000, and 122,000 years ago by the Th^{230}/U^{234} method. One of these figures does not agree with the deep-sea chronology as determined by Th^{230}/Pa^{231} measurements. In fact, while the age of 82,000 years corresponds to the interglacial stage 5, and the age of 122,000 years to the end of interglacial stage 7, the age of 103,000 years does not correspond to an interglacial but to a full glacial (temperature minimum of stage 6). The possibility that the 103,000-year-old terrace may not have been formed during an interglacial age should be investigated. In fact, supramarine littoral deposits formed during glacial rather than interglacial ages are not unknown. For instance, Emiliani (*17*) obtained definitely glacial isotopic values from the top of the falesia near Vila Nova de Milfontes, Portugal, and Emiliani and Mayeda (*15*) obtained similar values from a fossil beach at + 5 m in Sardinia, an island which should be much more stable than Barbados.

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East Pacific Rise Crest: A Near-Bottom Geophysical Profile

Abstract. *A deep-towed magnetometer profile made across the East Pacific Rise crest shows many anomalies with about 1000-gamma amplitudes and 500-meter wavelengths and has larger amplitude changes corresponding to magnetic field reversals. This profile across contacts between normal and reversely magnetized crustal blocks is interpreted to place an upper limit of 4700 years on the time required for field reversals and an upper limit of 280 meters on the width of the intrusion center at the rise crest. This intrusion center may occasionally shift several kilometers laterally with respect to the rise axis. The magnetometer records are compatible with the hypothesis that the magnetic field has undergone many fluctuations of short period and small intensity in the past 2 million years. Sediment accumulation increases from less than 2 meters at the rise crest axis to about 20 meters at the western end and 10 meters at the eastern end of the profile. This increase in accumulation appears to be the result of ocean-floor spreading.*

The segment of the East Pacific Rise that extends into the mouth of the Gulf of California is a continuous swell 350 km long in the ocean floor. This portion of the rise has been the subject of a magnetic survey by Larson *et al.* (*1*) who, along with Moore and Buffington (*2*), concluded that the area is an active site of ocean-floor spreading. They suggest that this spreading at a half-rate of 3.0 cm/year produced the Gulf of California during the past 4 million years.

In May 1968, TIP-TOW expedition surveyed an area (15 by 20 km) at the East Pacific Rise crest in this region with the Marine Physical Laboratory's deep-towed instrument package, generally referred to as the Fish (*3*). In the course of this survey a profile 65 km long was collected in three segments through the area across the crest. The profile includes the first three transitions on the western flank of the rise and terminates in the vicinity of the eastern edge of the central anomaly (*1*) (Fig. 1).

The instrumentation used in our study consisted of (i) a high-resolution, up-looking, down-looking, echo-sounding combination, (ii) a sea-floor penetration sounder operating at 3.5 khz, and (iii) a proton-precession magnetometer. The instrument package was towed behind the surface ship close to the ocean floor on several kilometers of armored coaxial cable. Conventional bathymetric and magnetic observations were also obtained from the towing ship.

The profile was made by towing the Fish at a generally constant height of 80 m from the ocean floor (Fig. 2). This strategy allowed us to obtain optimum bathymetric resolution and sediment penetration to the basement reflector while keeping the magnetometer at an approximately constant distance from the ocean floor.

The profile provides a bathymetric cross section of abyssal hills at the East Pacific Rise crest. These abyssal hills are typical of this segment of the rise (*1*) and also appear to be the characteristic bathymetric feature on the East Pacific Rise at other locations (*4*). Their average relief in this area is about 200 m, and they are several kilometers wide. They are lineated parallel to the trend of the rise and perpendicular to this profile (*1*).

The 3.5-khz system for acoustic penetration of sediment has a limit of resolution of about 2 m. This instrumentation detected no sediment over the central 22 km of the rise crest. A thin sediment cover containing no internal reflectors and overlying a distinct "basement" reflector appears on both sides of the rise-crest center. The western side of the profile (extending farther from the rise crest) shows sediment cover thickening away from the rise-crest center. The sediment penetration increases gradually from 0 to 0.025 second of two-way travel time. The bottoms of three gravity cores taken in the area all yield the same sediment velocity of 1480 m/sec (*5*). This is the velocity corrected for conditions in situ, and can be used for determining the true thicknesses of the profiled sediment (Fig. 2).

