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Refining the Formation and Early Evolution of the Eastern North American Margin (ENAM): New Insights from Multiscale Magnetic Anomaly Analyses

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ENAM Magnetic Anomalies

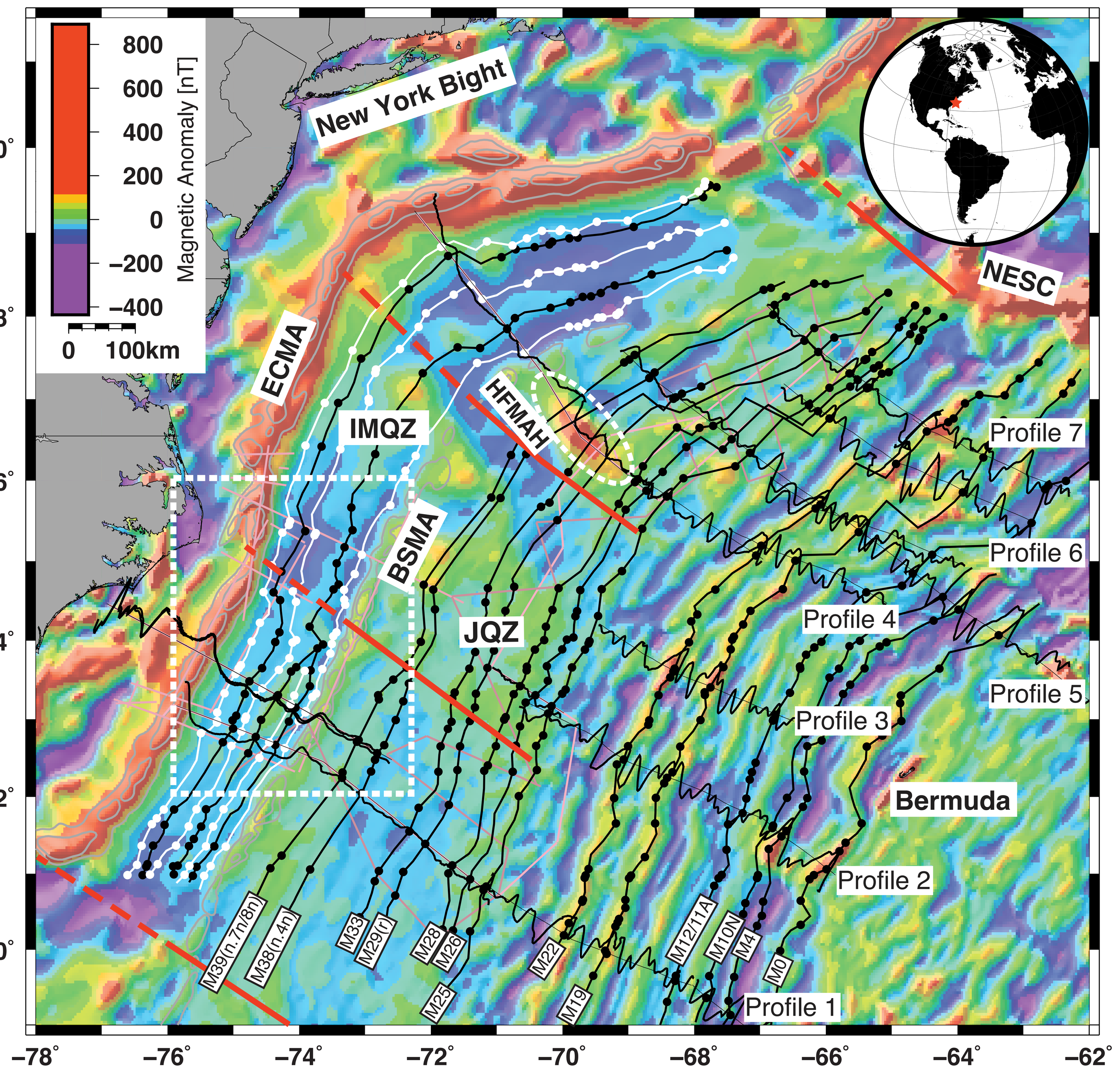

Figure 1. EMAG2 grid with identified magnetic anomaly lineations (black solid lines; dots- locations on seasurface profile; in IMQZ black- peaks, white- troughs). Select profiles (Profiles 1-7) used in age/chron assignment and spreading rate calculations (black curves). Boundaries of the three identified regions in the JQZ (red lines). ECMA and BSMA segmentation (grey contours) [Klitgord and Schouten, 1986]. Area shown in Figure 3A (white dashed box). Prominent features: New York Bight, East Coast Magnetic Anomaly (ECMA), Inner Magnetic Quiet Zone (IMQZ), Blake Spur Magnetic Anomaly (BSMA), Atlantic Jurassic Quiet Zone (JQZ), Hudson Fan Magnetic Anomaly High (HFMAH; white dashed circle), New England Seamount Chain (NESC), island of Bermuda.

