# 45. CORRELATION OF SEAFLOOR SPREADING MAGNETIC ANOMALIES ACROSS KING'S TROUGH, NORTHEAST ATLANTIC OCEAN[1]

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**ABSTRACT**

Taking into account the DSDP Leg 94 site survey and drilling results, a review of the magnetic data from the flanks of King's Trough has led to analysis of 12 tracks running subparallel to the feature. Magnetic anomalies have been projected as profiles on an azimuth of 110°, coincident with the regional trend of magnetic lineations. Comparison of the profiles with a reversal chronology model has shown unambiguous anomaly identifications to the north which extend close to the Trough on its north flank. South of the Trough the anomaly sequence is less clear.

Anomaly identifications across King's Trough have previously been used as evidence of dextral offset. This chapter, however, follows recent studies suggesting that a dextral offset of up to 45 km exists on a fracture zone just to the south, and implying that the Trough itself shows no offset along its axis.

Studies reported here have expanded that interpretation to incorporate the dating control of Leg 94 Site 608 into the model. The results define the position of a transform, probably in existence during the period between Anomalies 31 and 18, encompassing the early part of the Pyrenean convergence. In addition, other discontinuities are shown to have existed in the magnetic lineations north and south of King's Trough during the same interval. These predate the later Miocene tectonic events responsible for subsidence of the crust that makes up the King's Trough basins, after its formation from a hot spot.

## INTRODUCTION

Since the first description of King's Trough (Fig. 1) by Laughton (1965), various ideas have been advanced concerning its origin; often these have been contradictory. Differing interpretations of the regional tectonic evolution of the shallow bathymetry and thickened crust associated with King's Trough—known as the King's Trough High—have been proposed, including aspects of compressive, extensional, and transform tectonics (Matthews et al., 1969; Le Pichon and Sibuet, 1971; Cann, 1971; Williams and McKenzie, 1971; Vogt and Avery, 1974; Searle and Whitmarsh, 1978; Grimaud et al., 1982, 1983; Kidd et al., 1982). These interpretations have generally related King's Trough to one or more of the tectonic features adjacent to it. Those include the Peake and Freen deeps (Cann and Funnell, 1967), often referred to as part of the King's Trough complex; the Azores-Biscay Rise (Whitmarsh et al., 1982); the Charcot/Biscay seamounts; and the North Spanish marginal Trough, because of its association with the Tertiary motion of the Iberian Plate (Le Pichon and Sibuet, 1971; Grimaud et al., 1982).

Integration of the tectonic history of these major oceanic features with the Pyrenean compression has highlighted two fundamental questions regarding not only the origin of King's Trough but also the history of the Iberian Plate, particularly in the oceanic domain. The first is whether the Trough itself was formed at the same time as the Pyrenean compression. The second is how one should interpret the apparent offset in the magnetic anomaly pattern across King's Trough (Grimaud et al., 1982, 1983; Searle and Whitmarsh, 1978).

Both these questions have imposed significant constraints on tectonic interpretations of King's Trough. Searle and Whitmarsh (1978) found evidence neither of compression nor of significant transform motion across King's Trough, and hypothesized that it formed from rifting along the crest of a hot-spot-generated aseismic ridge. Kidd et al. (1982) and Whitmarsh et al. (1982) presented evidence supporting the idea of a hot-spot origin; Whitmarsh et al. (1982) linked the Azores-Biscay Rise and the Milne Rise (west of the Mid-Atlantic Ridge) into a hot-spot aseismic ridge pair that predates generation of the King's Trough High. Grimaud et al. (1983) suggested a leaky-transform origin for King's Trough through a tectonic association with the Pyrenean orogenic phase. Louden (1983) concluded, however, through a spectral analysis of gravity and topographic profiles, that formation of the Trough itself postdated the formation of the Pyrenees, unless that orogeny continued well after 38 Ma, the late Eocene.

Site surveys for DSDP Site 608, together with intensive geophysical investigation of the area south of King's Trough between 1979 and 1982 (by the Institute of Oceanographic Sciences [IOS], U.K. [Kidd et al., 1983]), have provided new magnetic profiles with which to investigate regional anomaly patterns.

