Protracted continental breakup along the Eastern North American Margin

Brandon Shuck, Harm Van Avendonk, and Anne Bécel

The Eastern North American Margin (ENAM) is a mature rifted margin that contains the geologic record of early Jurassic breakup of supercontinent Pangea. Rifting was accompanied by voluminous magmatism along the continental shelf of eastern U.S., evidenced by seismically imaged volcanic flows and lower crustal intrusions, which produce the high-amplitude East Coast Magnetic Anomaly (ECMA; Fig 1B). Magmatism is thought to assist rifting by reducing stresses required to rupture the lithosphere (Buck, 2006), therefore making it easier and faster to achieve continental breakup and initiate seafloor spreading. Alternatively, the onset of seafloor spreading may be accompanied by a long period of persistent thermal erosion of the lithosphere. Previous studies assumed that seafloor spreading commenced seaward of the ECMA (Holbrook and Kelemen, 1993). However, the timing and duration of the rift-to-drift transition remained poorly constrained.

The ENAM was selected as a GeoPRISMS primary site and a 2014 community seismic experiment collected active-source multichannel streamer and wide-angle ocean bottom seismometer (OBS) data along the margin (Fig. 1B; Lynner et al., 2019). These new seismic profiles extended farther offshore than previous surveys, crossing the enigmatic Blake Spur Magnetic Anomaly (BSMA) located about 200 km seaward of the ECMA. Between the ECMA and BSMA, seismic tomography models and reflection images reveal thin igneous crust with high velocity lower crust and a rough, heavily faulted upper crust (Figs 1C, 1D). This zone, termed the proto-oceanic domain, has characteristics that are anomalous for volcanic rifted margins and instead similar to oceanic crust formed at ultra-slow spreading rates. In contrast, an abrupt basement step up and crustal root at the BSMA mark a rapid transition to smooth and relatively thick crust farther seaward, consistent with normal Jurassic oceanic crust.

