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MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

Transcurrent Faulting in the Ocean Floor

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Phil. Trans. R. Soc. Lond. A 1965 **258**, 77-81
doi: 10.1098/rsta.1965.0022

B. HORIZONTAL DISPLACEMENTS IN THE EARTH'S CRUST

VI. Transcurrent faulting in the ocean floor†

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Displacements along strike slip faults in the ocean floor are measured by fitting magnetic anomaly patterns. In the northeastern Pacific Ocean the combined left lateral displacement of 1400 km across the Mendocino and the Pioneer faults can now be followed with a few interruptions from 140 to 165° W, or a distance of 2200 km. The western end of the correlatable pattern has not yet been reached. In latitude the pattern stretches between 28 and 41° N, or a distance of 1450 km. Right lateral displacements of 150 and 680 km separated by a disturbed zone have been measured on the Murray fault between 125 and 152° W. The disturbed zone occurs on the south side of the Murray fault. It is characterized by more rugged topography and is bordered by groups of volcanoes at its eastern and western boundaries. Across the faults the bathymetric contours are displaced in the same direction and roughly by the same amount as the magnetic intensity pattern. Fourteen magnetic profiles across the Mid-Atlantic Ridge between 30 and 6° S show a persistent magnetic anomaly on the crest of the ridge which can be followed from one profile to the next, whereas topographic features lack this continuity. Mapping the position of the crest anomaly suggests that if the ridge was originally continuous, it has now been cut into sections by strike slip faults.

The floor of the northeastern Pacific Ocean carries a pattern of total magnetic intensity anomalies which is oriented north–south (Mason & Raff 1961; Raff & Mason 1961). The great east–west fault zones discovered from bathymetric data intersect and break up this pattern (Menard 1955). Slipping the pattern in the east–west direction so as to make it fit together across a given fault establishes the direction and the magnitude of the strike-slip displacement along this fault.

Thanks to recent cruises of ships of the U.S. Coast and Geodetic Survey, the U.S. Naval Oceanographic Office, and the Scripps Institution of Oceanography, additional data on the displacements along the faults of the northeastern Pacific have been obtained. The new information confirms the published (Vacquier, Raff & Warren 1961; Raff 1962) results on the displacements, and nearly doubles the length of the overlapping segments of the magnetic profiles as shown on figure 1. The profiles of anomalous total magnetic intensity are plotted approximately at their proper latitudes. The area extends from 26·5 to 41·5° N latitude. There are five scales of longitude because the chart has been sliced along the traces of the faults and the sections shifted in the east–west direction until correspondence of features was obtained to the eye. Some of these features have been connected by approximately vertical dashed lines solely for the purpose of identifying them. The southern boundary of the north–south magnetic anomaly pattern is probably in the neighbourhood of 25° N. Attempts to measure the displacement on the Molokai fracture, the next big fault south of the Murray, have been unsuccessful probably because the anomaly pattern, if it exists, is insufficiently continuous. To the north some anomalies on

† This paper is the result of work sponsored by the Office of Naval Research and the National Science Foundation.

