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Mesozoic Seafloor Spreading History of the Central Atlantic Ocean

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ABSTRACT

The history of Mesozoic seafloor spreading in the Central Atlantic Ocean includes asymmetric spreading between Chrons M25 and M0 (154.1 Ma to 120.6 Ma), and two ridge jumps at about 170 Ma and 160 Ma. We identify and map twenty-three Mesozoic Chrons, including several in the Jurassic Magnetic Quiet Zone (JQMZ), between the Atlantis and Fifteen-Twenty fracture zones on the North American Plate, and between the Atlantis and Kane fracture zones on the African Plate. Chron M40 (167.5 Ma) is mapped about 65 km outboard of the conjugate Blake Spur and S1 magnetic anomalies, over the respective North American and African flanks of the ocean basin. Inboard of these prominent anomalies, the conjugate East Coast and S3 magnetic anomalies, are respectively located about 180 km and 30 km inboard of the BSMA-S1 pair. Therefore the ridge jump to the east between BSMA and ECMA anomalies at about 170 Ma theorized by Vogt and others in 1971 is supported by this study. The width of the African JMQZ is about 70 km greater (22%) than the North American JMQZ. A second ridge jump is suggested by additional, correlable anomalies over the African flank. Modeling results indicate that this jump occurred between 164 Ma and 159 Ma (Chrons M38 and M32). The ridge jumps can be related to plate interactions as North America separated from Gondwana. It has not escaped our attention that these ridge jumps, especially the latter, could correspond with the opening of the Gulf of Mexico.

Introduction

Closing ocean basins along geomagnetic isochrons is an objective method for analyzing reconstructed continental margins. If similar geophysical or geological features can then be identified on conjugate margins, then these features can be used to further close ocean basins. We close the Central Atlantic Ocean by focusing on the oldest magnetic anomaly provinces: Mesozoic Chrons M25 to M0; JMQZ Chrons M40 to M28; and a zone of low amplitude anomalies between the ECMA and BSMA over the North American flank of the ocean basin (Table 1). The conjugates to ECMA and BSMA, S3 and S1, are located over the African flank inboard of Chron M40 (Bird *et al*. 2007).

Table 1. Finite rotation poles for North America relative to Africa.

Chron	Age (Ma)	Latitude	Longitude	Rotation Angle
M0	120.6	66.7ºN	18.55ºW	54.23º
M25	154.1	66.10ºN	16.40ºW	65.83º
M40	165.1	65.50ºN	15.30ºW	71.76º
--	~185.0	67.76ºN	5.42ºW	72.97º

The overall kinematic history of the Central Atlantic Ocean is well understood (Klitgord and Schouten 1986; Muller and Roest 1992; Muller *et al.* 1999; Withjack *et al*. 1998). Following Middle to Late Triassic rifting between North America and Africa, seafloor spreading began at approximately 185 Ma (Withjack *et al*. 1998). We combine flow lines, approximated from fracture zones, and magnetic anomalies to determine the age and relative Mesozoic rotation history between the North American and African Plates. This history includes asymmetric seafloor spreading (120.6 Ma to 154.1 Ma), ridge jumps at 170 Ma (Vogt *et al.* 1971) and between 164 Ma and 159 Ma (Bird *et al*. 2007), and variable extension of the continental crust along-strike. The position of the Bahaman Islands directly along the intersection of the Demarara Rise and Guinea Nose as the basin is closed from Chron M40 (165.1) to final closure (ca. 185 Ma), suggests that the Central Atlantic Magmatic Province (CAMP) plume track lies beneath the Bahaman Islands (Dietz 1973).

Data and Methods

Open-file geophysical data were used in this study: two magnetic anomaly grids, two gravity anomaly grids, and three magnetic anomaly profile data sets. The magnetic grids partially cover the Central Atlantic Ocean (Hinze *et al*. 1988; Verhoef *et al.* 1996). The gravity grids include one that partially covers the Central Atlantic Ocean and another that covers the world's oceans and seas (Tanner *et al.* 1988; Sandwell and Smith 1997). The magnetic anomaly profile data sources are: NOAA / NGDC GEOphysical DAta System (GEODAS) database, Geological Survey of Canada Kroonvlag project data (Collette *et al.* 1984), and 42 lines digitized from Vogt *et al.* (1971).