The sediment generally thickens away from the crest, but it appears to be preferentially ponded in local lows.

Many local highs and side slopes are bare. The rise is a regional high that should be free of turbidite sedimentation from the surrounding continents. It is subjected only to a steady rain of pelagic debris that should drape uniformly over the basement unless disturbed by processes active on the bottom. Our data indicate that the biologic activity on the bottom can account for the resuspension of significant amounts of sediment, and that bottom currents are strong enough to transport this resuspended material to its final resting place in local lows.

The profile includes all of the central magnetic anomaly and the first three transitions of the magnetic field on the western flank. The eastern boundary of the central anomaly was not crossed on this survey and has been defined by locating these data with respect to a more extensive magnetic survey (*1*). The western side of the profile ends in the second reversed interval (*6*). Magnetic data were collected at both the ship and the Fish by instruments having precision of about 1 part in 10^5, or 1 gamma. The magnetic anomalies observed close to the ocean floor have an average amplitude of 1000 gammas and wavelength (*7*) on the order of 500 m. The sea-surface magnetometer shows a lower amplitude and smoother trace that reflect the much greater distance of the instrument from magnetic material. The vertical scales for the two magnetic profiles (Fig. 2) differ by a factor of ten. The deep magnetic anomalies show the same general character both inside and outside the central anomaly. Superimposed on this are large offsets occurring very suddenly over an average horizontal interval of 140 m. At the west edge of the central anomaly this offset is 2000 gammas, about twice the average anomaly amplitude.

Ewing and Ewing (*8*) compiled data showing that sediments thicken in a generally uniform manner away from the crests of most of the world's major oceanic rises. Our data appear to bear out these findings at an order of magnitude of finer scale than was discussed by Ewing and Ewing. If the sediment thickness is in fact a result of the spreading rate in this region over the past 1 or 2 million years, then the spreading rate coupled with average sediment thickness at various distances from the center of the rise crest should yield a reasonable sedimentation rate for the equatorial Pacific. Such a calculation from our data produces a sedimentation rate of about 1 cm/10^3 years which is a roughly reasonable approximation of sedimentation rates for this depth and latitude (*9*).

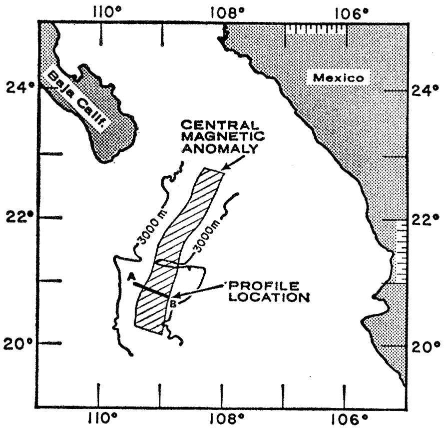

Fig. 1. Location of the profile across the East Pacific Rise crest near the Gulf of California (*21*). The rise crest is indicated by the 3000-m contours (*22*) and the central magnetic anomaly (*1*).

For our discussion of the magnetic data we assume that the ocean floor has spread at a constant rate of 3.0 cm/year for at least the last 2 million years (*1, 2*). This assumption is based mainly on the amount of available data for the region and on the fit of the model made by Larson *et al.* (*1*). The uniform increase in sediment thickness on the western side of our profile also indicates a constant spreading rate.

From analysis of the magnetic stratigraphy and rate of sedimentation in a deep-sea core, Harrison and Somayajulu (*10*) suggested that the transition between the first reversed interval and the Jaramillo event took 5000 to 10,000 years. The statistical evaluation of the length of these transition intervals was approached by Cox and Dalrymple (*11*) for the transition intervals in the past 3.4 million years. From the number of rocks sampled from transition intervals in this time span, their total number of samples, the number of transitions, and the amount of time involved, they estimate the average amount of the time required for each of the last nine reversals in polarity to be 4600 years. Our profile crosses three transitions between normal and reversely magnetized sections of ocean crust. On the average, the transition occurs in the deep magnetics over a horizontal interval of 140 m. At 3.0 cm/year it takes 4700 years to produce 140 m of ocean crust from an infinitely narrow intrusion center. This places an approximate upper limit on the length of time over which the earth's magnetic field reverses itself.

