6. THE MID-ATLANTIC RIDGE AT 23°N: BATHYMETRY AND MAGNETICS[1]

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INTRODUCTION

We present a compilation of all available bathymetry data in the area around Sites 395 and 396 (Figure 1 and accompanying map in jacket pocket). Four long east-west magnetics profiles crossing both drilling sites are used to date the crust on which Holes 395 and 396 were drilled. Site 395 is on anomaly 4′ west of the Mid-Atlantic Ridge and Site 396 is on anomaly 5 east of the ridge.

The two site surveys (Site Survey AT-5, Drill Site 395, Hussong et al., this volume; Site Survey AT-6, Drill Site 396, Purdy et al., this volume) provide dense data coverage over two approximate one-degree squares on the flanks of the Mid-Atlantic Ridge at 23°N. This paper attempts to place these detailed surveys in their regional context. We will discuss the compilation of bathymetry data shown in Figure 1 and present inversions of four magnetic profiles which detail the spreading history in this region since anomaly 5 time (µ10 m.y.B.P.).

DATA

The sources of bathymetry data are listed in Table 1. In addition to the IPOD site surveys and miscellaneous data available from NGSDC, the existence of the following four large data sets in this region made this compilation practical: the survey of the western flank of the Mid-Atlantic Ridge by van Andel and Bowin (1968), the *Vema* survey of the transform section of the Kane fracture zone by Fox et al. (1969), and the *Kane* 9 (Lowrie and Escowitz, 1969) and *Knorr* 54-4 (Rabinowitz et al., 1977) surveys of the eastern Kane fracture zone. Merging these data was difficult, because small navigational discrepancies over such precipitous topography result in large cross-over errors. We present Figure 1 as our best interpretation of the currently available data. The 500-meter contour interval is the smallest we found justified by the average data density.

Magnetics tracks 1, 3, and 4 (Figure 2) were carried out by Woods Hole Oceanographic Institution research vessels; the data were recorded at 1-minute intervals. Track 3 consists of two tracks which were merged after the non-linear inversion was carried out. Track 2 (Figure 2) was carried out by *Glomar Challenger* during Leg 46 (Rabinowitz et al., this volume) while en route from Site 395 to Site 396.

BATHYMETRY

The predominant features of the bathymetry map shown in Figure 1 are the median valley of the Mid-Atlantic Ridge and the Kane fracture zone trough. The median valley south of the Kane fracture zone is defined well by the available data. The average trend of the deepest point in the median valley is approximately 9° east of north. The 3500-meter contour shows an apparent 5-km right lateral offset of the median valley at about latitude 22°55′N.

The median valley to the north is offset left laterally by about 150 km along the Kane fracture zone. There is some evidence to suggest a small right lateral offset at 25°N, but this northern median valley is poorly defined by only 4 or 5 crossings. The two junctions of the median valley and the Kane fracture zone trough are marked by deeps about 1000 meters below the surrounding sea floor. The shape and extent of these deeps is not well defined by existing tracks.

The average trend of the transform section of the fracture zone trough is 100°. This is essentially perpendicular to the southern median valley, and agrees with the present-day flow line direction predicted by the pole of Minster et al. (1973). The width and depth of the fracture zone trough are so variable that more detailed determinations of its trend are not possible. A linear ridge 500 to 1000 meters high forms the northern wall of the trough between 43° and 45°W. The western end of this ridge coincides with the intersection of the southern median valley with the fracture zone trough.

Sites 395 and 396 lie about 110 km and 50 km south of the fracture zone, respectively. The well-defined bathymetry around these two drill sites shows a significant difference in character east and west of the median valley. It may be seen in Figure 1, and more clearly in the 100-meter contour interval chart in Purdy et al. (this volume), that the topography of the area around Site 396 is characterized by linear troughs and ridges trending approximately north-south. In contrast, Site 395 (Hussong et al., this volume) is surrounded by

[1]Woods Hole Oceanographic Institution Contribution No. 4046.