This chapter describes the interpretation of 12 selected magnetic profiles flanking King's Trough (Fig. 2). The magnetic anomaly chart of Roberts et al. (1985) has generally been the reference compilation for identification of magnetic anomalies in this area (Searle and Whitmarsh, 1978; Grimaud et al., 1982; Kidd et al., 1983). The establishment of a basement age for Site 608, situated on one of the previously unpublished magnetic pro-

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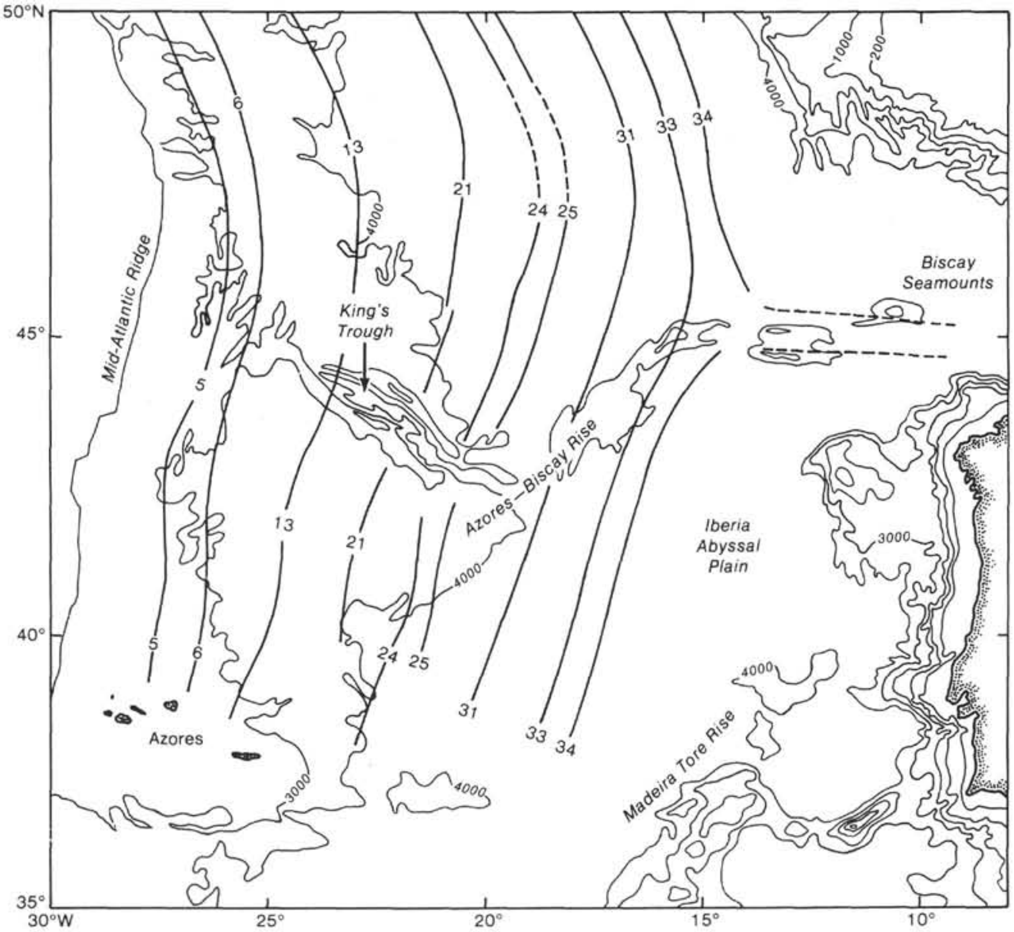


Figure 1. Regional setting of King's Trough in the northeast Atlantic, with the principal magnetic anomalies. Bathymetry is in meters.

files, now leads us to quantitative assessment of the magnetic anomalies. This provides new constraints on the origin of King's Trough and the seafloor spreading history of the lower Tertiary ocean crust in which the complex is situated.

## MAGNETIC ANOMALY DATA

The magnetic data used in this analysis were selected from the World Data Center files and those available at the Institute of Oceanographic Sciences (Table 1). Only profiles parallel or subparallel to King's Trough were chosen for analysis. Each magnetic anomaly profile was recomputed to the DGRF or IGRF80, as appropriate (International Association of Geomagnetism and Aeronomy, 1981), and was projected onto a line of azimuth 110°, orthogonal to the average strike of seafloor Anomalies 6 to 33 (corresponding to early Miocene to Late Cretaceous ages) adjacent to King's Trough. In Figure 3 these data are shown stacked from north to south in order of their intersection with Anomaly 24. For acutely intersecting tracks, some profiles have been split to maintain their correct spatial relationships. To clarify the anomaly sequence, a model anomaly was computed that would also be used to investigate the previous interpretations of the area.

