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The Cretaceous opening of the South Atlantic Ocean

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ABSTRACT

The separation of South America from Africa during the Cretaceous is poorly understood due to the long period of stable polarity of the geomagnetic field, the Cretaceous Normal Superchron (CNS, lasted between ∼121 and 83.6 Myr ago). We present a new identification of magnetic anomalies located within the southern South Atlantic magnetic quiet zones that have arisen due to past variations in the strength of the dipolar geomagnetic field. Using these anomalies, together with fracture zone locations, we calculate the first set of magnetic anomalies-based finite rotation parameters for South America and Africa during that period. The kinematic solutions are generally consistent with fracture zone traces and magnetic anomalies outside the area used to construct them. The rotations indicate that seafloor spreading rates increased steadily throughout most of the Cretaceous and decreased sharply at around 80 Myr ago. A change in plate motion took place in the middle of the superchron, roughly 100 Myr ago, around the time of the final breakup (i.e., separation of continental–oceanic boundary in the Equatorial Atlantic). Prominent misfit between the calculated synthetic flowlines (older than Anomaly Q1) and the fracture zones straddling the African Plate in the central South Atlantic could only be explained by a combination of seafloor asymmetry and internal dextral motion (<100 km) within South America, west of the Rio Grande fracture zone. This process has lasted until ∼92 Myr ago after which both Africa and South America (south of the equator) behaved rigidly. The clearing of the continental–oceanic boundaries within the Equatorial Atlantic Gateway was probably completed by ∼95 Myr ago. The clearing was followed by a progressive widening and deepening of the passageway, leading to the emergence of north–south flow of intermediate and deep-water which might have triggered the global cooling of bottom water and the end for the Cretaceous greenhouse period.

1. Introduction

Seafloor spreading between South America and Africa began around Anomaly M13 (134 Myr ago, Channell et al., 1995) in the southernmost part of the South Atlantic Ocean and then propagated northward toward the Equatorial Atlantic Ocean. The initial breakup probably resulted from the inception of the Tristan hotspot that formed the Paraná–Etendeka large igneous province (Renne et al., 1992). Despite their geodynamic and paleooceanographic importance, the relative motions between the two plates during most of the breakup period are still poorly resolved due to the lack of reversal-related magnetic anomalies on crust of age 121 (Anomaly M0y) to 83.6 (Anomaly C34y) Myr old (Malinverno et al., 2012; Ogg, 2012). This crust, formed during the Cretaceous Normal Superchron (CNS), is termed the magnetic “quiet zone” and is the focus of the present study.

The available kinematic models for the opening of the South Atlantic during the CNS (Eagles, 2007; Heine et al., 2013; Jones et al., 1995; Moulin et al., 2010; Nürnberg and Müller, 1991) are based on interpolation between the rotation parameters of M0y and C34y, predicting an opening age of ∼110–104 Myr ago (clearing of continental–oceanic boundaries, COBs) for the Equatorial Atlantic Gateway, even though equatorial sedimentary facies and subsidence rates (Pletsch et al., 2001) and global compilation of benthic foraminifera stable isotopes (Friedrich et al., 2012) indicate that the establishment of deep-water circulation between the South and Central Atlantic Basins started roughly 10–15 Myr later. Recent studies have tried to overcome this contradiction by using either the seaward-edge of the salt basins (Torsvik et al., 2009) or gravity scars located within the South Atlantic quiet zones (Pérez-Díaz and Eagles, 2014) to constrain the rotation parameters during the superchron. These works had to assume that these markers were stable since their formation (i.e., isochrones-like features) and assign ages, which are poorly constrained.

