GEOPHYSICAL RESEARCH LETTERS, VOL. 13, NO. 1, PAGES 157-160, FEBRUARY 1986

A STATISTICAL CORRELATION BETWEEN RIDGE CREST OFFSETS AND SPREADING RATE

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Abstract. Ridge crest offsets follow the statistical distribution, $N = A \exp[-B \ln(L/L_o)]$, where N is the cumulative number of ridge crest offsets with lengths greater than L, L_o is the cutoff length, and A and B are constants. We measured A and B for the slow spreading mid-Atlantic ridge, the intermediate spreading Juan de Fuca Ridge, and the fast spreading east Pacific Rise. The predicted mean distances between offsets greater than 4 km long are 30, 32, and 74 km on the slow, intermediate and fast spreading ridge crests. These distances are in agreement with observations of other workers and calculations of modal ridge lengths.

Introduction

Oceanic crust created at a fast spreading ridge has lower basement relief and fewer ridge crest offsets than crust created at a slow spreading ridge [MacDonald, 1983]. In part, the greater topographic roughness of oceanic crust created at a slow spreading ridge is due to a greater number of ridge offsets without a corresponding decrease in average offset length. Because of the slower spreading rate, the same length of offset on a slow spreading ridge results in a larger age difference between the offset pieces of oceanic lithosphere. Because the oceanic crust subsides as it ages [Sclater et al., 1971], this increased age difference will increase the local topographic relief. Furthermore, the depth of the valley at ridge-transform intersections is proportional to the age-offset between the two ridge-segments [Fox and Gallo, 1984]. Although some of the relief is due to hydraulic head loss [Sleep and Biehler, 1970], these fracture zone valleys are often preserved on older seafloor [Menard and Chase, 1971]. Similarly, the size of the topographic step across fracture zones is proportional to the age difference between the seafloor on either side of the fracture zone [Sandwell and Schubert, 1982]. Because ridge crest processes control most of the morphology of older oceanic basement, the offset length distribution of ridge crests has many potential applications in analyzing the basement topography of older oceanic crust.

Recent multibeam bathymetric surveys of spreading centers with slow, intermediate, and fast total opening rates have shown that small offsets of the ridge crest are more abundant than large offsets [McDonald and Fox, 1983; Ramberg et al., 1977]. Fox and Hayes [1985] found that the basement relief of oceanic crust as a function of spatial frequency can be fit by a power law. We have derived a similar quantity which describes the probability of finding a ridge crest offset of a given length.

Paper number 5L6762
0094-8276/86/005L-6762$03.00

Measurement Technique

The data used to determine the spectral character of the distribution of ridge crest offsets included multibeam (SEABEAM) and detailed single beam (PDR) bathymetric surveys of the ridge crest. Continuous sections of ridge crest (Figure 1) were used, because detailed surveys are preferentially located on the longer offsets. The locations of the ends of a single ridge crest segment were always determined from the same map, to minimize navigational errors and discrepancies between different maps. We used bathymetry from three ridge crests spanning a range of whole spreading rates: the slow spreading (3 cm/yr) Mid-Atlantic ridge, the intermediate spreading (6 cm/yr) Juan de Fuca ridge, and the fast spreading (9-12 cm/yr) east Pacific rise.

We measured the maximum perpendicular offset between ridge segments. This measurement differs from another common measure; the actual fault length. We used the perpendicular offset because it more accurately reflects the age-offset between the two ridge segments and it reduces the possibility of bias between different bathymetric data sets.