Our interpretation also implies that there is an approximate upper limit on the width of the intrusion center at the rise crest axis. The intrusion center cannot be much wider than twice the average transition interval,

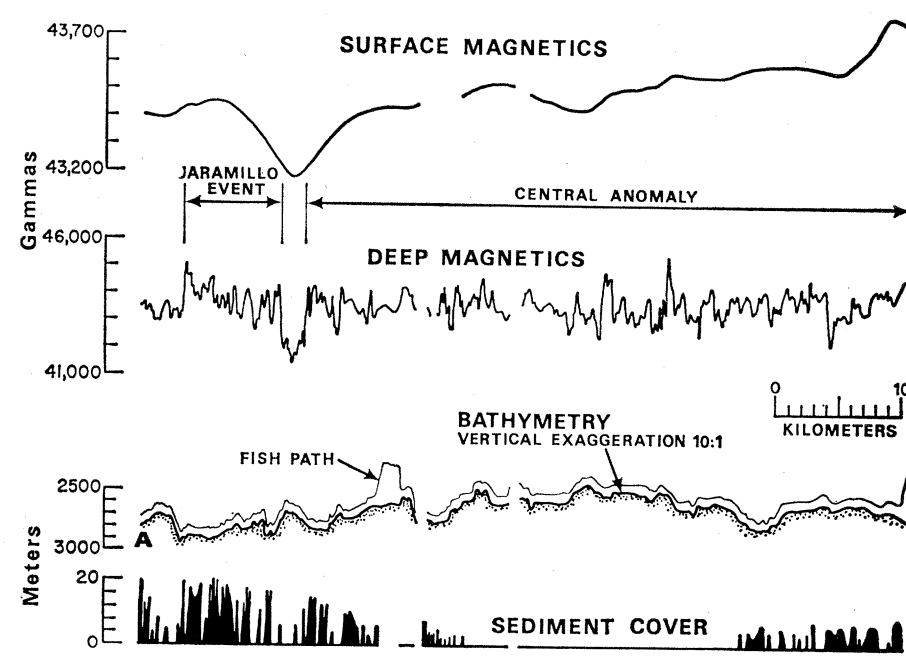

Fig. 2. Profile across the East Pacific Rise crest from west (at left) to east. Surface magnetics are vertically exaggerated ten times with respect to the deep magnetics. The trace above the bathymetry is the track of the instrument above the ocean floor. The sediment cover is illustrated as true thickness to the basement reflector (*5*).

that is, 280 m. Matthews and Bath (*12*) and Harrison (*13*) approached this problem with computer models of a normally distributed dike intrusion process and concluded that such intrusion centers are on the order of 10 km wide. Our conclusion that this intrusion center is considerably less than 1 km wide is somewhat startling when one considers the total dimensions of the East Pacific Rise, but it is something that necessarily follows if this explanation of the data is correct.

Again, if 3.0 cm/year is the constant spreading rate, the duration of the first reversed interval is 0.065×10^6 years and the duration of the normal Jaramillo event is 0.27×10^6 years. This is in apparent contrast with the data concerning this interval derived from deep sea cores (*14, 15*); these authors interpret their data as showing the relative lengths of the two intervals to be approximately opposite to our results. Ninkovich *et al.* (*14*) used the absolute time of the last transition interval as derived by Doell and Dalrymple (*4*) to calibrate the sedimentation rate in their cores. They then calculated the duration of the first reversed interval to be 0.20×10^6 years and the duration of the Jaramillo event to be 0.05×10^6 years. In any event the simple assumption of constant sedimentation rate, applied for the time involved, leads to a ratio of 4 to 1 for the durations of the two periods while constant spreading rate leads to a ratio of 1 to 4. These apparently conflicting results would initially seem to indicate that at least one of the basic assumptions is wrong.