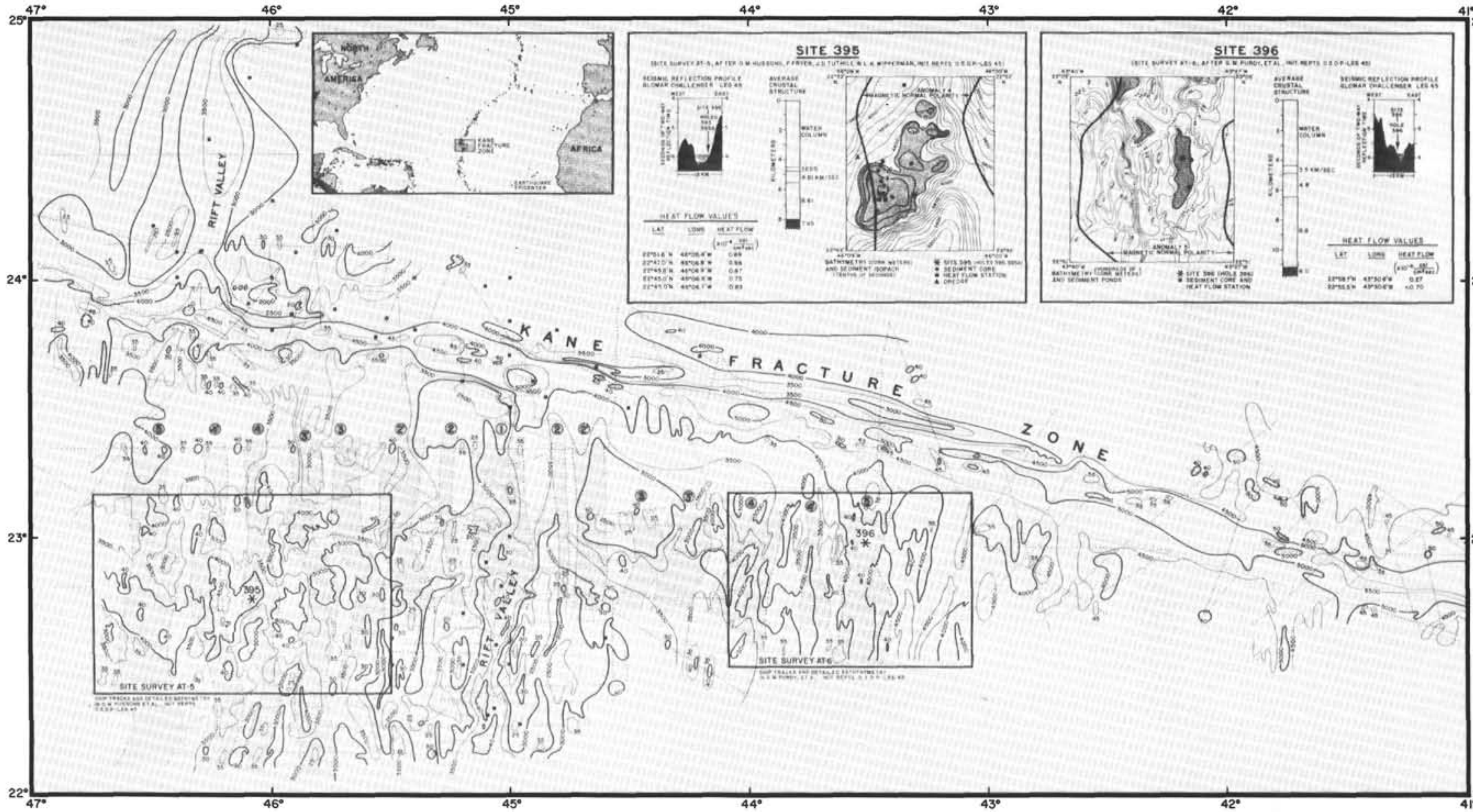

Figure 1. *Bathymetry of the Kane fracture zone and Mid-Atlantic Ridge; contour interval is 500 meters, corrected. Location of Sites 395 and 396 shown by asterisks; small black squares are USGS earthquake epicenters. Shaded stripes are a smoothed fit to the location of the positively magnetized blocks required as sources for the anomalies (see text). Boxed areas are approximate 1° squares where results of site surveys are given in Hussong* et al, *and Purdy* et al, *(both this volume). The insets give details of sea floor and ocean crust in immediate (approximately 10-mile square) vicinity of drill site.*

TABLE 1
Data Source

R/V *Vema*
R/V *Robert D. Conrad*
R/V *Knorr*
R/V *Atlantis II*
OSS *Discoverer*
USNS *Kane*
D/V *Glomar Challenger*
H.Neth.M.S. *Snellius*
R/V *Kana Keoki*
R/V *Akademik Kurchatov*
R/V *Chain*
R/V *Washington*

irregular mounds and depressions showing no recognizable trend.

MAGNETICS: PROCESSING

The projected magnetic anomaly and bathymetry profiles along tracks 1 through 4 (Figure 2) are shown in Figures 3 through 6. After removal of the IGRF 1975 (IAGA, 1976), the magnetics were smoothed and sampled every 3 minutes using a 5-point triangular smoothing function. To prepare for fast Fourier transform filtering operations, the smoothed magnetics and the bathymetry data points were projected on a west-east track and sampled every 1.0 km using linear interpolation. The *Glomar Challenger* Leg 46 magnetics data were sampled at an average interval of 1.2 km and projected and interpolated without smoothing.

The profiles shown in Figures 3 through 6 show that the magnetic anomalies have a highly variable character and are not immediately correlatable from track to track. To aid in our identifications, we applied the non-linear inversion technique of Parker and Huestis (1974) to the observed magnetic anomalies, modeling the horizontal distribution of magnetization in a source layer of 0.5 km thickness following the observed topographic relief. The signal-to-noise ratio in the observed magnetic anomalies is < 1 for wavelengths shorter than 3.5 km, and a low-pass filter was applied to the anomalies before inversion to avoid the enhancement of more noise than signal. Consequently, no wavelengths shorter than 4 km are present in the inversions.