The Fifteen-Twenty, Kane, and Atlantis Fracture Zones span most of the Central Atlantic and extend close to the coasts of North America and Africa. We infer flowlines related to these fracture zones on maps of gravity and magnetic anomalies by tracing gravity minima through the transform offsets. Magnetic anomalies produced by sea-floor spreading are identified in a two-step process: 1) by simultaneous interpretation of gridded and profile magnetic anomalies to correlate significant anomaly trends, and 2) by comparison of selected anomaly profiles with synthetic anomaly profiles that are calculated from 2D magnetic models based on the geomagnetic polarity reversal time scales of Channell *et al*. (1995) and Sager *et al*. (1998).

Total reconstruction poles were calculated for M0 (120.6 Ma), M25 (154.1 Ma) and M40 (165.1 Ma). A method similar to that described by Engebretson *et al.* (1984) was used to find the best fit Euler pole for pairs of control points defined by the intersections between interpreted geomagnetic isochrons and fracture zones. Each pair of control points is assumed to have been originally coincident such that a plate rotation exists that will restore them to a single point and a computer program minimized mismatch between one set of control points and the rotated set of control points by least squares approximation (Bird 2004). The final closure pole is estimated from two pairs of control points located along the 1000 m isobaths along the North American and African coasts, and a third pair of control points that connect the Florida shelf with the intersection of the Guinea Nose and Demarara Rise (Pindell and Dewey 1982). The two pairs of points located on the 1000 m isobaths were interpreted by comparing combinations of gravity and magnetic data and conjugate terranes of North America and Africa (Dallmeyer *et al.* 1987; Mueller *et al.* 1996; Murphy *et al.* 2004; Stillman 1988).

Reconstructions

Twenty-three geomagnetic Chrons from M40 to M0 have been interpreted and mapped outboard of the North American and African continental slopes: M40, M38, M32, M29, M28, M25, M24, M23, M22, M21, M20, M20n-1, M19, M18, M17, M16, M14, M12A, M10N, M4, M3, M1 and M0. Inboard of the anomalies, the conjugate pairs Blake Spur Magnetic Anomaly (BSMA) – S1 and East Coast Magnetic Anomaly (ECMA) – S3 have also been interpreted and mapped. Bird *et al.* 2007) described the character and correlation of these anomaly sequences in detail.

The spreading rate for the high amplitude M25 through M0 Chrons in the North American plate (14.4 mm/a) is about 10.5% faster than the 12.9 mm/a spreading rate for the African plate, which indicates asymmetric spreading in this interval. The spreading rate for the North American JMQZ of 19 mm/a differs significantly from the African JMQZ rate of 24.6 mm/a, which is about 22% greater. This large difference in spreading rates suggests that a ridge jump may have occurred in this time interval. Therefore the magnetic data over the African side were inspected for repeated anomalies. A sequence of anomalies near M38 appears to repeat on the few profiles we analyzed and could account for an additional ~70 km of oceanic crust that seems to be absent from the North American side. The seafloor spreading models were modified by removing these chrons from the North American model and inserting them into the African model. Comparing JMQZ anomalies with those calculated from our ridge jump models suggests that a sequence of anomalies approximately between M38 and M32 could be produced by a sliver of oceanic lithosphere that was abandoned by a ridge jump. We suggest that the difference in JMQZ widths indicate that a ridge jump occurred between 164 and 159 Ma (Chrons M38 to M32), abandoning about 35 km of North American lithosphere on the African side of the Central Atlantic ocean basin.

Our identification of M40 along North America suggests that the high-amplitude western and eastern basin bounding anomalies, ECMA-S3 and BSMA-S1, are conjugate pairs. The asymmetric spreading required to create oceanic crust from ECMA to BSMA (180 km), and S3 to S1 (50 km), greatly exceeds the maximum asymmetry reported by Muller *et al*. (1998). We conclude that a ridge jump occurred within the IMQZ, substantiating the ridge jump hypothesized Vogt *et al*. (1971).