Atlantic Jurassic Quiet Zone (JQZ):

- We identify three regions in the JQZ between the BSMA and M25 based on notable differences in magnetic anomaly coherency and lineation strike angle.

- Indicative of variable tectonic processes along the ridge during the formation of the JQZ between the BSMA and M25.
  - New York Region (36-40°N): Narrowest (~220km), less coherent, closer spaced magnetic anomalies.
  - Virginia Region (34-36°N): Intermediate width (~300km), least coherent magnetic anomalies.
  - Carolina Region (30-34°N): Widest (~360km), most coherent magnetic anomalies.

M25-M0:

- Very coherent magnetic anomaly lineations exist until the island of Bermuda.

- The strike of the anomaly lineations is more or less consistent throughout this area (~25° in the south transitioning to ~50° in the north).

Data and Methods

- We corrected recently acquired (MGL1407, 1408, and 1506 and AR1-06) and archived (39 cruises) sea surface total magnetic field data for ship-to-sensor offset, the International Geomagnetic Reference Field, and diurnal variation, which were integrated with USGS aeromagnetic total magnetic field and EMAG2 satellite magnetic anomaly data.

- We correlated magnetic anomalies and identify lineations on the ENAM by qualitatively matching the character (i.e. amplitude, spacing, and shape) of individual magnetic anomalies on the seasurface magnetic segments.

- To assign chron numbers and ages to our identified magnetic anomalies (using the 2012 Geomagnetic Polarity Time Scale [Ogg, 2012]), we correlated select observed anomaly profiles (Profiles 1-7) with synthetic magnetic anomaly profiles generated by Pacific M-series polarity block models using the Parker [1973] Fourier summation approach.

- With our assigned anomaly ages and the spacing, we calculated spreading rates for Profiles 1-7 to evaluate the variation in spreading rates both along the margin and over time.

- Satellite gravity and bathymetry data, along with recent multichannel seismic data, were examined to ensure our identified magnetic anomalies were produced by seafloor spreading processes, rather than secondary magmatic events.

- Two dimensional magnetic forward modeling was done to investigate the magnetic source architecture for the HFMAH.

Acknowledgements and References

We thank the captain and crew of the R/V Langseth MGL1407, 1408, and 1506 and R/V Neil Armstrong AR1-06 cruises. Data were provided through the USGS-ECS program. Archived data from the National Centers for Environmental Information.

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Atlantic Jurassic Quiet Zone (JQZ) Formation

