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The role that plate tectonics, inferred stress changes and stratigraphic unconformities have on the evolution of the West and Central African Rift System and the Atlantic continental margins

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ABSTRACT

The Muglad rift basin of Sudan, is a good example of polyphase rifting, with at least three major phases of basin development. Each phase has resulted in the generation of source rock, reservoir and seal geology with structural traps often closely linked to basement highs. In this paper we investigate on a regional scale the tectonic processes that have contributed to rift basin development.

On a regional scale, the evolution of the Africa-wide Mesozoic rift system is intimately linked to relative movements of African sub-plates and to global plate tectonic processes and plate interactions. Changes in plate interactions are observed in the oceanic crust as azimuth changes of fracture zone geometries and by inference have caused significant modifications to both the orientation and magnitude of the motions of the African sub-plates. Such plate motion processes have controlled the polyphase development of the West and Central African Rift System. On the basinal scale, changes of sub-plate motions have resulted in changes in the stress field which have had a clear impact on the deformation and fault geometries of rift basins and on the resulting stratigraphy. The construction of the first unified stratigraphic chart for the West and Central African Rift System shows a close correlation in the timing of the major unconformities with the timing of changes in relative plate motion as observed in the changes of the azimuthal geometry of the oceanic fracture zones in the Central Atlantic. Since similarly timed unconformities exist along the continental margins of Africa and South America, we propose that the causative mechanism is change in relative plate motion which leads to an increase or decrease in the tension on the plate and thus controls the strength or effective elastic thickness, T_e, of the crust/plate beneath the margins. This results in a focused change in isostatic response of the margin during short-period changes in relative plate motion; i.e. more tension will mean that loads are not compensated locally resulting in local uplift of the margin.

1. Introduction

The Mesozoic plate tectonic link between the opening of the Atlantic Ocean and the development of the West and Central African Rift System (WCARS) via the Benue Trough and shear zones cutting Cameroon is not a new idea (Binks and Fairhead, 1992), nor is the polyphase development of the WCARS (Guiraud et al., 1992). What is new is the improved resolution and definition of the data sets used to establish the linkage. We now have for the Atlantic Ocean, the best available satellite derived free air gravity data set (Fairhead et al., 2009; Fig. 1) which has improved the spatial resolution down to ~6.5 km (half wavelength). The free air gravity data principally image the response of the bathymetry and near sub-seafloor structures, resulting from seafloor spreading processes at the mid-Atlantic ridge. Thus the enhanced resolution gravity data are able to improve our knowledge of the opening history of the Atlantic Ocean and to refine the associated plate reconstruction model. The message that comes repeatedly from the gravity field of the oceans is that the opening process at the mid-oceanic ridge clearly responds to changes in relative plate motions resulting from local and far field changes in plate interactions e.g. Africa–Europe and India–Asia plate collisions. This is recorded by both subtle and distinctive changes in the direction of the fracture zones (or flowlines) with an estimated response time of a few millions of years based on the smooth curvature of the fracture zones and the momentum changes that are needed to change the direction of motion of plates. The African plate has traditionally been considered as a rigid plate in plate reconstruction models. However, to explain the development and evolution of the Mezosoic rift systems in Africa there is a need to consider Africa as subject to intra-plate deformation by representing it as a set of three sub-plates — NW Africa, Nubia (NE Africa) and S Africa; the Somali Plate and the East African Rift System which divides it from

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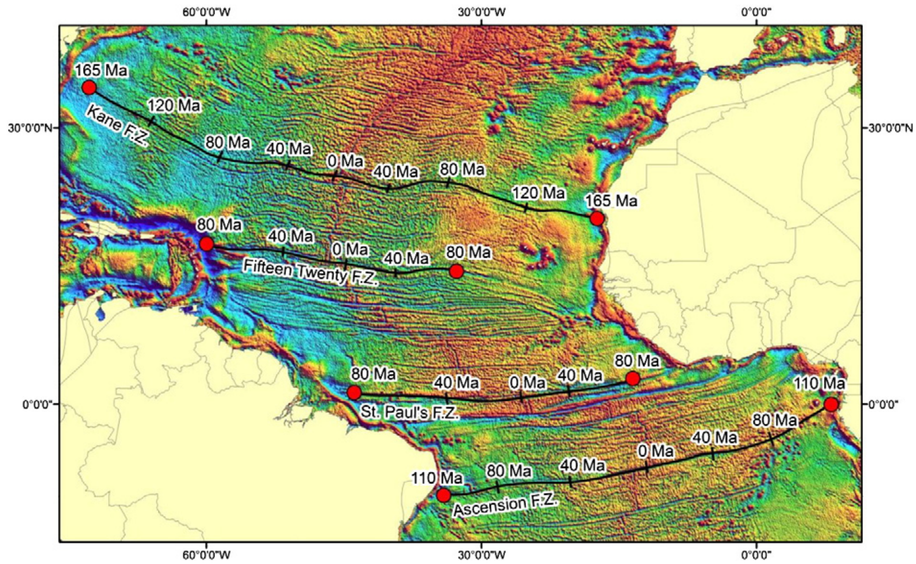