Ideally, this technique removes the effect of topography on the observed magnetic anomalies and calculates a magnetization intensity profile more distinct and identifiable than the original anomaly. The correction for the skewness of the magnetic anomalies was estimated by phase shifting the anomalies in increments of 10° (Schouten and Cande, 1976). A phase shift of 80° produced the most satisfactory magnetic anomaly symmetry with respect to the ridge axis. Assuming that the average magnetization direction in the recent crust conforms to an axial geocentric dipole field, and assuming an average trend of the lineations of 10°E, the theoretical phase shift is closer to 50°. The phase shift of 80° estimated from magnetic anomaly symmetry remains a subjective estimate. A smaller phase shift would displace most of the boundaries a few kilometers to the east. The variability of the magnetic anomalies of the same age on each side of the ridge axis is pronounced. The variability of the magnetization intensity anomalies of the same age has not been reduced by the removal of the topographic effect. A number of polarity transition boundaries are better defined. This is attributable mainly to the phase shifting, and to a lesser degree to enhancement of the shorter wavelength information by the inversion technique.

MAGNETICS: INTERPRETATION

Figures 3 through 6 show the magnetic anomaly, bathymetry, and calculated magnetization profiles. Also shown are our interpretations of the location of the polarity transition boundaries, as determined from the magnetization profiles. The precision with which these boundaries may be positioned is highly variable. For example, on track 3, anomaly 4 east is well constrained by the box-car shape on the magnetization profile, but the western boundary of 3′ and the eastern boundary of 3 are poorly defined.

The results of the non-linear inversions presented here have been combined in Figure 1 with the linear inversions carried out on the closely spaced tracks within the detailed survey areas (Hussong et al., this volume; Purdy et al., this volume). The shaded areas in Figure 1 are a smoothed fit to the location of the positively magnetized blocks required as sources for the anomalies. The irregularity of these shaded stripes is evidence for a temporally and spatially variable process of accretion of oceanic crust in this area.

There is evidence for a short-lived left lateral offset in anomalies 2′ to 3′ west of the ridge at about latitude 22°50′N (Figure 1). A flow-line direction of 100° (Minster et al., 1973) would place the eastern corollary to the south of our survey area. Within the resolution of these data and of our interpretation techniques, no other offsets were defined. The half-total spreading rate graph (Figure 7) shows three spreading phases determined from the two longest tracks, 1 and 3. The spreading rate during anomaly-5 time is poorly controlled but is about 15 mm/year. The half-total rate during 3′ through 4′′ increases to 23.5 mm/year and decreases to 14.4 mm/year from anomaly 3 to present. Figure 7 shows there is a maximum discrepancy of 8 km between the two tracks in the separation of the same polarity transitions on either side of the ridge axis.

DISCUSSION

An important observation of this study is the difference in the large-scale morphology of the crust at corresponding ages east and west of the ridge. The north-south-trending scarps and ridges within Site Survey AT-6 do not occur within Site Survey AT-5. Assuming, however, the 100° flow-line direction of Minster et al. (1973) (confirmed by the trend of the transform section of the Kane fracture zone trough),