## MAGNETIC MODEL AND ANOMALY IDENTIFICATION

The key anomalies shown in Figure 3 were identified by correlation with the model anomaly sequence. This model was generated from the magnetic reversal time scale of Berggren et al. (in press), adopted for this volume. The half-spreading rates used to derive the model are shown in Figure 3. Spreading rates given by Kristoffersen (1978) for Anomalies 33 to 23 (84–54 Ma) off the Celtic margin have been found to be consistent with the data for the west Iberian abyssal plain (Masson and Miles, 1984); they fit the profiles well, with an average half-spreading rate between these anomalies of 14.2 mm/yr., from the rates given in the model (Fig. 3). This compares with 16.5 mm/yr. in the Kristoffersen (1978) model at 40°N, although the latter model was derived from a reversal time scale some 8% shorter between these anomalies. A half-spreading rate of 9.4 mm/yr. for Anomalies 13 to 5 (37–10 Ma) (Pitman and Talwani, 1972) was assumed from the correlations shown in Figure 3. The half-spreading rate between Anomalies 23 and 13 was calculated to be 12.2 mm/yr., from the unambiguous correlation of Anomalies 24 to 13 on the northern flank of King's Trough.

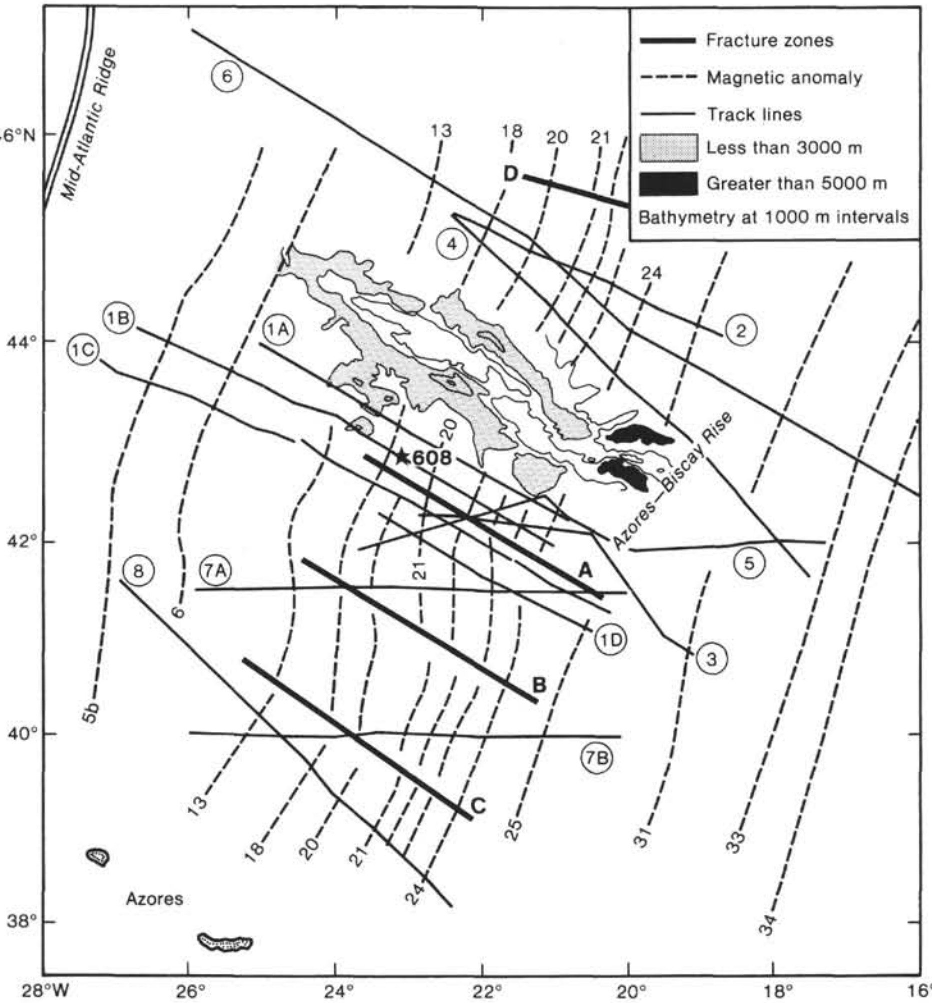


Figure 2. Locations of magnetic profiles flanking King's Trough, and magnetic Anomalies 5 to 34 and fracture zones A to D, as interpreted in this chapter. Tracks are identified by the circled numbers, corresponding to those given in the "Cruise" column of Table 1.