It is possible that the East Pacific Rise has maintained a reasonably constant spreading rate for the time involved, but that the narrow intrusion center has occasionally shifted laterally at the rise crest over geologic time. Such a process would not alter the gross magnetic pattern observed at the ocean surface, but would be of such a scale that the widths of the normal and reversely magnetized blocks could be altered by several kilometers. That is, these shifts would be on the order of a few kilometers in extent, so that the intrusion center would generally shift inside the central anomaly present at the time of the shift. If this were not so, the shifting would have destroyed the magnetic pattern present on the western flank of the rise today. Furthermore, the shifts could only occur at discrete, occasional points in geologic time, since a constantly shifting, narrow intrusion center is effectively not narrow at all, but has a width on the order of the extent of the shifts. This process could explain the apparent disparity in the relative widths of our normal and reversely magnetized blocks. It has the additional facet that if the intrusion center jumps outside the central anomaly, the 140-m wide transition intervals might no longer be a measure of the reversal time of the magnetic field, but instead would measure how fast the intrusion center can jump.

We are finally left with the ever present deep magnetic anomalies of lower amplitude and shorter wavelength. The abyssal hills in this area are much wider than most of these anomalies and have relief on the order of 200 m. Other observations (*1*) and unpublished data show that they are lineated parallel to the trend of the rise and perpendicular to this profile. Thus, a strictly topographic model in which a uniform effective susceptibility is used would produce anomalies of much lower amplitude and longer wavelength than those observed. The possibility that each of these anomalies records a short-lived reversal in polarity can be eliminated because no such short-period reversals have been reported from core data. It is equally unfeasible to account for them by supposing the injection of oppositely magnetized material into a predominately normally or reversely magnetized block on the flank of the rise. This mechanism would leave the central block substantially free of such anomalies, and our data show an abundance of these phenomena with shorter wavelength in the central region as well as on the western flank beyond it. An oceanic crust of varying susceptibility due to an interlayering of lava flows and sediments is not a likely answer as the observed sediment thickness to basement in this area yields a reasonable sedimentation rate when combined with the spreading rate of 3.0 cm/year. Such an explanation is especially unlikely inside the central anomaly where the relative youth of the crust should preclude a large accumulation of sediment. Luyendyk *et al.* (*16*) observed deep-tow magnetic anomalies of smaller amplitude and shorter wavelength in an area of the northeastern Pacific having a similar abyssal-hill type of bathymetry. They suggested that these are the result of fracturing and hydrothermal alteration that produce fine-scale contrasts in petrology and magnetic susceptibility in the oceanic crust (*17*). This possibility cannot be eliminated, but it is unlikely in our area because the vast majority of rocks dredged from the East Pacific Rise are unaltered basalts.

Possible models for reversal in the magnetic field were reviewed by Cox (*18*) who described an analogy to the earth's magnetic field proposed by Rikitake (*19*), in the form of a double-disk dynamo. The model possesses not only the ability to undergo self-reversal, but also has the characteristic that the current will first oscillate about a positive mean value and then a negative mean value. These latter oscillations have considerably shorter periods and smaller amplitudes than the actual reversals. The earth's magnetic field has gone through at least one of these minor oscillations in intensity, the period being approximately the past 10^4 years (*20*). Oscillations of this type with a period of 10^4 years would produce anomalies with a 300-m wavelength at the rise crest.

If these anomalies are due to changes in the intensity of the earth's field, then one might expect to find a symmetrical pattern within the central anomaly. Such symmetry is not obviously present in the data. This indicates either that the fine-scale magnetics are not due to this cause or that the fidelity of the spreading rise as a magnetic tape recorder is not sufficient to reproduce oscillations of such fine scale. This would not be surprising in that, at this latitude, there is little symmetry in the long-wavelength portion (*1*). In any event, comparison of the observed anomaly trace with the curves calculated by Cox for the fluctuations in the strength of the magnetic field (*18*) certainly supports the plausibility of the model of Cox and Rikitake.