Gravity and magnetic anomalies suggest tectonic relationships between the North American and African Plates after closing the basin to M40 (Fig. 1). Gravity anomalies over the Guinea Nose of Africa, and Demarara Rise of South America, show the pre-Gondwana breakup position between these two plates (Hall and Bird 2007; Pindell and Dewey 1982). The northern end of the BSMA in the North America magnetic data appear to be continuous with an anomaly in southern end of the Africa magnetic data.

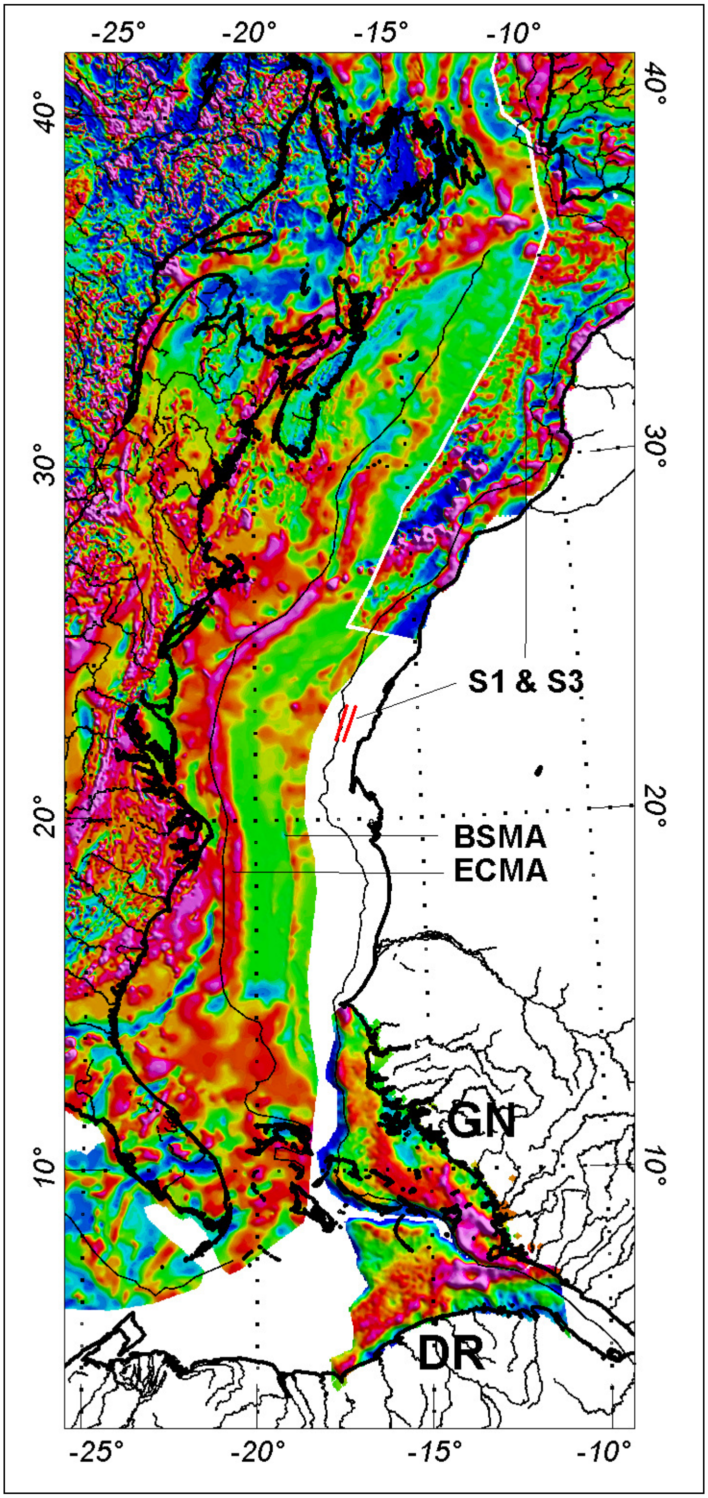

Figure 1. M40 (165.1 Ma) reconstruction relative to Africa, with 1000 m isobaths for North America and Africa. Magnetic anomaly data: North America = Decade of North American Geology (DNAG) (Hinze *et al.* 1988). Gravity anomaly data = satellite-derived free air anomalies (Sandwell and Smith, 1997). S1 & S3 = magnetic anomalies; identified offshore northwest Africa (Roeser *et al.*, 2002), and identified (red lines) offshore Western Sahara (Bird *et al.* 2007). BSMA = Blake Spur Magnetic Anomaly, ECMA = East Coast Magnetic Anomaly, GN = Guinea Nose, DR = Demarara Rise.