Table 1. Data sources of magnetic profiles.

| Cruise | Source | Availability |
|---|---|---|
| (1) *Discovery* Cruise 33 | M. T. Jones (personal communication, 1972) | IOS data report |
| (2) *Discovery* Cruise 93 | World Data Center | Tape |
| (3) *Discovery* Cruise 118 | IOS | IOS |
| (4) *Discovery* Cruise 131 | IOS | IOS |
| (5) *Discovery* Cruise 134 | IOS | IOS |
| (6) *Lynch* LY73F | World Data Center | Tape |
| (7) *Kane* KA70 | World Data Center | Tape |
| (8) *Chain* CH082 | World Data Center | Tape |

A 2-km-thick magnetic model, with a magnetization of 6 A/m at a depth of 4 km below sea level, was adopted to represent oceanic Layers 2A and 2B. The 2-km thickness is greater than that proposed for average ocean crust by Banerjee (1984), but it was chosen to explain the large-amplitude anomalies present over the southern flank of King's Trough. The results of Searle and Whitmarsh (1978) show that these anomalies may be related to abnormally thick ocean crustal layers, particularly Layer 2. The remanent magnetic parameters of the model, taken from Cande and Kristoffersen (1977), have a Late Cretaceous/early Tertiary remanent inclination (Ir) of 41°. A lower inclination of the remanent field direction would require a significant increase in magnetization to match the anomaly amplitudes.

The skewed magnetic anomaly associated with the reversed-polarity interval between Anomalies 33 and 34 can be clearly identified striking east of North across the Iberian abyssal plain (Kristoffersen, 1978; Masson and Miles, 1984). Profile 6 (Fig. 3) locates Anomaly 33–34 on the stacked profiles. To the west, Anomaly 31 is identifiable crossing the Azores–Biscay Rise at an acute angle. In agreement with Whitmarsh et al. (1982), this continuity suggests no relative transform motion across the rise itself. To the south, Anomaly 31 continues as a strong linear feature, except for a small break at 42°N, 19°W (Fig. 2), where the King's Trough axis projects onto the Azores–Biscay Rise at the northern end of a group of seamounts. Whitmarsh et al. (1982) interpret here a small dextral offset in Anomaly 31, which is not unreasonable (see discussion following), but their indicated offset (35 km) is too large.

