be uplifted during Early Miocene and Late Pliocene tectonic pulses.