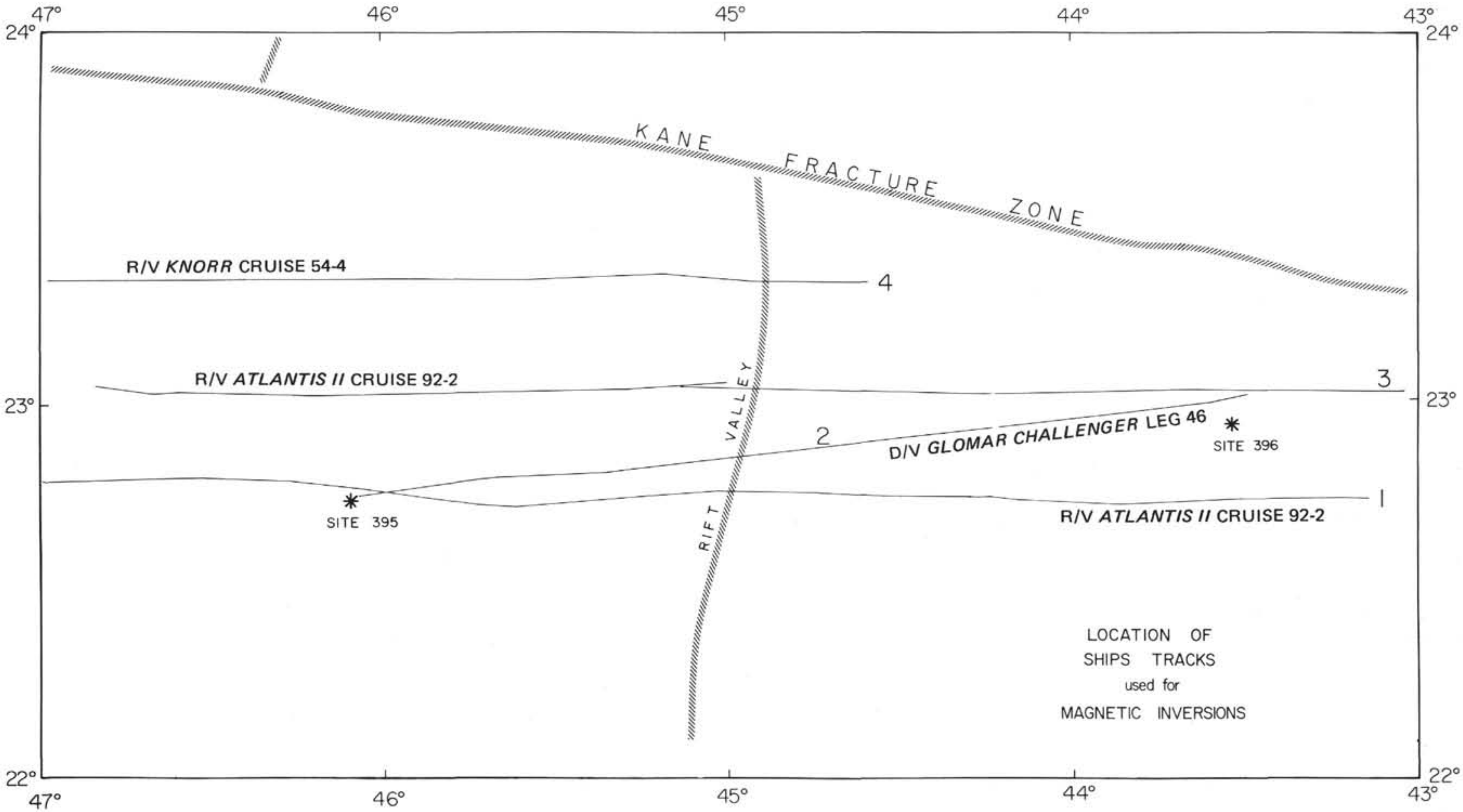

Figure 2. *Location of ship's tracks used for magnetic inversions.*

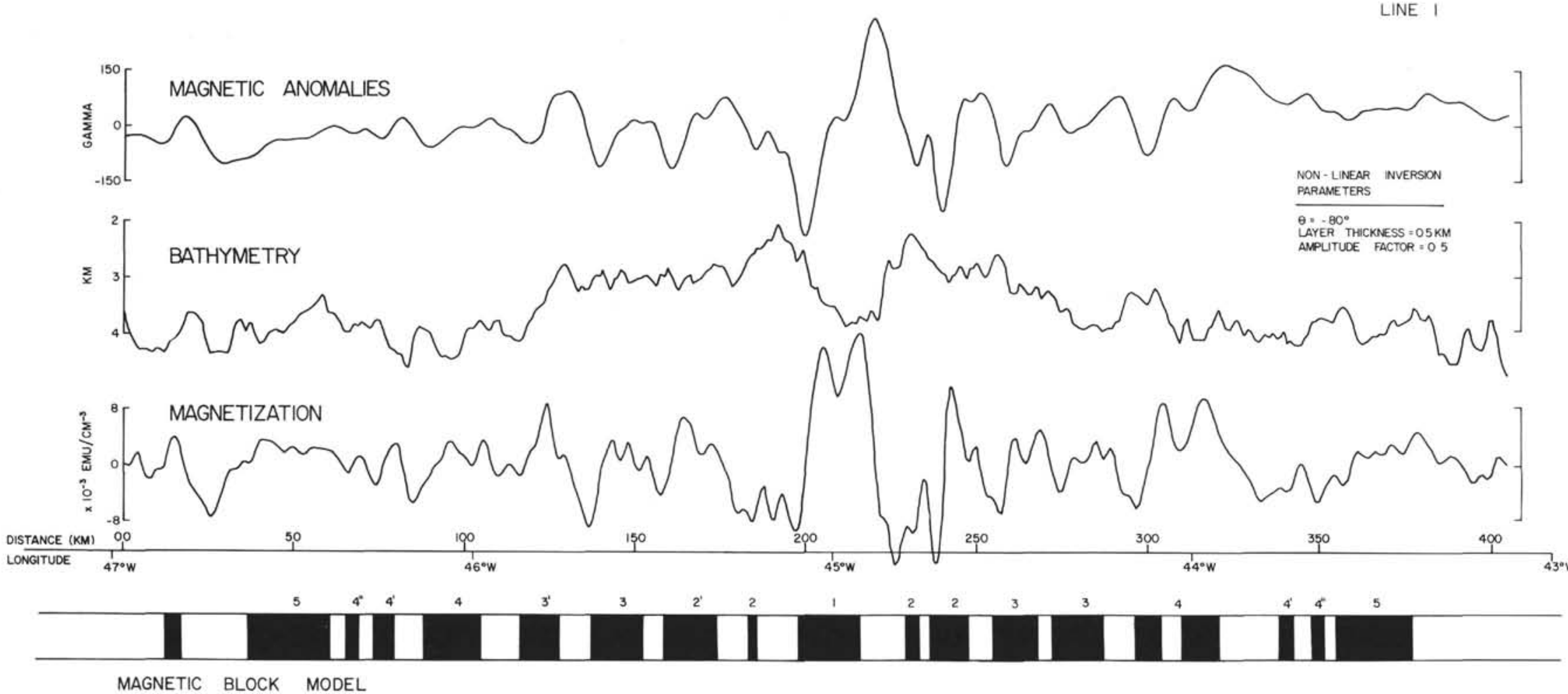

Figure 3. *Observed magnetic anomaly, bathymetry, magnetization profile determined from non-linear inversion and