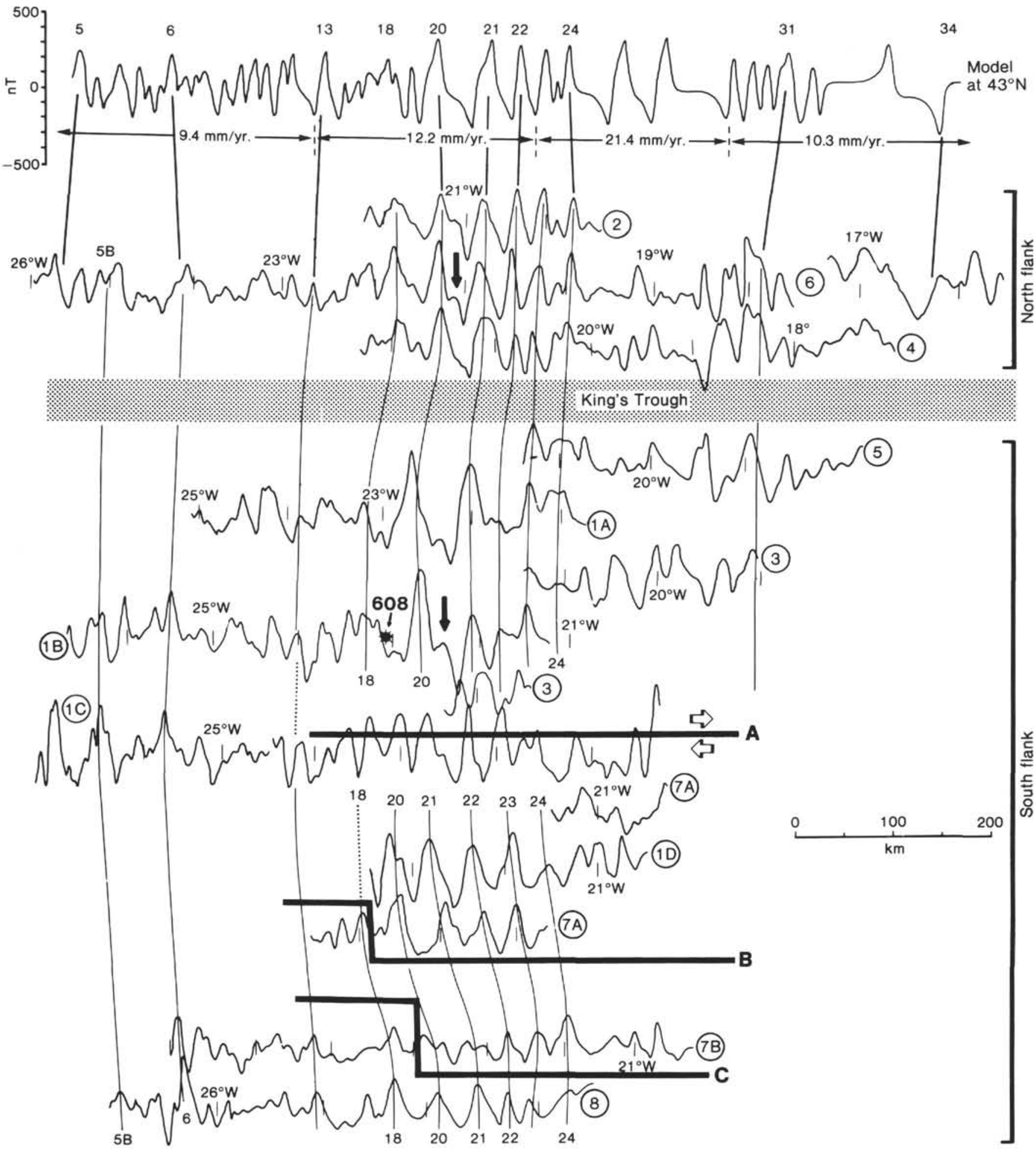


Figure 3. Projected magnetic profiles stacked in the order of intersection with Anomaly 24. Higher-amplitude anomalies exist north of the proposed fracture zone A at line 1C; the change in anomaly character is interpreted as an integral offset between Anomalies 20 and 21. This mirrors White and Matthews' (1980) interpretation of the small fracture zone north of the Trough. The additional phase in the profiles between Anomalies 20 and 21 is indicated by the arrow. Profiles are annotated at each degree of longitude and identified as in Figure 2.

The ambiguity in magnetic anomaly interpretation across King's Trough is evident in Figure 3 by comparing the clear sequence of correlatable Anomalies 18 to 25 north of the Trough (top three profiles) with that on the southern flank, even with the close line spacing of this data set. This confused anomaly sequence in the Eocene crust south of King's Trough, above the northward bend in Anomalies 18 to 24 at 41°N (Fig. 2), has been correlated up to the Trough flanks by Searle and Whitmarsh (1978) and, alternatively, has been stopped short by Kristoffersen (1978). The chart of Roberts et al. (1985) is difficult to interpret in this area, but does provide the framework for the interpretation proposed by Kidd et al. (1983). They identify a WNW-ESE (101°) dextral offset in the magnetic anomalies subparallel to King's Trough between latitudes 42.7°N and 42.2°N. The offset can be seen as a bend in Anomaly 18 and as the apparent termination of Anomaly 20 on the chart of Roberts et al. (1985), and is visible in the Atlantic seafloor spreading lineations compiled by Klitgord and Schouten (personal communication, 1984). It is disguised by the apparent continuity, through integral displacement, of Anomalies 20 and 21 across it near 42°N, 23°W. The anomalies north of this offset (Fig. 3) show an additional anomaly phase between Anomalies 20 and 21 and an increase in anomaly amplitude. Both of these characteristics can be correlated with those described by White and Matthews (1980) for the anomalies south of a small fracture zone with a 15-km sinistral offset—associated with a short period (9 m.y.) of asymmetric spreading—some 150 km northeast of King's Trough, at 45.5°N, 21°W (line D on Fig. 2). Figure 3 shows that this special characteristic of the magnetic anomaly signature extends south to King's Trough and continues, with the increased amplitude on its southern flank, to the dextral offset, where the anomaly sequence and amplitudes return to normal, so mirroring the effects of the White and Matthews (1980) fracture zone to the north.

