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# The African Plate: A history of oceanic crust accretion and subduction since the Jurassic

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ABSTRACT

We present a model for the Jurassic to Present evolution of plate boundaries and oceanic crust of the African plate based on updated interpretation of magnetic, gravity and other geological and geophysical data sets. Location of continent ocean boundaries and age and geometry of old oceanic crust (Jurassic and Cretaceous) are updated in the light of new data and models of passive margin formation. A new set of oceanic palaeo-age grid models constitutes the basis for estimating the dynamics of oceanic crust through time and can be used as input for quantifying the plate boundary forces that contributed to the African plate palaeo-stresses and may have influenced the evolution of intracontinental sedimentary basins. As a case study, we compute a simple model of palaeo-stress for the Late Cretaceous time in order to assess how ridge push, slab pull and horizontal mantle drag might have influenced the continental African plate. We note that the changes in length of various plate boundaries (especially trenches) do not correlate well with absolute plate motion, but variations in the mean oceanic crust age seem to be reflected in acceleration or deceleration of the mean absolute plate velocity.

## 1. Introduction

The African plate is at the present the third largest tectonic plate (~60 million km$^2$) with approximately half of it covered by land. This plate comprises several old cratonic units and accreted younger crust, representing a period of more than 2.5 billion years of continental and oceanic crust growth (e.g. Burke, 1996). Initially part of Gondwana since 550 million years (Ma) and Pangea since 320 Ma, and now surrounded almost entirely by spreading centers, the African plate moved relatively slowly for the last 150 Ma (Lithgow-Bertelloni and Richards, 1998; Torsvik et al., 2010). However, its continental interior experienced many changes throughout this time including rifting and variations in sedimentary basin subsidence, most of them in regions situated thousands of kilometers away from plate boundaries. The African plate was also partly underlain by mantle with above the average temperature—either induced by a series of hotspots or a superswell, or both—that contributed to episodic volcanism (including several Large Igneous Provinces—LIPS), basin-swell topography, and consequent sediment deposition, erosion, and structural deformation (e.g., Bumby and Guiraud, 2005).

Long-term intra-continental crustal deformation may be the related to local and regional tectonic events (e.g., Cloetingh and Burov, 2011; Zoback et al., 1993) and mantle–lithosphere interaction (e.g. Heine et al., 2008). Far-field stresses related to changes in plate boundaries are able to propagate within the lithospheric plates over thousands of kilometers and therefore may trigger rifting, folding and changes in sedimentary basin subsidence rate in remote regions (e.g. Xie and Heller, 2009). The relationship between plate boundary forces and observed deformation within plate interiors has been studied for several large tectonic plates and numerous authors attempted modelling and quantification of ensuing present day and palaeo-stresses resulted from this connection: North America (e.g., Faure et al., 1996), South America (e.g., Meijer and Wortel, 1992), Africa (Meijer and Wortel, 1999), Eurasia (e.g., Nielsen et al., 2007; Warners-Ruckstuhl et al., 2012), Australia (e.g., Coblentz et al., 1995; Dyksterhuis and Muller, 2004), and Pacific (e.g., Faccenna et al., 2012; Wortel et al., 1991).

A systematic study of plate boundaries for the African plate since the opening of surrounding oceanic basins is lacking. This is mainly because geophysical data were insufficient and various models proposed for different oceanic basin formation were not properly linked. The publication of regional and global geophysical datasets in the last couple of years, including magnetic and gravity data acquired by satellites (e.g., Maus et al., 2007; Sandwell and Smith, 2009), prompted us to systematically

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reconstruct the ages and extent of oceanic crust around Africa for the past 200 Ma. Location of continent ocean boundary (COB) and old oceanic crust (Jurassic and Cretaceous) are updated in the light of new data and models of passive margin formation. Data, methods and a short review of available recent studies used to construct a model for the oceanic crust of the African plate are presented in Section 2. The model is presented in detail for selected times in Section 3.

This study aims to take a step further in understanding the causal link between the evolution of one of the largest tectonic plates, the African plate (Fig. 1), and its continental interior at times when important tectonic changes have been recorded. In Section 4, a new model for the evolution of the African plate boundaries from the Jurassic to Present is used to assess whether changes in plate geometry and plate boundaries correlate with deformation in the continental interior. Finally, as a case study, we show how ridge push, slab pull and horizontal mantle drag might have influenced the interior of the African plate in the Late Cretaceous by computing a simple model of palaeo-stresses.

As more detailed observations and measurements point to far-field stresses playing an important role in sedimentary basin evolution (e.g. Abadi et al., 2008; Bosworth et al., 2008) this study can contribute not only to a better understanding of the long-term tectonic history of Africa, but also can be used as an exploration tool for the hydrocarbon industry.