interpreted block model for Line 1; R/V* Atlantis II *Cruise 92-2.*

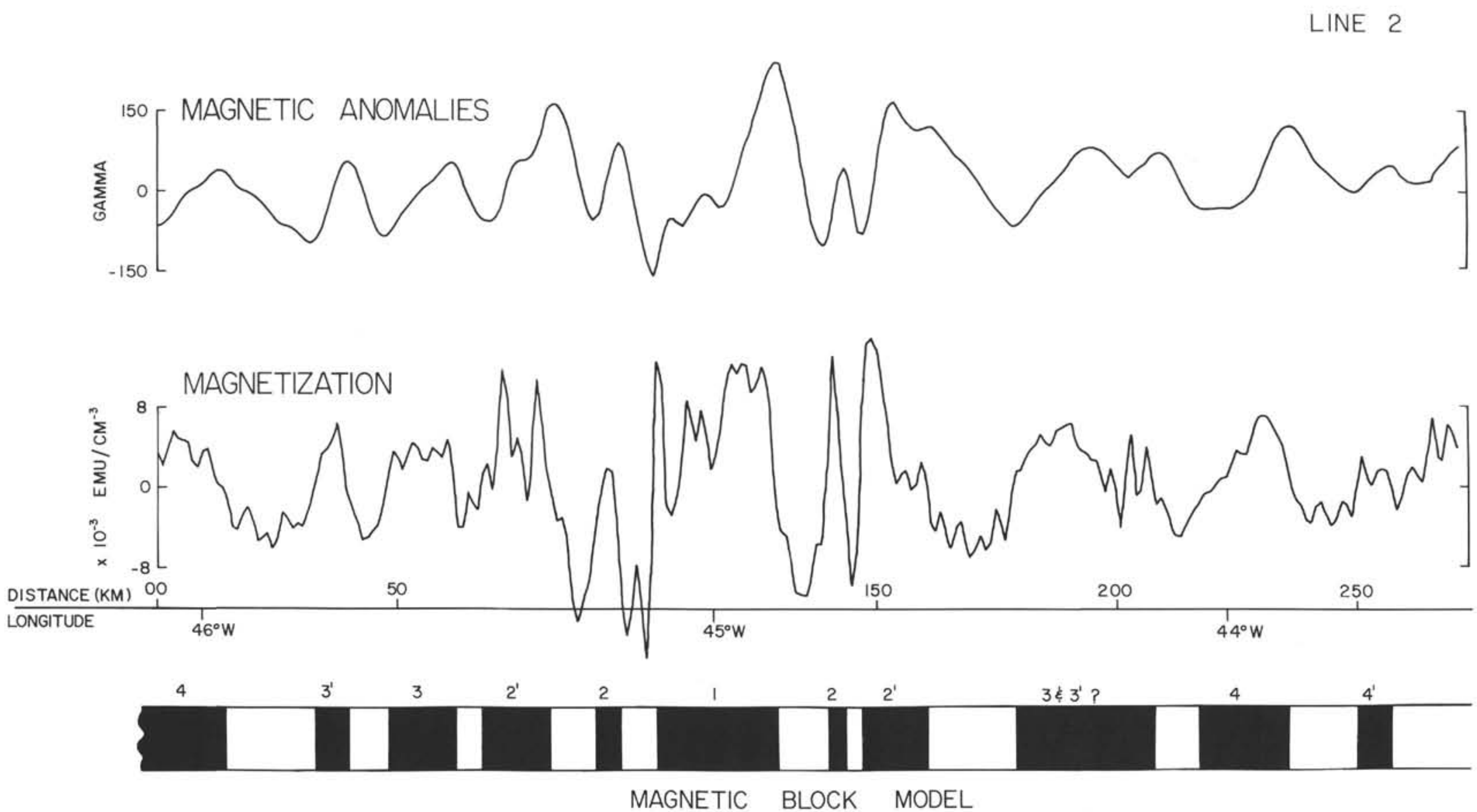

Figure 4. *Observed magnetic anomaly, magnetization profile determined from linear inversion and interpreted block model for Line 2; D/V* Glomar Challenger *Leg 46.*