Distribution of Offsets

Locations of the ends of the maximum perpendicular offsets were used to generate two data sets: the distribution of offset lengths and of ridge segment lengths. The offset lengths could also be used to generate a distribution of age-offsets, but for convenience in the comparison with other data sets, the data has been kept in the form of offset length distribution. On each ridge crest, the distribution of offset lengths was plotted as a cumulative distribution: the log of the length of offset versus the log of the cumulative number of offsets longer than a given length (Figure 2a). We found that the cumulative number of ridge offsets, N, which are longer than a given length, L, is given by the relationship: $N = A \exp[-B \ln(L/L_o)$, where L_o is the cutoff length, and A and B are constants. This formula is similar to one used in seismology to describe the distribution of earthquake magnitudes. In the seismic case the constant B is called a 'B-value'. We will also use this phrase, recognizing, of course, that there need not be any physical connection between these two types of B-values. Formulas for estimating B-values and their standard errors are given by Aki [1965]. As with earthquake B-value plots, the slope of the log normal line remains constant only in the region of 100% detection, that is for $L>L_o$. Each of the three data sets can be fit by the exponential distribution, in the sense that they pass a chi-squared test.

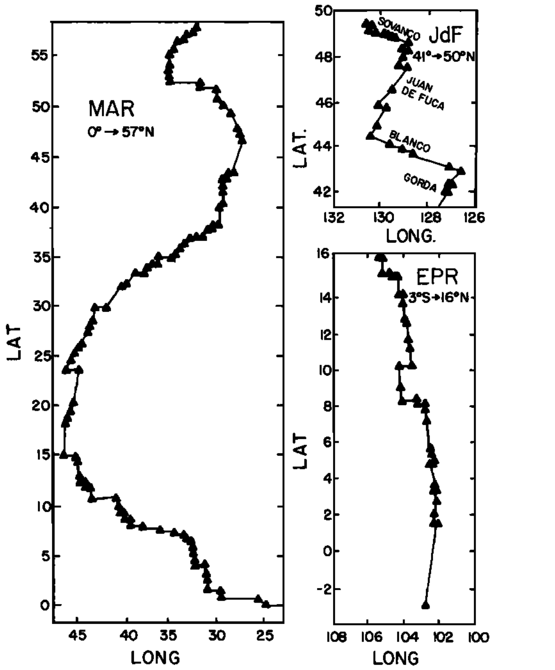

Fig. 1. Location of offsets. Short offsets (single triangle) and long offsets (two connected triangles). Data sources below not cited in text. (left) Mid-Atlantic ridge (MAR): Laughton and Searle, 1979; Perry et al., 1981; Searle, 1981; Searle and Laughton, 1977; R. Bell, pers. comm., OTTER, 1984; Rona et al., 1976; Detrick and Purdy, 1980; Salisbury and Hyndman, 1984; Collette et al., 1974; Detrick et al., 1982; Van Andel et al., 1971; Heezen et al., 1964; Belderson et al., 1984. (right top) Juan de Fuca ridge (JdF): Juan de Fuca Ridge Atlas, 1985; Crane et al., 1985; Embley et al.; 1984; A. Malahoff, pers. comm. (right bottom) East Pacific Rise (EPR): Madsen et al., 1986; Lonsdale, 1977, 1983, 1985a, 1985b.

Deviations from the exponential distribution can be explained by random error.

On each spreading ridge, we choose an offset length above which there appears to be 100% detection of all offsets (Figure 2a). These lengths are respectively: L_o = 43 km on the Mid-Atlantic ridge, L_o = 4.8 km on the Juan de Fuca ridge and L_o = 6.4 km on the East Pacific rise. The east Pacific rise and the Juan de Fuca ridge have nearly complete multibeam bathymetric coverage and, consequently, a very low detection limit.

On the slow-spreading Mid-Atlantic ridge, A = 3.43 per 1000 km of ridge crest, B = 0.96 +/0.39. We predict a cumulative number of 34 offsets >4 km long for every 1000 km of ridge crest with an average of one offset every 30 km and a range of 12-74 km. This range overlaps early estimates of one offset every 50-80 km [Schouten and White, 1980; McDonald, 1982], and coincides with more recent estimates of one offset every 40 km [Schouten et al., 1985].