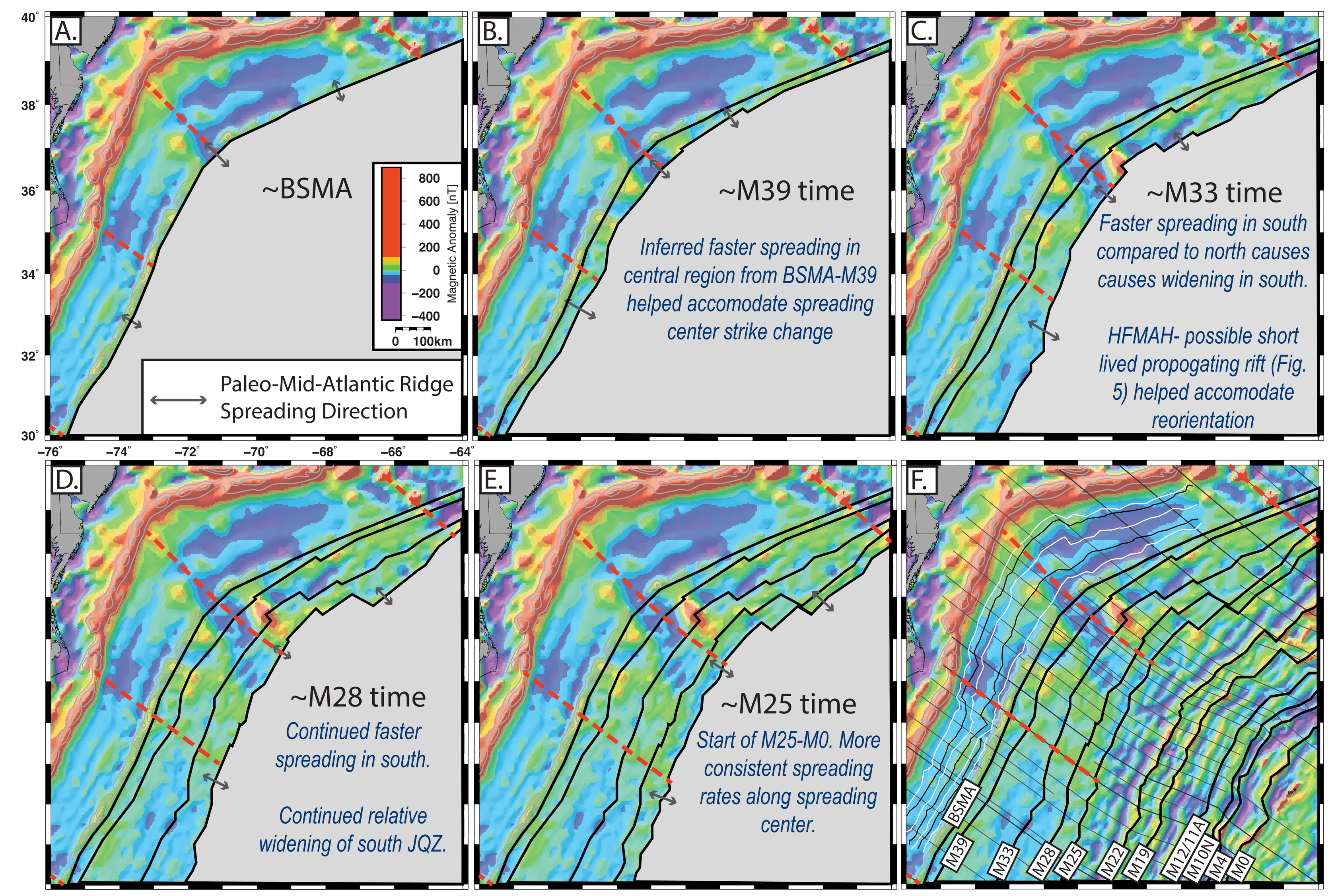


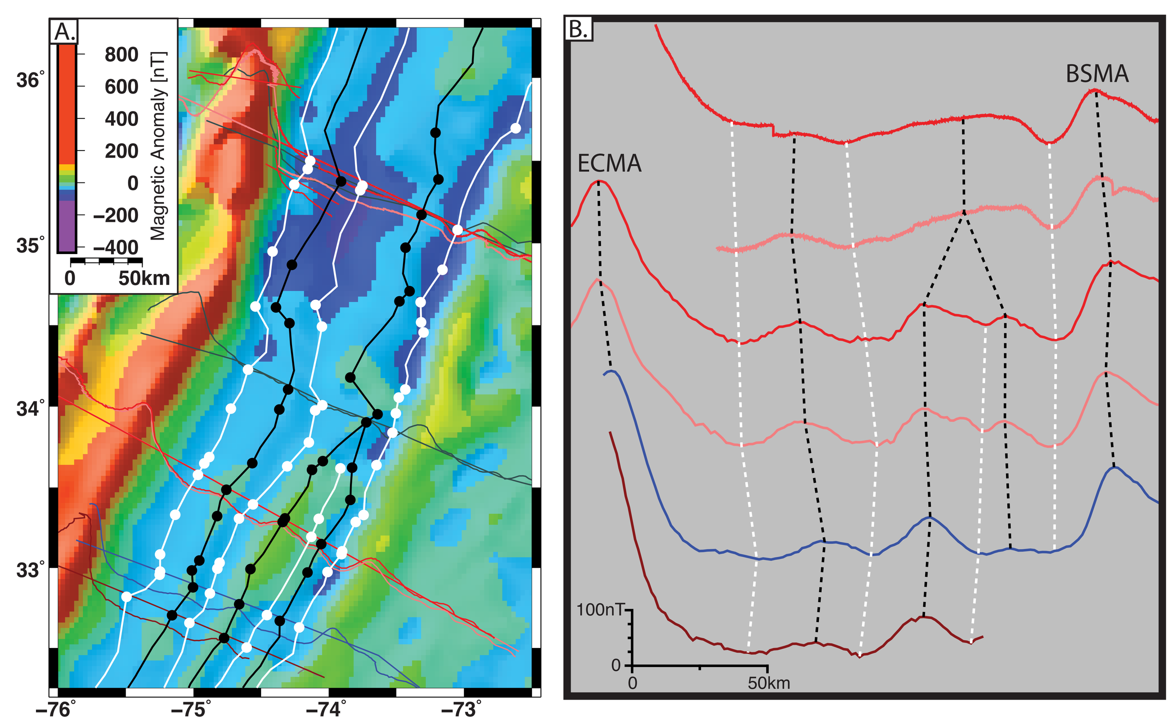
Figure 2. Schematic of JQZ formation over time. Red dashed lines mark three identified JQZ region boundaries (Fig. 1). Grey lines are predicted fracture zone extensions [Klitgord and Schouten, 1986].