This interpretation of the magnetic anomalies is substantiated by the basement age at Site 608 (42 Ma), corresponding to ocean crust of Anomaly-18 age or just predating it on line 1B (Fig. 3).

The location of the Kidd et al. (1983) fracture zone is modified in this chapter as fracture zone A (Figs. 2 and 4), striking WNW-ESE (120°) from a point coincident with that shown by Kidd et al. (1983) for their offset on Anomaly 18. The 120° direction is chosen in preference to that of Kidd et al. (1983), which met Anomaly 31 coincidently with the along-strike projection of King's Trough, for two reasons illustrated in Figure 3. First, profile 1C is difficult to correlate with those to the north but shows contiguity to the south, particularly east of Anomaly 20. Also, the anomaly signatures east of Site 608 on profiles 3, 1A, 1B, and 5 cannot be correlated with those to the south as would be expected from the offset position given by Kidd et al. (1983). Second, the sediment-thickness isopach chart of Jacobs (this volume) shows basement outcrop—identified from GLORIA coverage at 42.5°N, 23°W—to trend NNE-SSW, with a relief of some 250 m on crust of approximately 45 Ma (Anomaly 20). This outcrop terminates along its southern edge coincidently with the proposed location of fracture zone A.

## DISCUSSION

The interpretation of anomaly patterns that we have proposed here is illustrated in Figures 2 and 4 using the modified contours of Roberts et al. (1985). We also suggest that two other discontinuity zones, B and C, are possible within the magnetic lineations southwest of King's Trough (Figs. 2 and 3). These are interpreted to coincide with abrupt changes in direction of the magnetic lineations, and may reflect other minor plate adjustments south of our main fracture zone A, as already discussed.

The dextral offset across fracture zone A (Fig. 5) reaches a maximum of 45 km at Anomaly-21 time (49 Ma), decreasing to the east and west. The offset was already in existence at Anomaly-24 time (55 Ma), and appears to have eradicated itself during a continued period of asymmetric spreading across the transform between Anomalies 18 and 20 (middle Eocene). This would suggest a small fracture zone existing between Anomaly-25 and -18 times (59–42 Ma), because Anomaly 31 does not appear to be affected along the strike of this offset, as it does southeast of King's Trough.

We inferred in the preceding section that fracture zone A effectively mirrors the characteristics of the magnetic anomalies and some of the spreading-rate changes identified by White and Matthews (1980) 150 km northeast of King's Trough. Both fracture zones are associated with discontinuities in basement structure and bathymetry, but more significantly, both show strong affinities in asymmetric spreading and magnetic anomaly relationship during approximately the same interval, particularly at Anomaly 20–21 time. The seismic refraction results obtained by White and Matthews (1980) give a fracture-zone velocity structure which they interpret as evidence for the juncture of two magma chamber systems or separate sections of ridge crest emplacing different magnetic layers. From this we propose that their interpretation could also apply to fracture zone A. It would then follow that King's Trough could have been formed in crust generated from an individual spreading center isolated between these two fracture zones. This would explain the correlation of some magnetic anomaly characteristics across King's Trough and the conformity of spreading rate seen in Figure 5.

It should be noted here that, from the interpretation of gravity models by Searle and Whitmarsh (1978), the southwestern limit of thick ocean crust associated with King's Trough between Anomalies 13 and 18 (36–42 Ma) corresponds to the northwestern end of fracture zone A, although this limit recedes north toward the Trough on Anomaly 20.

## CONCLUSIONS

The preceding discussion establishes two important markers in the history of the King's Trough High. First is that a period of asymmetric spreading across small-offset (45 km maximum), ESE-trending fracture zones on each side of King's Trough occurred between the early and middle Eocene. This just predates the middle to late Eocene main Pyrenean orogenic phase. The maximum offset along fracture zones A and D exists at Anomaly 21 (49 Ma) but affects seafloor spreading Anomalies 18 to 24 in the area of fracture zone A. The second point is that minimal offset of the magnetic anomalies is obtained across King's Trough itself. This suggests that the Trough was not an important transform plate boundary during the early to middle Eocene.