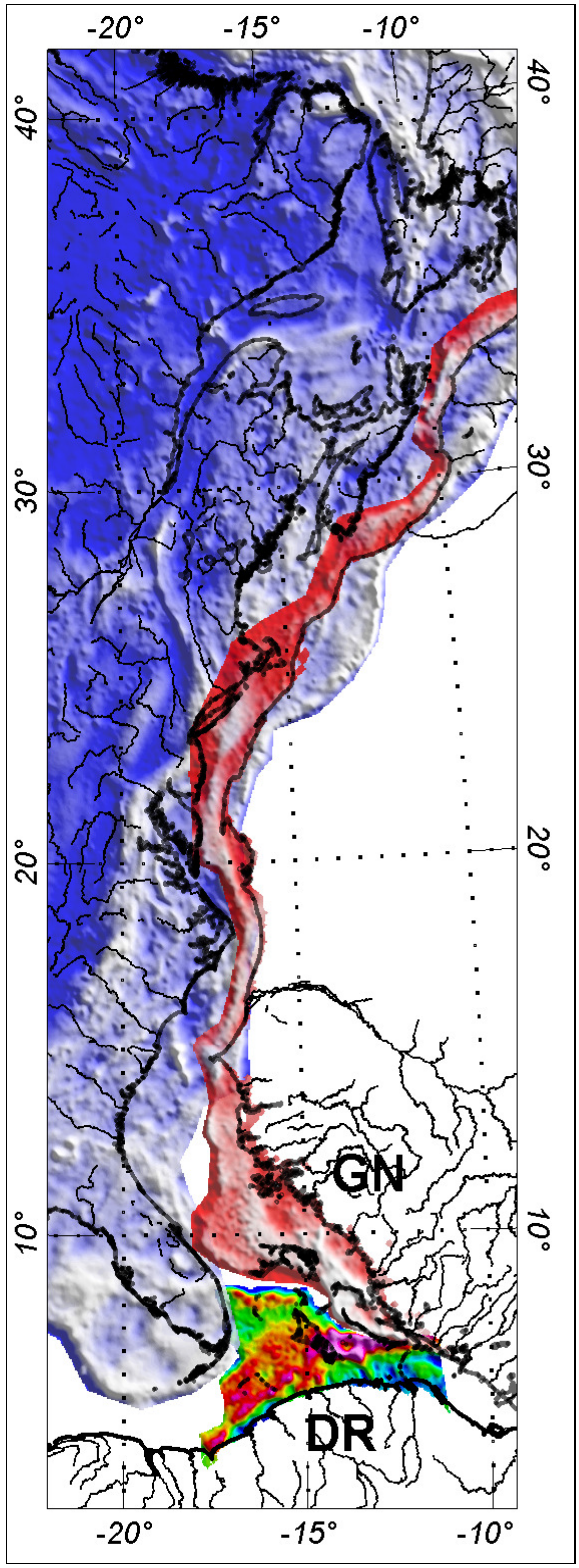

Figure 2. Final closure reconstruction (ca. 185 Ma) and gravity anomalies. North American gravity (blue) = Decade of North American Geology (DNAG) (Tanner *et al.* 1988). African gravity (red) and Demarara Rise (red-blue color stretch) = Satellite-derived free air anomalies (Sandwell and Smith 1997). GN = Guinea Nose, DR = Demarara Rise.

We chose to identify rotation control points along the 1000 m isobaths because: 1) the continental crust beneath this depth is interpreted to be partially extended and located near the ocean-continent boundaries, 2) prominent gravity anomalies correlate with the 1000 m isobaths, and 3) ECMA and S1 / S3 magnetic anomalies also correlate with the 1000 m isobaths. Figure 2 shows our final closure of the Central Atlantic Ocean with gravity data masked just outboard of prominent anomalies correlated with 1000 m isobaths. Gravity anomalies are shaded blue over North America, red over Africa, and by a typical red-blue color stretch over the Demarara Rise. The overlap of gravity data north of about 23° N suggests greater continental extension. For this and the M40 reconstructions, the Bahaman Islands map directly over the intersection between Guinea Nose and Demarara Rise suggesting that these structures were formed by the CAMP plume (Dietz 1973).