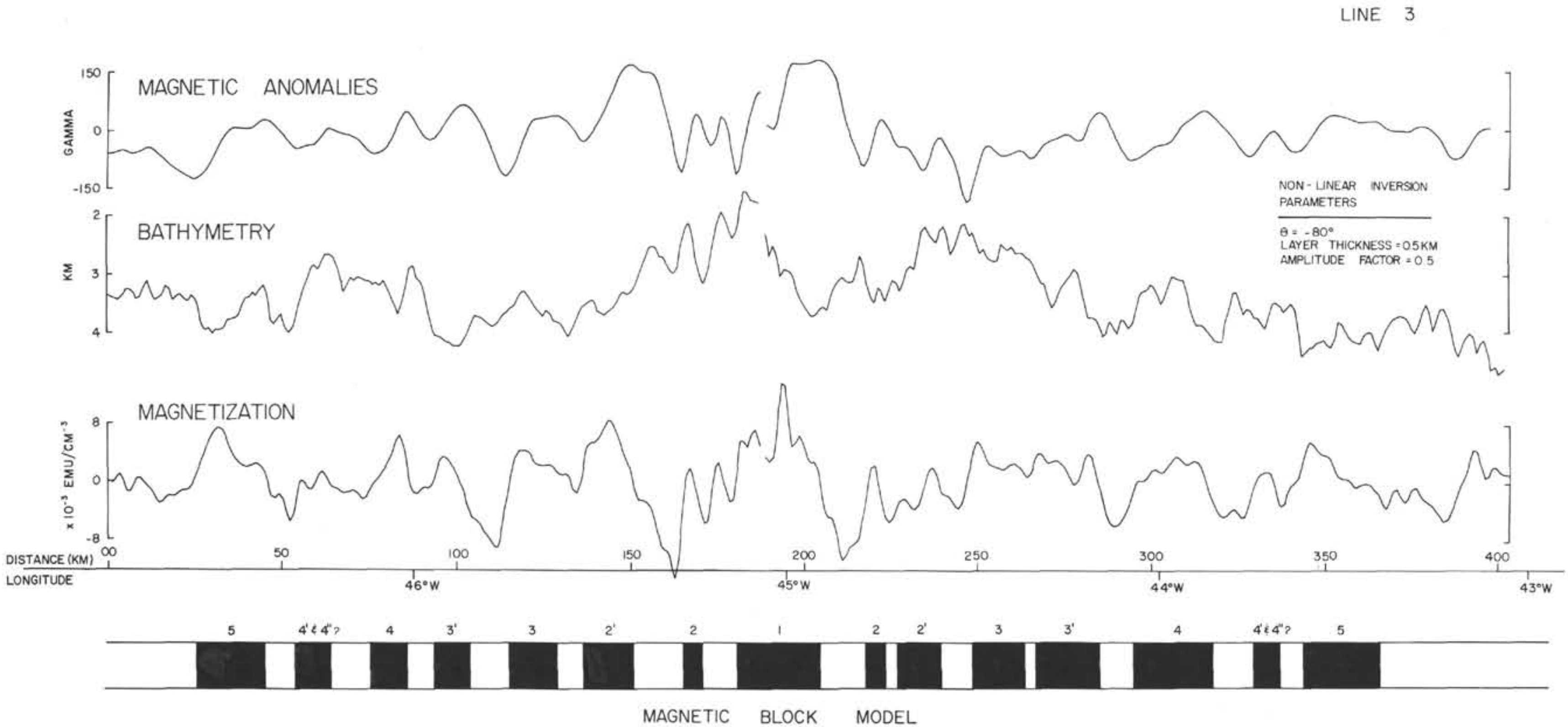

Figure 5. *Observed magnetic anomaly, bathymetry, magnetization profile determined from non-linear inversion and interpreted block model for Line 3; R/V* Atlantis II *Cruise 92-2.*