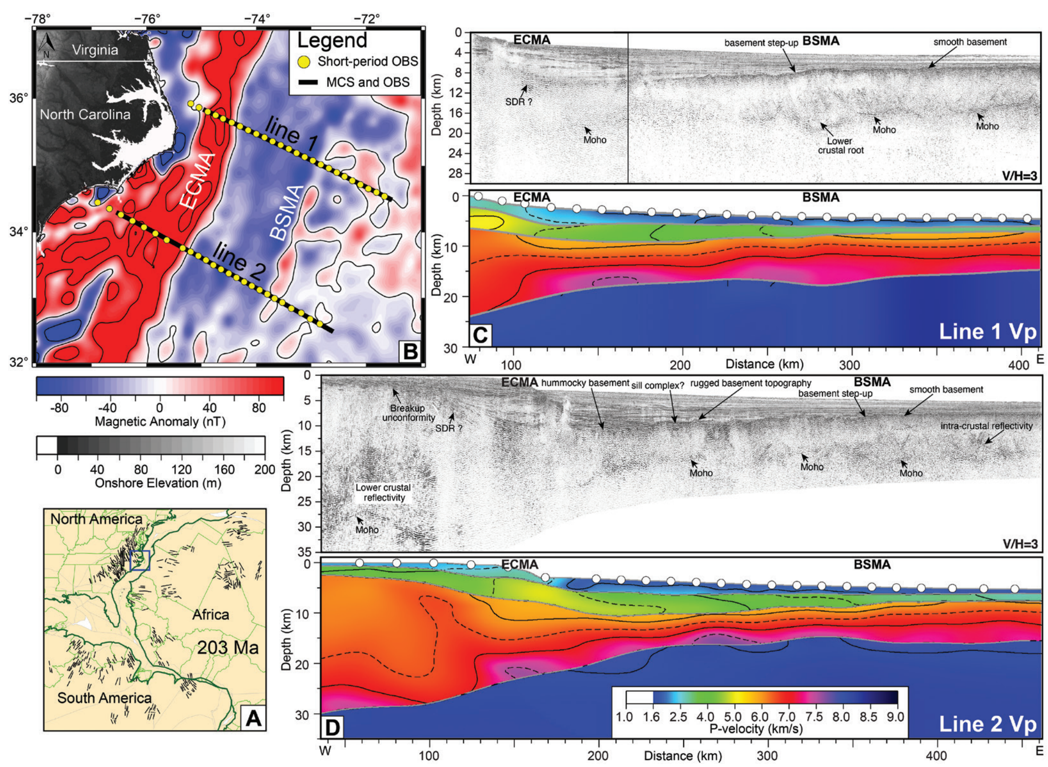

Figure 1. A. Plate reconstruction of Pangea at 203 Ma, courtesy of the PLATES Project. The approximate map location of Figure 1B is marked by a blue box; B. Elevation and magnetic anomaly map showing the location of ENAM CSE margin-perpendicular active-source seismic profiles. Onshore topography derived from ETOPO1 and offshore magnetic anomaly data derived from EMAG2v3; both are publicly available from the NCEI database. Kirchhoff prestack depth migrated seismic reflection images (top) and compressional-wave (Vp) seismic tomography models (bottom) of ENAM Line 1 (C) and Line 2 (D). Seismic velocities are contoured at 1.0 km/s (solid) and 0.5 km/s (dashed).

We developed petrologic modeling routines to reconcile the seismic images and explore mantle melting conditions and melt crystallization processes during formation of the oldest Atlantic oceanic crust. The results suggest that the thin proto-oceanic crust between the ECMA and BSMA with high seismic velocity formed under moderately elevated mantle temperatures and the presence of a ~15-20 km thick lithospheric lid, which prevented melting in the shallow mantle (Shuck et al., 2019). Similarly, very rough basement in this zone and low extension rates inferred from seismic images support the presence of a mantle lithospheric lid during igneous crustal accretion (Bécel et al., 2020). Elevated mantle temperatures (~1420°C) would inhibit an oceanic lithospheric lid; thus, it is likely that the lid consisted of continental mantle lithosphere.

Our findings indicate that the volcanism that produced the nearshore ECMA did not lead to rapid breakup as previously thought. Instead, we propose that proto-oceanic crust was formed by diffuse percolation of mafic melts through an extending continental lithospheric lid (Fig. 2A). Complete rupture of the lithosphere transpired at the BSMA, sparking normal seafloor spreading in the Central Atlantic (Fig. 2B). These observations imply that although the transition from rifting to seafloor spreading was accompanied by abundant magmatism, continental breakup was protracted and occurred by thermal erosion of the lithosphere over ~25 My. ■

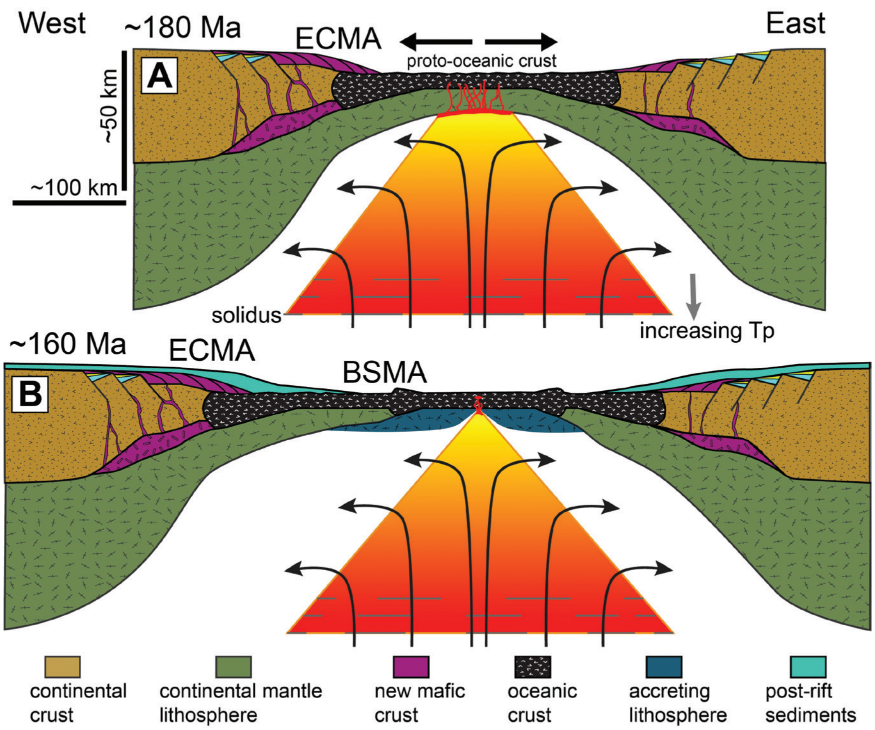

Figure 2. A. Schematic cartoon representing the tectonic setting during formation of proto-oceanic crust, which forms on the thermally eroding lithospheric lid until rupture of the conjugate Atlantic and African margins; B. Normal seafloor spreading in the Central Atlantic begins after complete rupture of continental lithosphere at the BSMA.

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