- Relatively faster spreading rates and wider anomaly spacing of magnetic anomalies in the south suggests the JQZ crust formed in a swinging manner. Accounts for JQZ width variation (~360km at 31°N; ~220km at 37°N).

- Magnetic anomaly lineation strike variation across the New York JQZ region indicates reorientation of the paleo-Mid-Atlantic Ridge.
  - Lineations consistently have a strike of ~25° in the south, but the strike varies from ~65° to ~50° from west to east in the north.
  - Possibly accommodated by HFMAH and earliest seafloor spreading in the central region of the JQZ (producing the wider distance between the BSMA and first JQZ lineation).

Inner Magnetic Quiet Zone (IMQZ) Magnetic Anomaly Lineations

Figure 3. A: Southern IMQZ (see Fig. 1 for location). B: Correlation of magnetic anomalies on select profiles. Lines show interpreted magnetic anomaly lineations (black- peaks; white- troughs). Dots show location of magnetic anomalies on sea surface profiles.

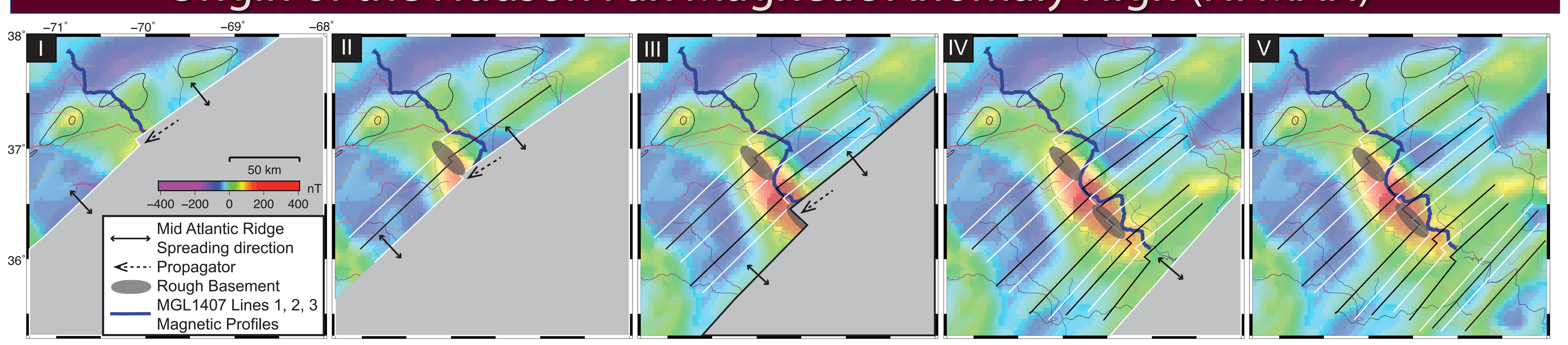


- We identify five correlatable, low amplitude magnetic anomaly lineations that have not been previously discussed.

- Oriented parallel to both the ECMA and BSMA, with a change in lineation strike (~25°in south; ~70° in north) at 39°N (Fig. 1).

- These five magnetic anomalies possibly document the earliest seafloor spreading of the early Mid-Atlantic Ridge (regardless of if a ridge jump or spreading rate/direction change occurred in the vicinity of the BSMA).