## 2. Plate boundaries within and around the African continent

### 2.1. Continent–ocean boundaries

Mapping the transition between the continental and oceanic crust (Continent–Ocean Boundary (COB) or Continent–Ocean Transition Zone (COTZ/OCTZ) proves to be a difficult task taking into account the structural complexities of some of the continental margins as highlighted in numerous recent studies (see Table 1 for an overview of the African continental margin studies). Particularly for the so-called non-volcanic margins, where the presence of exhumed (and serpentinized) continental mantle and isolated blocks of extended continental crust exist for at least tens of kilometers (e.g., Manatschal, 2004), a clear boundary between extended continental crust and oceanic crust is almost impossible to identify. In those cases, the COB is rather defined as the (oceanward) boundary that marks the onset of true oceanic crust. An integrated set of geophysical data is usually necessary for defining these boundaries, because unequivocal evidences resulted from drilling are rarely available. Seismic reflection and refraction data, heatflow and potential field data (for a review see e.g., Geoffroy, 2005; Minshull, 2009), as well as plate reconstructions are usually employed to define and test COBs and COTZs.

The passive margin community is currently in the process of reviewing the strict terminology of *volcanic* and *non-volcanic* margin types, as the criteria so far applied are insufficient and possibly obsolete. For example, a considerable amount of volcanic material is now observed in detailed seismic studies of presumed *non-volcanic* margins, (e.g. Peron-Pinvidic et al., 2010), whereas hyperextension and subcontinental mantle exhumation can also occur in volcanic margins (e.g. Lundin and Doré, 2011). In the case of the so-called *volcanic margins*, the presence of seaward dipping reflectors (SDRs)—volcanic material deposited on rifted and newly formed margins—hinders imaging techniques to fully resolve the exact position of the transition between the broken extended continental crust and newly formed oceanic crust. Similar problems are encountered on highly extended passive margins where subsequent salt deposition may also obstruct imaging deeper structures. While being aware of these complexities, we will use the terminology that defines the two extreme end-members of passive margins when discussing various COB segments in this paper: the magma-dominated (or magma-rich) and magma-poor margins by

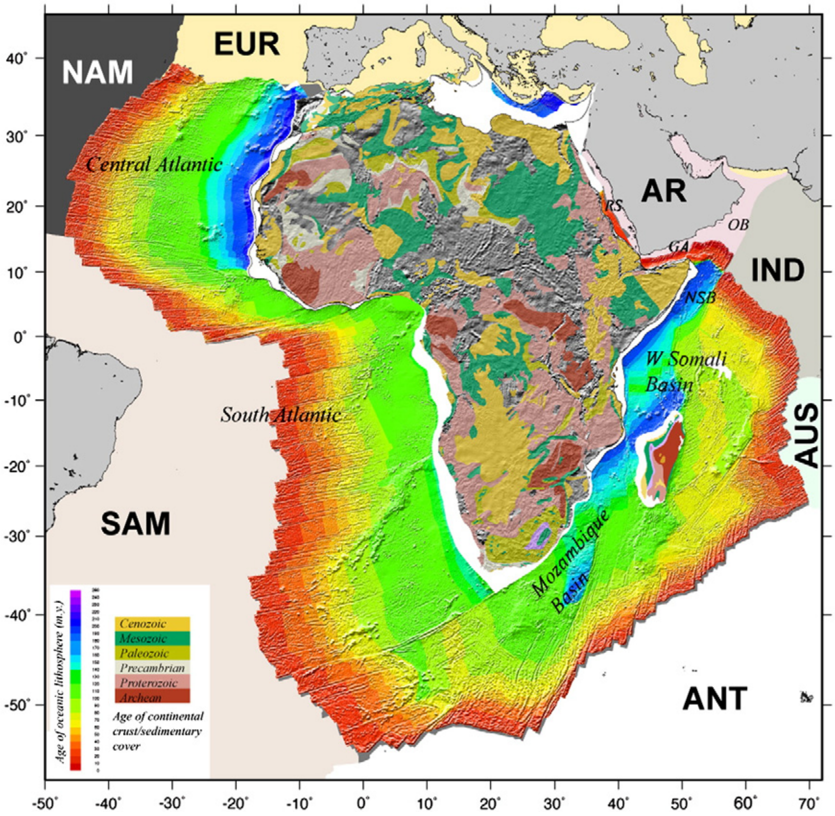

**Fig. 1.** Present day extent of the African plate. Age of oceanic crust (this study) and ages of continental basement and sedimentary cover (Persits et al., 2002) are draped on shaded relief of free air gravity anomaly (Sandwell and Smith, 2009). The white region surrounding present day coastlines is interpreted as extended continental crust and its oceanward limit is considered the continent–ocean boundary (COB). Neighboring tectonic plates are: Eurasia (EUR), Arabia (AR), India (IND), Australia (AUS), Antarctica (ANT), South America (SAM) and North America (NAM). Other abbreviations: GA—Gulf of Aden, NSB—North Somali Basin, RS—Red Sea, OB—Oman Basin.