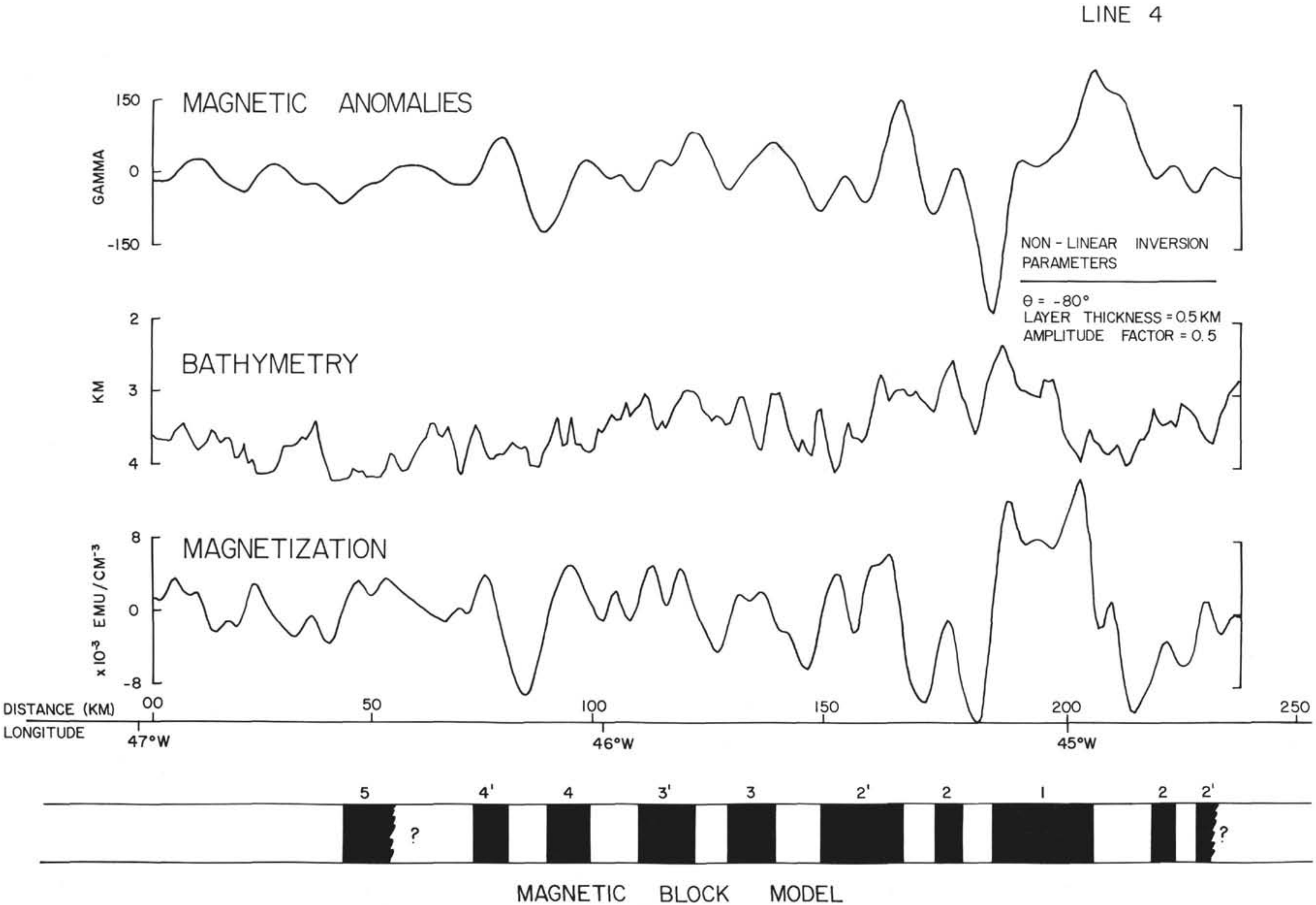

Figure 6. *Observed magnetic anomaly, bathymetry, magnetization profile determined from non-linear inversion and interpreted block model for Line 4; R/V* Knorr *Cruise 54-4.*