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Moving Flame Experiment with Liquid Mercury: Possible Implications for the Venus Atmosphere

Abstract. *A bunsen flame rotated under a cylindrical annulus filled with liquid mercury forces the liquid mercury to rotate in a direction counter to that of the rotating flame. The rate of rotation of the liquid is several times greater than that of the flame. This observation may provide an explanation for the high velocities of apparent cloud formations in the upper atmosphere of Venus.*

The idea that periodic radiative heating of the earth's atmosphere might cause it to acquire a net angular momentum was originally suggested by Halley (*1*). Fultz (*2*) performed an experiment in which a flame was rotated around the outside bottom rim of a cylindrical vessel filled with water. Within the fluid a net angular momentum was established in the sense opposite to the motion of the flame. Stern (*3*) carried out a similar series of experiments in which the water was confined within a cylindrical annulus in order to reduce the effects of radial convection. The water acquired an average rotation in a direction counter to that of the flame which was 0.1 to 1.0 percent of the rate of rotation of the flame. A linearized analysis (*4*) of the two-dimensional motions induced in a horizontal layer of fluid by traveling sinusoidal temperature perturbations applied at the boundaries demonstrates how the Reynolds stress associated with fluctuations in the induced velocity supports the mean shear of the fluid. This analysis is valid only if the speed of the traveling thermal wave is very much greater than the mean velocity induced in the fluid.

These experiments show that a moving source of heat can impart angular momentum to a fluid in a sense opposite to the motion of the source. However, the fluid rotates with an angular speed several orders of magnitude smaller than the rate of rotation of the source. Thus the physically important question of whether a moving source of heat could produce a mean motion of a fluid with velocity comparable to or even greater than that of the source has thus far remained unanswered. We have measured mean rotational speeds in liquid mercury which are four times as great as the speed of the moving flame.

The experimental apparatus (Fig. 1) consisted of a cylindrical annulus of rectangular cross section. The bottom of the channel was an aluminum disk 1 mm thick; the side and top walls of the channel were made of Plexiglas (5 mm thick). Inside and outside diameters of the channel were 25 cm and 35 cm, respectively, and the channel height was 2 cm. A bunsen flame, mounted on a turntable, provided a rotating source of heat beneath the bottom wall of the channel. The flame was spread out radially in order to provide uniform heating and to minimize the radial motions within the liquid. Liquid mercury filled the channel to a depth of 1.5 cm and was covered with a layer of distilled water 0.5 cm thick in order to retard oxidation. If we interpret the mean length of the annular channel as an equivalent wavelength, then 2π times the ratio of the depth of the mercury to the wavelength is 0.1. The rotation rate of white ball bearings (4 mm in diameter), floating at the mercury-water interface, provided a measure of the angular velocity of the mercury, and the speed of the bunsen flame was indicated by a synchronized pointer directed at the flame.

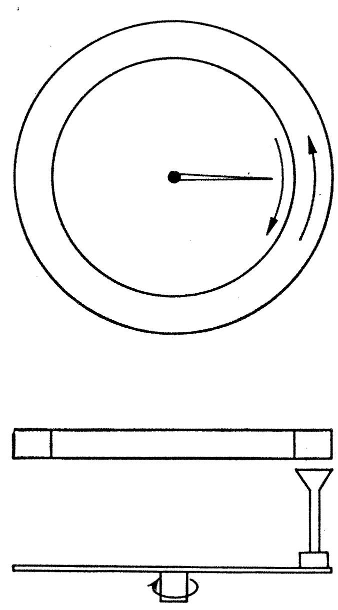

Fig. 1. Schematic diagram of the apparatus for the moving flame experiment.

The speed of the flame was 1 mm/sec, and the temperature of the mercury increased from room temperature at the rate of about 3°C per minute. The time scale for thermal diffusion from the bottom to the top of the mercury is about one flame rotation period. A steady-state flow was established after about 5 minutes (about one-third the time required for the flame to complete a rotation); however, the mercury was rotating so rapidly in a direction counter to that of the flame, about 4 mm/sec, that it completed almost two revolutions over the flame in this time.

The motion of a large number of vapor bubbles floating at the mercury-water interface showed that the flow was uniform over a large portion of the cylindrical annulus. However, immediately above the flame, and in a small wake behind it, the motion was disorganized. An indication of the velocity below the surface of the mercury was obtained by observing a ball bearing 1 cm in diameter moving almost as fast as the smaller ones (the speed of the large bearing was within a few percent of that of the smaller ones). With water as the working fluid, velocities that were negligibly small compared with the flame speed were imparted to the liquid.

The high angular velocities observed in the experiment with liquid mercury are the result of the rapidity of thermal diffusion as compared with viscous dif-