Fig. 1. Free air gravity map of the Central, Equatorial and northern part of the Southern Atlantic Ocean (Fairhead et al., 2009). The mid-Atlantic ridge (axis at 0 Ma) is clearly seen to be offset progressively by the fracture zones. Four named major fracture zones are identified and their curvature is seen to change as a function of distance away from the mid-oceanic ridge. The age of the oceanic crust is given in Ma along each of the four fracture zones.

the rest of Africa is more recent and inactive over most of the time period being considered here. Within our plate reconstruction model (Masterton et al., 2012), these sub-plates are allowed to move relative to each other. For this study, we consider the NW Africa and S Africa sub-plates as the most significant blocks — separated by the WCARS. We show that changes in plate motions, seen within the oceanic domain are replicated within the rift basins of the WCARS (sub-plate boundary between NW Africa and S Africa) in the form of changes in structural style (extension, shear and compression) such that extension in one basin can be associated with shear with little extension in another basin that is orientated perpendicular to it. Many of the basins show this change in tectonic style whereas the Muglad basin in Sudan shows only three major periods of extension. Using gravity studies we show that the fracture patterns of the basement within the rift has a distinct 'rhomb' geometry that is considered to have developed from repeated periods of trans-tension. We further show that the times of changes in plate motion correlate well with the timing of the stratigraphic unconformities found within the WCARS basins to indicate that there is both a cause and effect. We also show that the timing of plate motion changes correlate with the unconformities associated with the continental margin of the Atlantic. This suggests that changes in plate motion are the cause of these phenomena but their effect at sub-plate boundaries (rifts) is more tectonic than the response at continental margins, which are located within the heart of the sub-plate where vertical sedimentary loading has weakened the crust and made it more susceptible to converting horizontal plate stress changes into changes of flexural response. For the latter, it is proposed that during periods of change in plate motion the crustal/plate stress will change which will change the elastic strength of the crust beneath continental margins resulting in a change in the isostatic response of the margin.

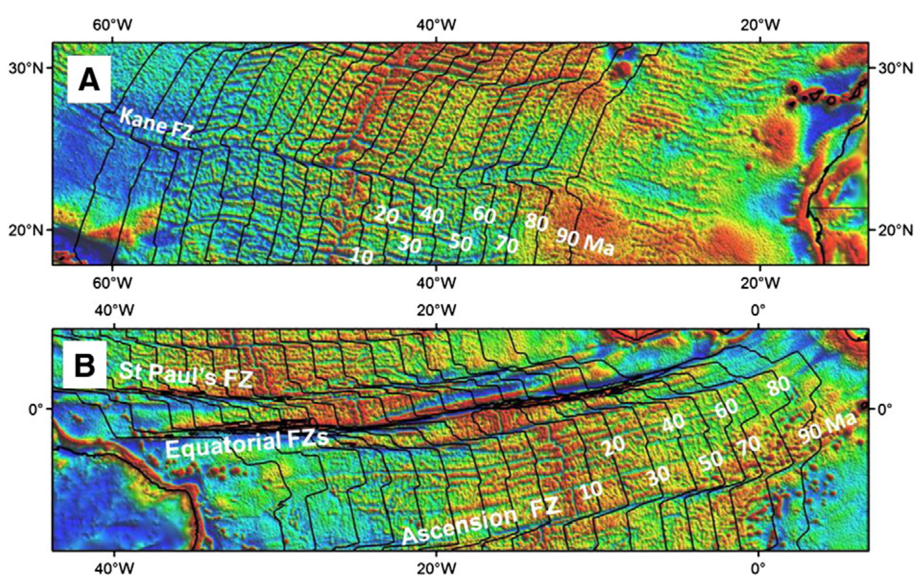

Fig. 2. Free air gravity map for A: the Central Atlantic and B: northern South Atlantic based on the satellite solution after Fairhead et al. (2009). The changes in curvature of the well-defined fracture zones indicate subtle changes in relative plate motions. Superimposed are the synthetic isochrons of Müller et al. (2008) at 10 Ma intervals with 0 Ma not shown. The tracking of the fracture zones by the offsets in the isochrons shows that the plate model closely follows the changes in fracture zone curvature.