Conclusions

We calculate a new Euler total reconstruction pole that closes the Central Atlantic Ocean, completing our kinematic reconstructions of the Central Atlantic Ocean (Bird *et al*. 2007), South Atlantic (Hall and Bird 2007), and the Gulf of Mexico (Bird *et al*. 2005)**.**

Recently mapped M-Series Chrons in the Jurassic Magnetic Quiet Zone (JMQZ), and interpretations of geological and geophysical data, support the identification of:

- asymmetric seafloor spreading from M25 (154.1 Ma) to M0 (120.6 Ma) (Bird *et al*. 2007),
- a previously theorized eastward ridge jump at approximately 170 Ma as (Vogt *et al*. 1971),
- westward ridge jump between M32 and M38 (159 Ma and 164 Ma) (Bird *et al*. 2007),
- variable continental extension between North America and Africa north of 23°N, and
- the CAMP hotspot track beneath the Bahaman Islands (previously theorized by Dietz, 1973).

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References

Bird, D. E., 2004, Jurassic tectonics of the Gulf of Mexico and Central Atlantic Ocean: Univ. of Houston, Ph.D. Dissertation, 161p.

Bird, D. E., K. Burke, S. A. Hall, and J. F. Casey, 2005, Gulf of Mexico tectonic history: Hotspot tracks, crustal boundaries, and early salt distribution: American Association of Petroleum Geologists Bull., v.89, p.311-328.

Bird, D. E., S. A. Hall, K. Burke, J. F. Casey, and D. S. Sawyer, 2007, Early Central Atlantic Ocean seafloor spreading history: Geosphere, v.3, n.5, p.282-298.

Channell, J. E. T., E. Erba, M. Nakanishi, and K. Tamaki, 1995, Late Jurassic – Early Cretaceous time scales and oceanic magnetic anomaly block models: in, Geochronology, Time Scales and Global Stratigraphic Correlation: SEPM Special Publication 54, p.51-63.

Collette, B. J., A. P. Slootweg, J. Verhoef, and W. R. Roest, 1984, Geophysical investigations of the floor of the Atlantic Ocean between 10° and 38°N (Kroonvlag-project): *in*, Amsterdam, Proceedings Koninklijke Nederlandse Akadademie van Wetenschappen, Series B, v.87, p.1-80.

Dallmeyer, R. D., M. Caen-Vachette, and M. Villeneuve, 1987, Emplacement age of post-tectonic granites in southern Guinea (West Africa) and the peninsular Florida subsurface: Implications for origins of southern Appalachian exotic terranes: Geological Society of America Bulle., v.99, p.87-93.

Dietz, R. S., 1973, Morphologic fits of North America / Africa and Gondwana: A review: *in*, Tarling, D. H., and S. K. Runcorn, eds., Implications of Continental Drift to the Earth Sciences, v.2: London, Academic Press, p.865-872.

Engebretson, D. C., A. Cox, and R. G. Gordon, 1984, Relative motions between oceanic plates of the Pacific basin: Jour. of Geophysical Research, v.89, p.10291-10310.

Hall, S. A., and D. E. Bird, 2007, Tristan da Cuhna hotspot tracks and the seafloor spreading history of the South Atlantic: Eos, Transactions, American Geophysical Union, v.88, Fall Meeting Supplement, V31F-04.

Hinze, W. J., P. J. Hood, W. E. Bonini, J. E. Case, M. de la Fuente, R. H. Godson, S. A. Hall, W. F. Hanna, J. R. Heirtzler, R. H. Higgs, M. D. Kleinkopf, H. Meyers, A. R. Palmer, N. W. Peddie, M. S. Reford, D. J. Teskey, L. Thorning, I. and Zietz, 1988, Magnetic anomaly map of North America: The Leading Edge, v.7, n.11, p.19-21.

Klitgord, K. D., and H. Schouten, 1986, Plate kinematics of the central Atlantic: *in*, Vogt, P. R., and B. E. Tucholke, eds., The Geology of North America, The western North Atlantic Region: Boulder, Geological Society of America, Volume M, p.351-378.