Origin of the Hudson Fan Magnetic Anomaly High (HFMAH)



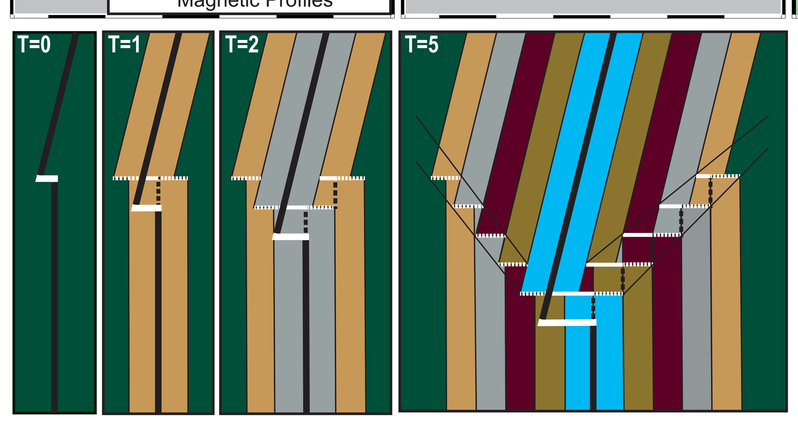


Figure 6. Propogating rift development showing spreading center (thick black lines), active transform (thick white line), pseudofault trend (thin black lines) [Modified from Hey et al., 1977].

Figure 5 (above). Proposed HFMAH origin: Seafloor spreading and propagation history from BSMA to M25. White/black lines are isochrons extended from correlatable magnetic anomaly peaks and troughs.

- In the sea surface magnetic anomaly data, two distinct anomaly highs occur within the originally recognized single peak of the HFMAH displayed in the EMAG2 grid. Magnetic forward modeling shows these two peaks can be reproduced by two highly magnetized bodies in the crust coinciding with two zones of rough basement topography in the MCS profiles.

- We propose the HFMAH was produced by crust emplaced by a short-lived propagating rift, which may have helped accommodate the inferred change in spreading center strike angle (Fig. 5 I-V).
  - Propagating rifts can produce basalt enriched in iron/titanium (produce higher amplitude magnetic anomaly), and the thickened layer 2 and rough basement topography that we observe at the HFMAH [Hey et al., 1980].