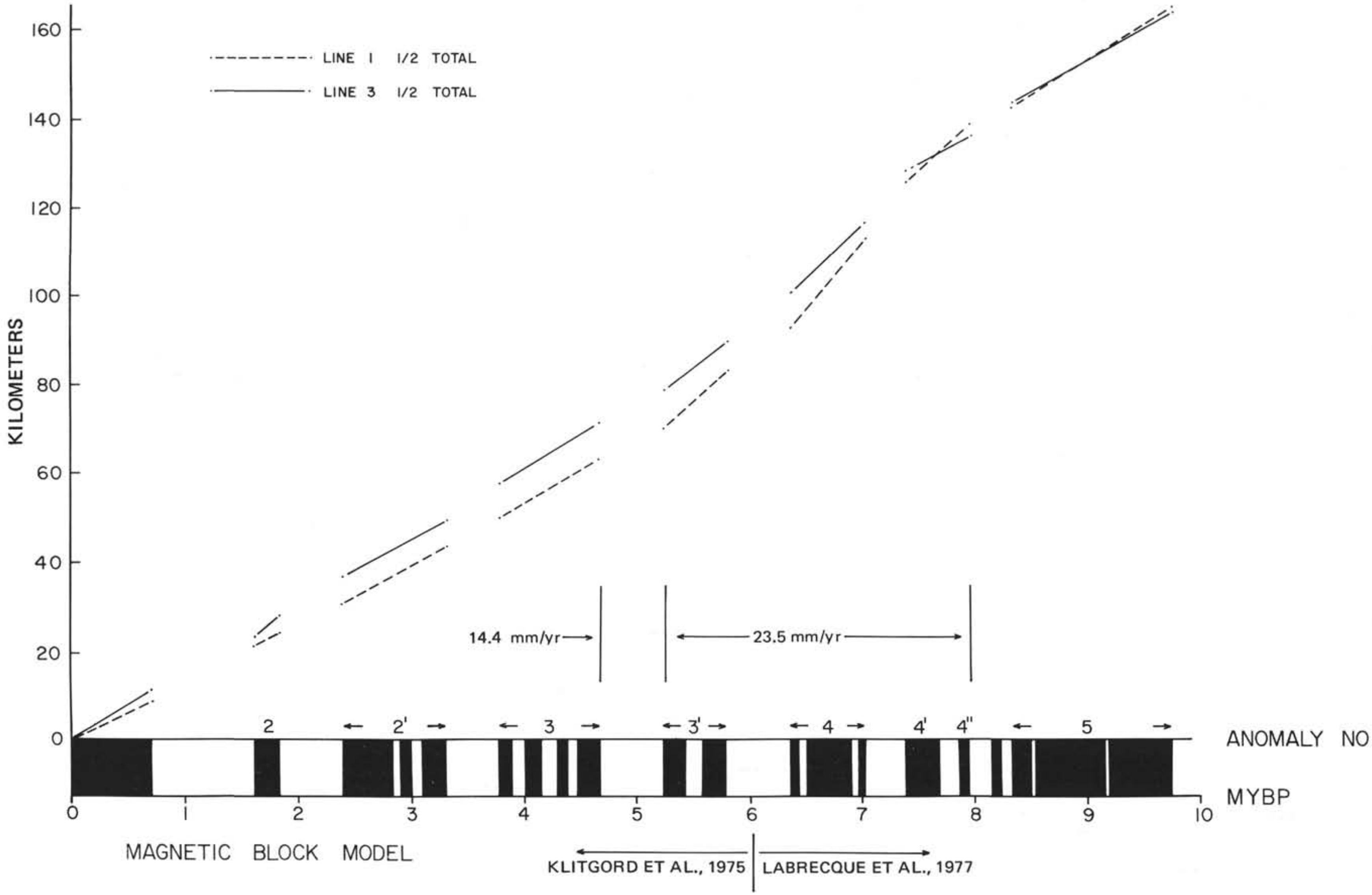

Figure 7. *Half-total spreading rates for Lines 1 and 3.*

only a negligible amount of crust within the two detailed survey areas was formed at the same section of the ridge axis. Thus, study of the symmetric or asymmetric nature of the process of formation of topography is not possible, because data coverage is insufficient outside the two detailed survey areas. The pattern of the magnetic stripes in Figure 7 indicates that the configuration of the accreting boundary has changed considerably and rapidly during the last 10 million years. This can have occurred only by local asymmetric spreading and/or ridge jumps. Evidence for variable asymmetric spreading also can be seen in the block models derived from the anomalies in Figures 3 through 5. We draw particular attention to the change in the sense of asymmetry occurring at anomaly 2 in these figures. The FAMOUS near-bottom magnetic data show a similar change in asymmetry, but in the opposite sense (Macdonald, 1977). We infer that at anomaly-2 time the central North Atlantic underwent a reorganization of plate motions, requiring readjustment of the accreting boundary, and resulting in local changes in the asymmetry of spreading.

South of 22°50′N, the Brunhes normal stripe is centered over the rift valley. Between 22°50′N and the Kane fracture zone, the rift valley broadens, becomes less well defined and the Brunhes normal stripe is centered over the western ridge crest. The subjective choice of the phase shift (80°) affects the inferred position of the stripe boundaries. However, a smaller phase shift (Justified by the more north-south trend of the central anomaly north of 22°50′N) would still result in a conspicuously asymmetric position of the Brunhes normal stripe with respect to the rift valley. Hence, it appears that part of the rift valley is under-lain by crust older than 0.7 million years (also see Figure 5 and 6). We hypothesize that in recent times (μ0.1 m.y.B.P.) the accreting boundary between 22°50′N and the Kane fracture zone jumped eastward to the edge of the present Brunhes normal stripe. This resulted in uplife of the old rift valley to form the western ridge crest, and subsidence of the eastern ridge crest to form the present rift valley.

The variability in amplitudes of the magnetic anomaly inversions reflects the variability of the magnetic source layer (thickness and/or magnetization intensity), both along and perpendicular to the isochrons. This degree of variability has been simulated with computer models of magnetic source layer emplacement at the accreting boundary by Matthews and Bath (1967) and Schouten and Denham (1977). The statistical parameters that determine this degree of variability are in general agreement with observations in the FAMOUS rift valley by Ballard and van Andel (1977) and can account for the poor quality of most sea-floor-spreading anomalies observed in the Atlantic Ocean.

Both linear and non-linear inversions were carried out on these data without producing any significantly different results. The non-linear method gives a more realistic representation of the magnetization intensities, because it removes the large-scale topographic effect. This method is more time consuming on the computer, however, and so more costly to use. The inversions illustrate the extreme variability of the magnetic source layer, and preclude a relationship between the smaller scale topography and the variability of the horizontal distribution of magnetization.

These results give ages of the crust of 6.5 million years at Site 395 and 8.8 million years at Site 396. The half-total spreading rate at these times was 23.5 mm/year and 14.4 mm/year, respectively.

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