In addition, the trachyte intrusive event within the King's Trough axis (32–34 Ma; Kidd et al., 1982) and the end of the period of formation of the major sedi-

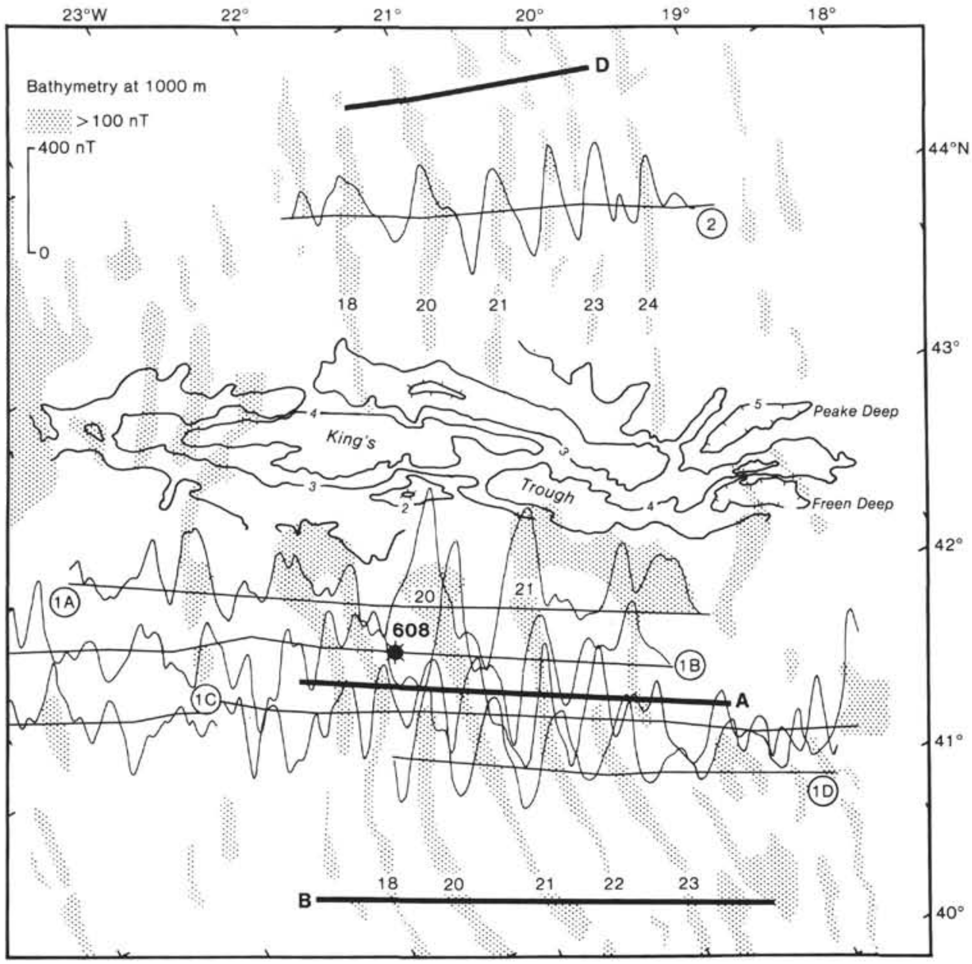


Figure 4. Detail of five magnetic anomaly profiles flanking King's Trough, together with regional positive anomaly contours (shaded) (modified from Roberts et al., 1985). Anomaly 20 is offset north of fracture zone A to give apparent continuity of Anomaly 21. Anomaly, track, and fracture zone annotation as in Figure 2.

mentary hiatus at Site 608 both postdate Anomaly 13 (36 Ma) and, consequently, the Pyrenean orogeny. The sediment-instability events deciphered within lithologic Subunits VC and VB of Hole 608 (Site 608 report, this volume) clearly postdate the Pyrenean events by 10 to 20 m.y.

It appears, therefore, that it remains marginally feasible to correlate the Pyrenean orogenic activity with the early events around the King's Trough complex. But the main tectonic events responsible for the formation of its troughs and basins probably occurred much later, during the Miocene. This is in agreement with a post-early Oligocene (< 30 Ma) formation of King's Trough, as suggested by Louden (1983), and an initial hot-spot origin for the King's Trough High.