JQZ and M25-M0 Magnetic Anomaly Correlation

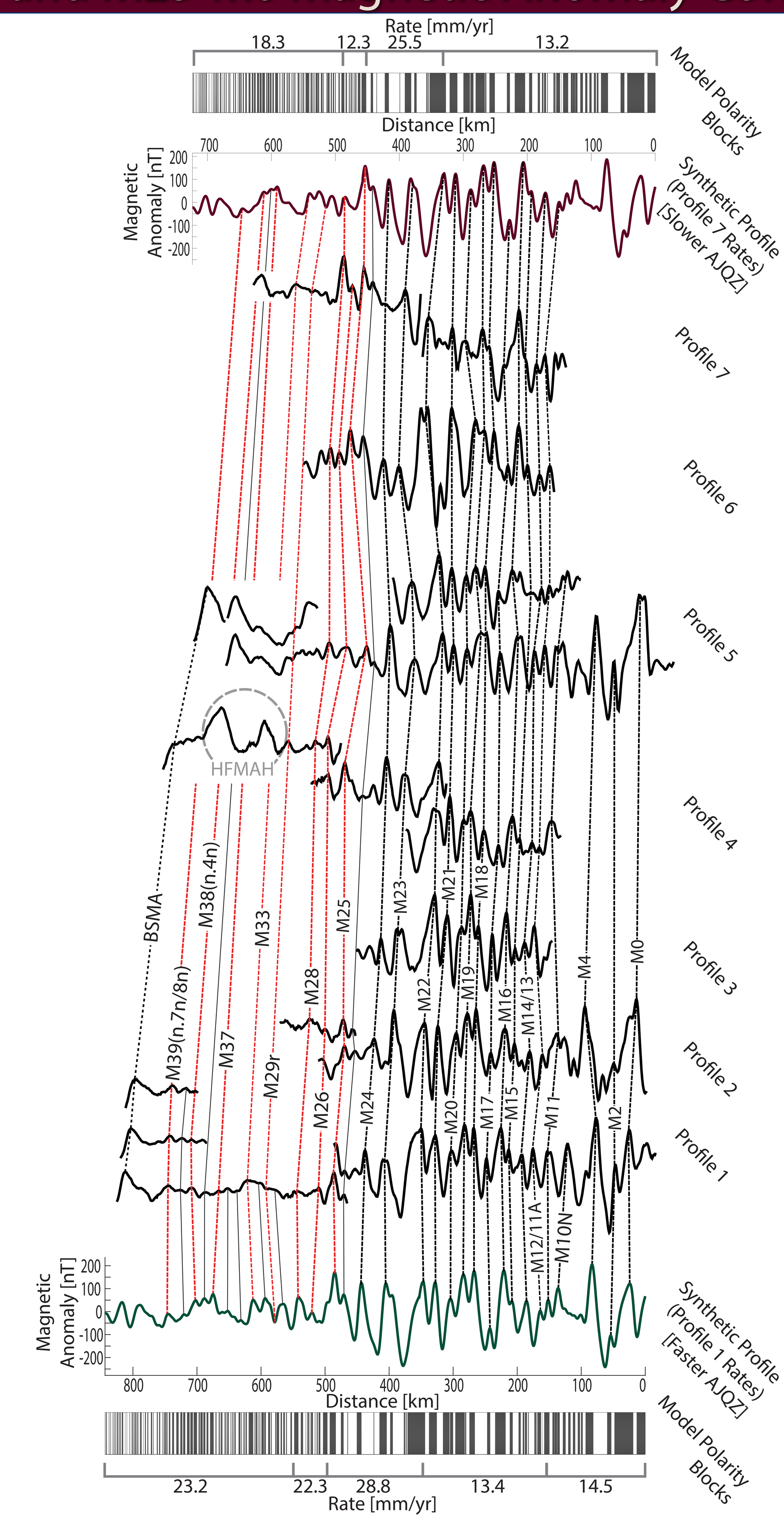


Figure 4. Anomaly correlations (dashed lines) for Profiles 1-7 (Fig. 1) and synthetic magnetic anomaly profiles created using half spreading rates for Profile 1 (bottom) and Profile 7 (top) [Table 1]. Red lines indicate new JQZ correlations. Chron numbers labeled.

- We identify and assign chron numbers and ages to 25 magnetic anomalies, including seven in the JQZ where few previous studies have identified magnetic anomalies due to lower amplitudes.

Calculated Half Spreading Rates

Chron Range	Age Range [Ma]	Profile 1	Profile 2	Profile 3	Profile 4	Profile 5	Profile 6	Profile 7
		Half Spreading Rate [mm/yr]						
M0-M11	126-136	14.5	14.8			15.6		
M11-M22	136-149	13.4	14.0	11.3 (M12-M22)	12.0	11.9	13.9 (M12-M22)	13.2 (M12-M22)
M22-M25	149-155	28.8	26.5		30.9	25.0	25.2	25.5
M25-M28	155-158	22.3	21.2		18.1		12.4	12.3
M28-M39*	158-166	23.2						
M28-M37/38**	158-165							18.3

* Chron range only available on Profile 1
** Chron range only available on Profile 7

Table 1. Calculated half spreading rates along Profiles 1-7 (see Fig. 1 for locations) for the JQZ and M25-M0.

- Profiles 1-7 (Fig. 1) perpendicular to margin provides insight on the spatial and temporal variations in spreading.
  - Half spreading rates varied along the margin during the JQZ (faster in south; slower in north).
  - Rates were more consistent along margin from M25 to M0, but did vary over time as found in previous studies.

Early Atlantic Opening Tectonic History

- Preexisting lithosphere structure and rift segmentation may have influenced the early seafloor spreading given the coincidence of our magnetic anomaly correlations, interpreted fracture zone offsets, ECMA segmentation, and hypothesized terrane boundaries.

IMQZ Tectonic History

- The consistent orientation of the five lineations and offsets suggest early spreading proceeded directly perpendicular to the margin, with no significant strike variation in the ridge axis during the IMQZ formation.

Atlantic JQZ Tectonic History

- Along margin spreading rate variation suggests the JQZ crust between the BSMA and M25 formed in a swinging manner, with relatively faster spreading in the south, slowing towards the north.
- Reorientation of paleo-Mid-Atlantic Ridge, accounting for the difference in strike between the prominent bend in the ECMA/IMQZ anomalies offshore the New York Bight and the more linear anomalies M0-M25.

M0-M25 Tectonic History

- Spreading rates varied over time from M25-M0, with little along margin variation.