On the intermediate spreading rate Juan de Fuca ridge system, A = 26.6 per 1000 km of ridge length, B = 0.81 +/- 0.32. On this ridge crest, we predict 31 offsets > 4 km long every 1000 km with an average distance between offsets of 32 km and a range of 30-34 km. Given the error limits, the theoretical models predict a 30-62 km average ridge length at a whole spreading rate of 6 cm/yr [Schouten et al., 1985]. My results are consistent with these predictions but are close to the maximum error limits. However, previous calculations indicate that the stresses on the Juan de Fuca transform faults may be increased by the subduction zone [Fujita and Sleep, 1978]. This increase in stress might cause the longest transforms to break up into shorter transforms separated by short ridges or pull apart basins. Consequently, the Juan de Fuca ridge may have more offsets per unit length than a 'typical' intermediate spreading rate ridge. Unfortunately, it is presently the only ridge crest with an intermediate spreading rate which has sufficiently detailed bathymetric coverage to calculate an offset length B-value.

On the fast spreading northern segment of the east Pacific rise, A = 8.21 per 1000 km of ridge crest, B = 1.07 +/-0.49. In this instance, we predict a mean distance of 74 km between offsets > 4 km long and a range of 58-95 km, or 14 offsets every 1000 km of ridge length. This range of distances between offsets brackets the 85-90 km distance predicted by some observations and theoretical models [McDonald, 1982; Schouten et al., 1985].

We estimate that these B-values are valid for offsets longer than the width of the zone of active intrusion, or approximately 4 km. Because cooling increases the thickness of the brittle layer, the rift valley floor on slow spreading ridges is narrowest where an active crustal magma chamber is present [Harper, 1985]. Detailed studies also show that magmatic activity is confined to the floor of the rift valley [Atwater, 1979]. Therefore, the minimum width (2-4 km) of the inner floor of the rift valley

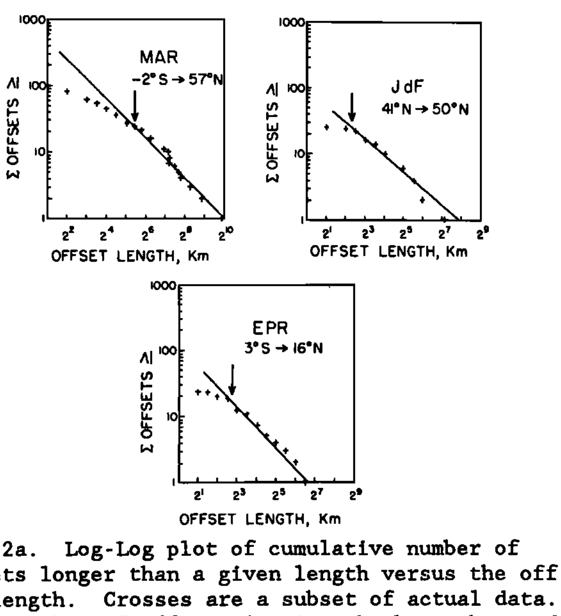

Fig. 2a. Log-Log plot of cumulative number of offsets longer than a given length versus the offset length. Crosses are a subset of actual data. Total number of offsets is given both as observed offsets and as the subset used to calculate the offset B-value. Arrow points to shortest length used. Line is offset B-value. The log-log scale increases the apparent errors of the longer offsets. The distance between the observed and predicted number of offsets is always less than one offset on the right side of each plot. (left) MAR: 81 offsets observed, 43 used. (Middle) JdF: 25 observed, 22 used. (right) EPR: 28 observed, 18 used.

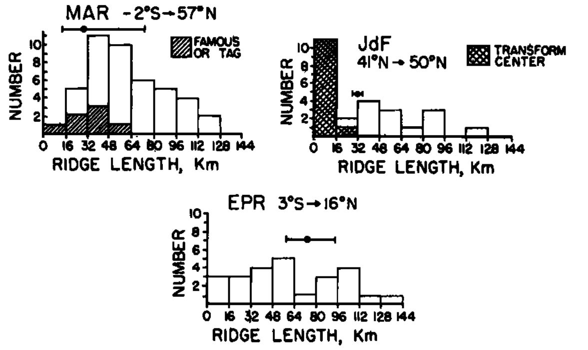

Fig. 2b. Histograms of ridge segment lengths. (left) MAR. Striped zones- ridge segments in the FAMOUS and TAG areas. (middle) JdF, (right) EPR. Hachures- ridge segments within transforms. Bold point with error bar is mean ridge length estimated from offset data.

on slow spreading ridges roughly defines the width of the zone of active intrusion. Ridge crest offsets which are contained within the zone of active intrusion may appear and disappear during different magmatic episodes. Consequently, the processes controlling the abundance of these short offsets are likely to be somewhat different and they should not be included in a ridge crest offset B-value relationship.