The results obtained from the magnetic data in this chapter do not indicate whether extension has occurred across King's Trough. If spreading has occurred during the formation of the Trough, either through post-early Oligocene rifting or through the existence of a short-lived spreading arm (Whitmarsh et al., 1982), then it must have taken place within the Trough axis, since there is no evidence for this on either flank. These results suggest that formation of the Eocene ocean crust of King's Trough was separate from the formation of the Trough, during the Miocene, and that there is little evidence that King's Trough is an important transform plate boundary.

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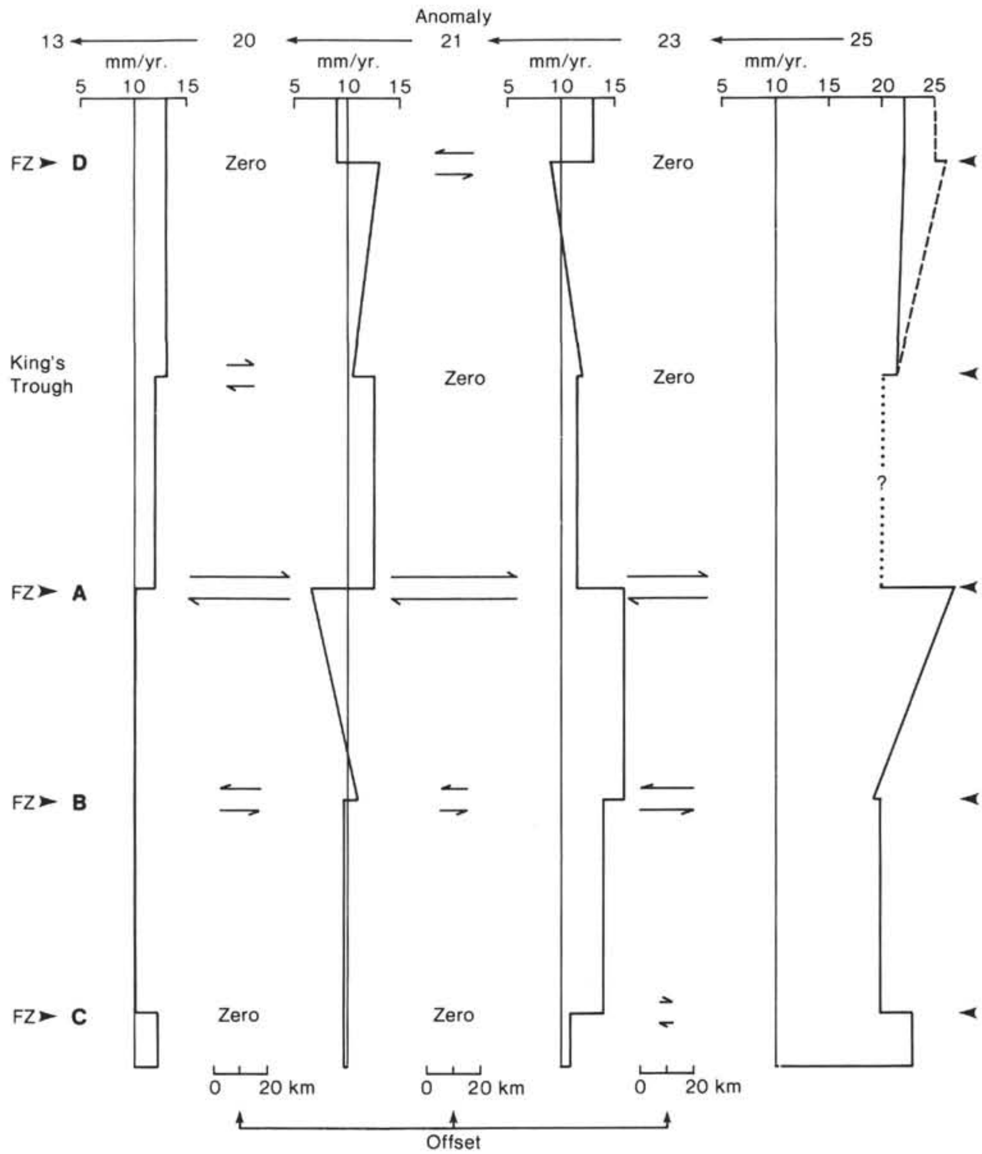


Figure 5. Offsets across each proposed fracture zone and King's Trough (offset ≡ line length) for magnetic Anomalies 20, 21, and 23. Half-spreading rates were obtained from the anomaly identifications in Figure 3. The dashed line is the half-rate between Anomalies 23 and 25, given by White and Matthews (1980).