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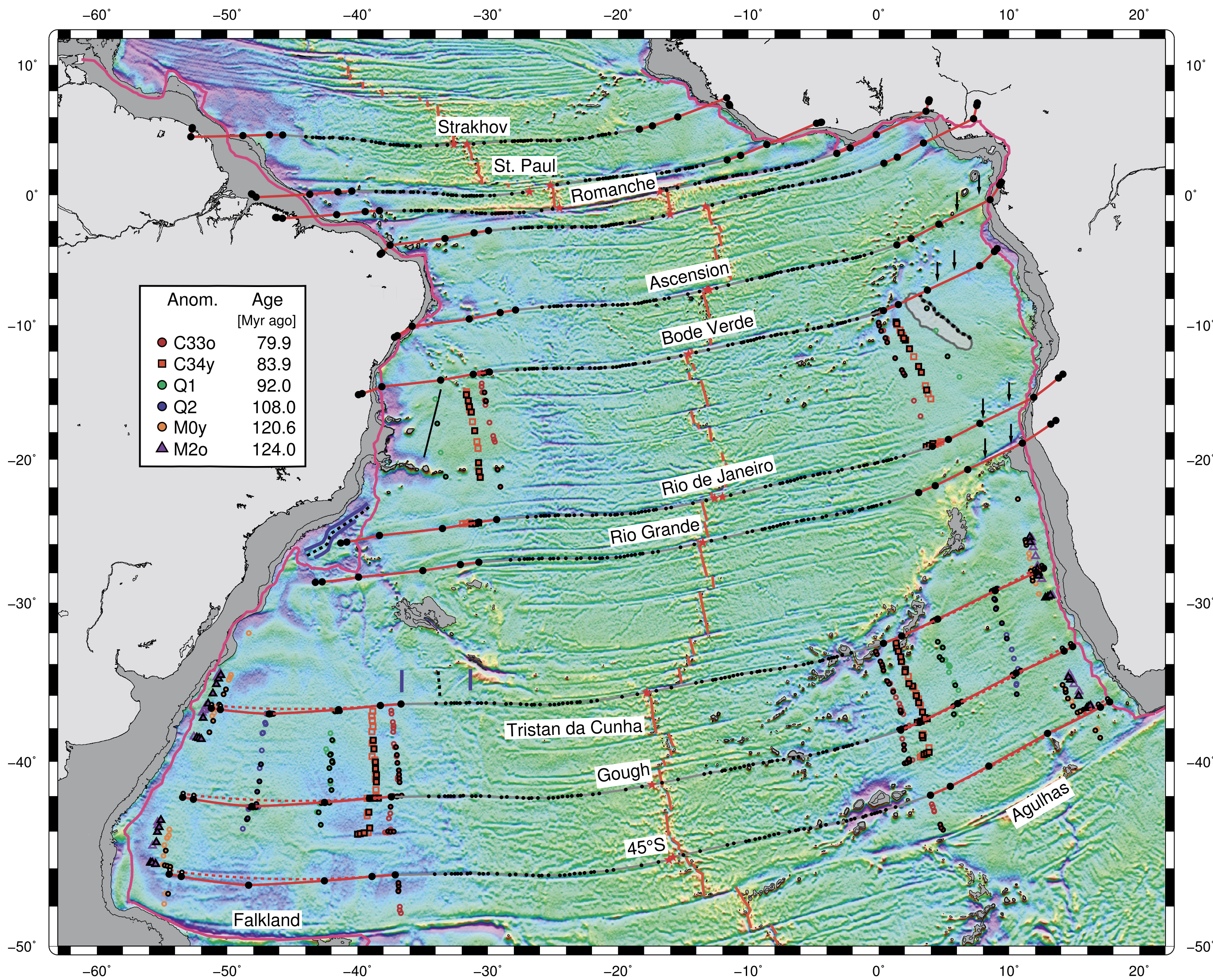

Fig. 1. Tectonic map of the South and Equatorial Atlantic Oceans superimposed on a satellite-derived free-air gravity field (Sandwell et al., 2014). Magnetic picks and FZs crossings are shown with empty symbols for the six anomalies used (rounded ages are shown in Myr). Filled symbols show the rotated picks (rotation parameters from Table 1). The gray flowlines are calculated on the basis of the rotation parameters of Cande et al. (1988), covering the last 79 Myr (Anomaly C33o to present), and the red lines are flowlines calculated on the basis of the new stage rotations (Fig. 3b, Anomalies M2o to C33o, marked with filled black circles). Red stars denote the initiation points of the displayed flowlines. For uncertainties on selected flowline locations see Fig. 4. Dashed red flowlines delineate the expected location of FZs using interpolation between the rotation parameters of Anomalies M0y and C34y. Blue lines mark the oldest conjugate anomalies formed along the fossil spreading axes (black dashed lines) (Cande et al., 1988; Cande and Rabinowitz, 1978). Arrows show the expected position of the flowlines based on the gravity data. Gray shaded area demarcates a sliver of transferred crust (Sandwell et al., 2014).

Although geomagnetic reversal-related anomalies are the most prominent magnetic signature of the oceanic crust, past changes in the strength of the dipolar geomagnetic field are also recorded, resulting in globally correlatable wiggles within geomagnetic chrons (Bouligand et al., 2006; Cande and Kent, 1992; Granot et al., 2012; Pouliquen et al., 2001). Two globally traceable magnetic anomalies from the CNS (Granot et al., 2012) are used here to define internal ages within the South Atlantic quiet zones: the oldest is a long-wavelength wiggle (Anomaly Q2, 108 ± 1 Myr ago) and the youngest (Anomaly Q1, 92 ± 1 Myr ago) is a short-wavelength wiggle, which is followed by subdued magnetic anomalies toward the younger end of the quiet zones. The ages (and uncertainties) of these anomalies are based on the ages of the oldest sediments that were drilled in the Central Atlantic Ocean (Granot et al., 2012). We have picked the location of these CNS magnetic anomalies and combined them with fracture zone (FZ) locations to compute internal rotation parameters for the superchron period. We complement these two rotations with a new set of picks for Anomalies M2o, M0y, C34y and C33o. From these finite rotations we derive stage rotations that constrain the relative motion of South America and Africa at 5 to 15 Myr intervals between 124 and 79 Myr ago. We then discuss the evolution of seafloor spreading in the South Atlantic and conclude with the geodynamic and paleooceanographic implications of our results.

2. Data and methods

We constrain South America–Africa motion by using magnetic anomaly picks and FZ traces found south of the Tristan da Cunha FZ, where both quiet zones are fully preserved (Figs. 1, 2 and S1). Locations of FZs were selected from the satellite gravity map (version 23) of Sandwell et al. (2014). Magnetic anomaly data were obtained from the National Geophysical Data Center (NGDC) and contain both shipboard and aeromagnetic (Project MAGNET) profiles. The locations of the reversal-related anomalies were picked based on forward modeling whereas the location of