Distribution of Ridge Crest Lengths

The distribution of ridge crest lengths is shown in Figure 2b. We assume that the modal ridge lengths, as measured from these distributions, are estimates of the mean ridge lengths. This relationship would hold if the true distribution were symmetical and peaked at some non-zero ridge length, an assumption supported by theoretical models [Schouten et al., 1985]. (We attribute the asymmetry of the observed distribution to the skewing effect of missing offsets). Having estimated a mean ridge length, we can then compare it to the mean ridge length implied by the ridge crest offset distribution, evaluated at 4 km.

On the slow spreading mid-Atlantic ridge, the modal ridge length is 32-48 km, which is within the range of the theoretically predicted 12-74 km average ridge length. This modal ridge length appears in both the larger data set and in the two areas of detailed surveys, FAMOUS and TAG. The appearance of this modal ridge length in the FAMOUS and TAG areas is particularly encouraging because none of the ridge crest offsets from these detailed survey areas are longer than 42 km. Consequently, the mode of this subset of the ridge lengths was derived from a completely independent data set. This mode confirms the basic validity of the offset length B-value for the northern Mid-Atlantic ridge.

On the east Pacific rise and the Juan de Fuca ridge, the ridge crest lengths are not completely independent from the offset length B-value. Nevertheless, the ridge crest length distribution does provide a test of the relationship. Both the Juan de Fuca ridge and East Pacific rise show a bimodal distribution of ridge crest lengths. Of the two dominant modes (Figure 2b), the mode which has the longest ridge crest length is the mode predicted by the model. On the Juan de Fuca ridge, the most dominant mode is associated with ridge crests within transform faults. On the east Pacific rise, the two dominant modes are both caused by ridge crest offsets. The modal peak at ridge crest lengths of 48-64 km agrees with our theoretical prediction of 58-95 km. The average of the two dominant modes of ridge crest length on the East Pacific rise is around 80 km. A simple average of all of the ridge lengths is 73 km, a value which is within the errors of other simple averages [Schouten et al., 1985]. Consequently, our results agree with other observations, but the bimodal distribution of modal ridge lengths indicates that the processes may be more complex than previously assumed.

Conclusions

The modal values of ridge length are in agreement with the predictions of ridge crest offsets for all three spreading centers: the Mid-Atlantic ridge, the Juan de Fuca ridge, and the East Pacific rise. The B-values and associated constants change in a fashion which is consistent with independent observations of an increase in the number of ridge crest offsets as the spreading rate decreases. Therefore, the B-value distributions of ridge crest offset lengths are reasonable in light of the present knowledge of ridge crest morphology. Furthermore, because the topographic relief of fracture zones is largely determined by the age offset of the fracture zone, these offset length B-values are an important step in quantifying the contribution of fracture zones to the basement morphology of oceanic lithosphere created at different spreading rates.

These offset length 'B-values' could contribute to several types of studies. They can be used to estimate sea floor roughness and thus have a bearing on models of tides and tsunamis [Fox and Hayes, 1985]. The technique can also be used to extrapolate low spatial resolution data, such as is collected by the SEASAT satellite altimeter. The offset distribution also predicts variations in seafloor morphology as a function of spreading rate. This spreading-rate-dependent morphology implies that this relationship might ultimately lead to a method of estimating the paleo-spreading rate of magnetically quiet seafloor.

Acknowledgements. We thank B. Brandsdottir, V. Kulm, and W. Menke for critical reading of the manuscript.

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(Received November 19, 1985;
accepted December 6, 1985.)