Mueller, P. A., M. Kozuch, A. L. Heatherington, J. L. Wooden, T. W. Offield, R. P. Koeppen, T. L. Klein, and A. P. Nutman, 1996, Evidence for Mesoproterozoic basement in the Carolina terrane and speculations on its origin: *in*, Nance, R. D., and M. D. Thompson, eds., Avalonion and related peri-Gondwanan terranes of the circum-North Atlantic: Geological Society of America Special Paper 304, p.207-217.

Muller, R. D., and W. R. Roest, 1992, Fracture zones in the North Atlantic from combined Geosat and Seasat data: Jour. of Geophysical Research, v.97, p.3337-3350.

Muller, R. D., W. R. Roest, and J. –Y. Royer, 1998, Asymmetric sea-floor spreading caused by ridge-plume interactions: Nature, v.396, p.455-459.

Muller, R. D., J. –Y. Royer, S. C. Cande, W. R. Roest, and S. Maschenkov, 1999, New constraints on the Late Cretaceous / Tertiary plate tectonic evolution of the Caribbean: in, Mann, P. (Hsu, K. J., series editor), Caribbean basins. Sedimentary Basins of the World, v.4: Amsterdam, Elsevier Science B.V., p.33-59.

Murphy, J. B., J. Fernandez-Suarez, J. D. Keppie, T. E. and Jeffries, 2004, Contiguous rather than discrete Paleozoic histories for the Avalon and Meguma terranes based on detrital zircon data: Geology, v.32, n. 7, p.585-588.

Pindell, J. L., and J. F. Dewey, 1982, Permo-Triassic reconstruction of western Pangea and the evolution of the Gulf of Mexico / Caribbean region: Tectonics, v.1, p.179-211.

Roeser, H. A., C. Steiner, B. Schreckenberger, and M. Block, 2002, Structural development of the Jurassic Magnetic Quiet Zone off Morocco and identification of Middle Jurassic magnetic lineations: Jour. of Geophysical Research, v.107, p.2207, doi:10.1029/2000JB000094.

Sager, W. W., C. J. Weiss, M. A. Tivey, and H. P. Johnson, 1998, Geomagnetic polarity reversal model of deep-tow profiles from the Pacific Jurassic Quiet Zone: Jour. of Geophysical Research, v.103, p.5269-5286.

Sandwell, D. T., and W. H. F. Smith, 1997, Marine gravity anomaly from Geosat and ERS 1 satellite altimetry: Jour. of Geophysical Research, v.102, p.10039-10054.

Stillman, C. J., 1988, Ordovician to Silurian volcanism in the Appalachian – Caledonian orogen: *in*, Harris, A. L., and D. J. Fettes, eds., Geological Society Special Publication 38, p.275-290.

Tanner, J. G., C. L. V. Aiken, P. Dehlinger, W. T. Dewhurst, M. de la Fuente, V. M. Godley, R. H. Godson, W. F. Hanna, T. G. Hildebrand, M. D. Kleinkopf, G. A. McCalpin, R. K. McConnell, H. D. Meyers, N. W. O'Hara, A. Palmer, D. M. Scheibe, R. E. Sweeney, and L. Thorning, 1988, Gravity anomaly map of North America, The Leading Edge, v.7, n.11, p.15-18.

Verheof, J., W. R. Roest, R. Macnab, and J. Arkani-Hamed, and Members of the Project Team, 1996, Magnetic anomalies of the Arctic and North Atlantic Oceans and adjacent Land areas: Dartmouth, Geological Survey of Canada (Atlantic), scales 1:10,000,000 and 1:6,000,000, 2 sheets.

Vogt, P. R., C. N. Anderson, and D. R. Bracey, 1971, Mesozoic magnetic anomalies, sea-floor spreading, and geomagnetic reversals in the southwestern North Atlantic: Jour. of Geophysical Research, v.76, p.4796-4823.

Withjack, M. O., R. W. Schlische, and P. E. Olsen, 1998, Diachronous rifting, drifting, and inversion on the passive margin of central eastern North America: An analog for other passive margins: American Association of Petroleum Geologists Bull., v.82, p.817-835.

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