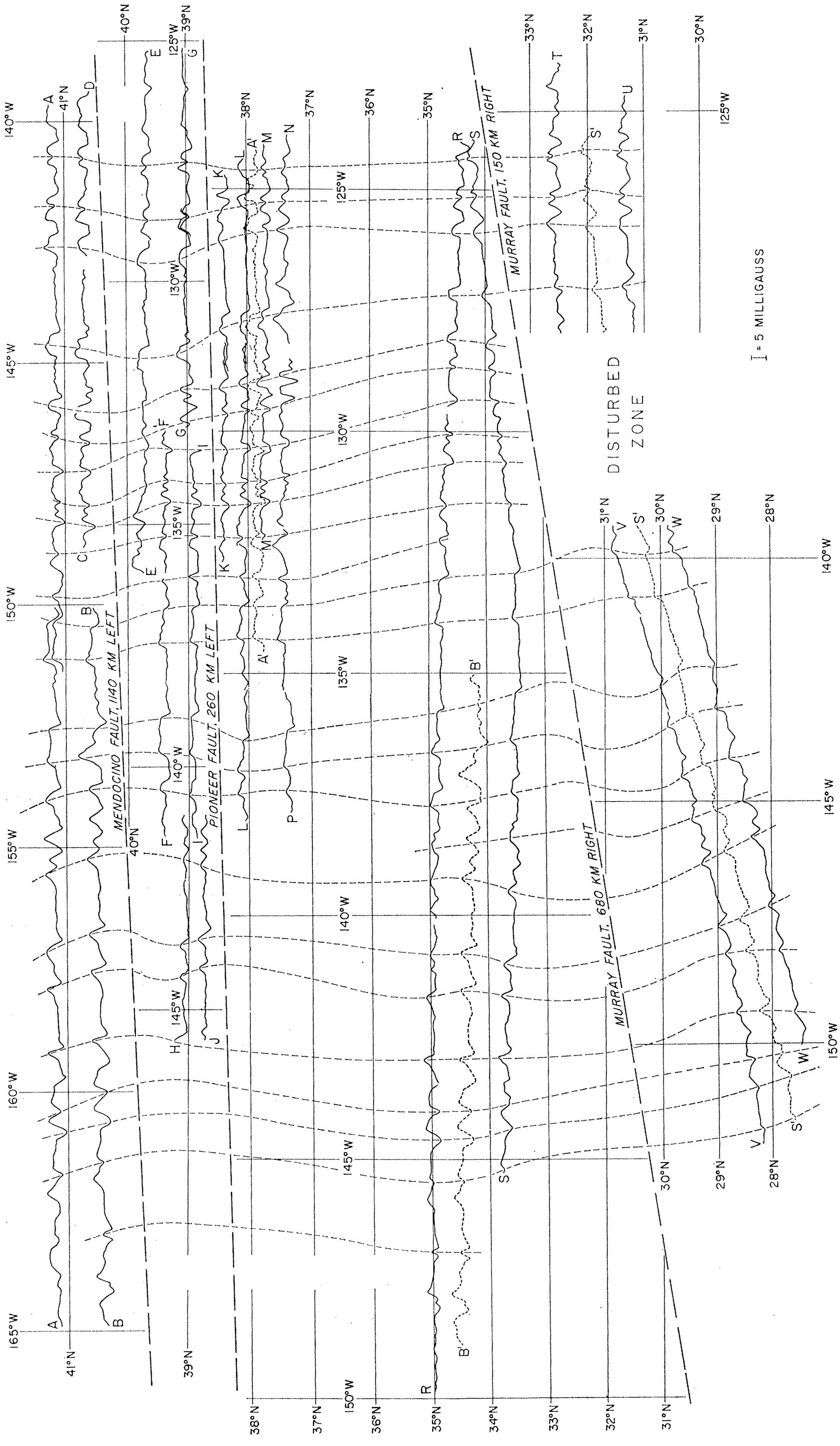

FIGURE 1. Total magnetic intensity profiles showing the displacements along the Mendocino, Pioneer and Murray faults in the floor of the northeastern Pacific Ocean.

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profile *AA* east of 158° W can be followed to latitude 48° N on two tracks of U.S. Naval Oceanographic Office ships between San Francisco and Adak (Bracey 1963). Conservatively, one can thus assign 48° N as the northern limit of the magnetic anomaly pattern which makes it about 2550 km long.

To facilitate the evaluation of the goodness of fit, some profiles have been repeated in dotted line across a fault. They are labelled on figure 1 with primed letters. Thus *A′A′* is an exact copy of a portion of *AA*, and *B′B′* is a copy of *BB*. A slight shortening of *S′S′* by only 10 miles with respect to the original *SS* profile greatly improved the fit on the western end of the Murray fault. Half of this shortening could be accounted for by navigation errors.

The existence of two magnitudes of displacement across the Murray fault, one of 680 km at the western end, and one of 150 km at the eastern portion, means that roughly between 130 and 139° W longitude, marked 'disturbed zone' on figure 1, ocean floor has been added on the south side of the Murray fault or removed on the north side in the amount equal to the difference between the two displacements, or about 500 km. This view is strengthened by both magnetic and topographic evidence. In the area of the disturbed zone, the coherence between east–west magnetic intensity profiles is lost, that is, the north–south magnetic anomaly pattern is missing (Raff 1962). Topographically the disturbed zone is bordered by two groups of seamounts situated at the eastern and the western boundaries of the disturbed zone just south of the fault. The zone is considerably rougher than the surrounding areas and stands out clearly on the physiographic diagram (Menard 1964).

The bathymetric contours in the northeastern Pacific are displaced across the Mendocino, Pioneer and Murray faults in the same direction and roughly by the same amounts as shown by the magnetic anomalies.

Except for the eastern extremity of the Mendocino fault, the transcurrent faults are seismically dead at the present time. Earthquake epicentres do not occur near them and a manned buoy at 39·6° N, 148° W failed to reveal an appreciable number of even small quakes during 8 days of observation (J. Northrop, personal communication).

The continuation of the oceanic faults on the North American continent has been traced from the aeromagnetic data of the Gulf Research and Development Company (Fuller 1964). The correlation between successive east–west magnetic profiles becomes small where the pattern is interrupted by the east–west faults. The Mendocino fault can be reliably traced into Nevada to 115° W longitude. The magnetic patterns, however, cannot be matched on land to determine the magnitude of lateral displacements as they can be matched at sea, probably because of the greater complexity of the continental crust. Perhaps the layers in which the transcurrent displacements have occurred lie deep under the continental rocks, the structure of which, although influenced by the east–west faults, does not participate in the displacements. This idea is plausible because it resolves the obvious difficulty created by the San Andreas fault which is presently active and which would have produced offsets in the traces of the oceanic faults had the magnetic anomalies originated from shallow layers. Estimates of the maximum depths of the sources of these anomalies might perhaps furnish another measurement of the depth to which the San Andreas fault extends. The notion also agrees with the observation that the oceanic magnetic anomaly pattern smooths out as one travels landward from the bottom of the continental slope, suggesting that the oceanic rocks carrying the magnetic pattern are depressed by the continental rocks.

A theory consistent with the facts is still needed to account for the existence of the north–south magnetic lineation in the northeastern Pacific and for the origin of the transcurrent faulting. A few obvious deductions can be made from the observations. One is that transcurrent movements have been so extensive that they imply that when transcurrent motion is in progress, the ferromagnetic layers of the ocean floor must ride with little distortion on the upper mantle material which must be moving laterally at considerable depth. There is thus no question that motion has taken place in the upper mantle.

The 'disturbed zone' in figure 1 also gives proof that a section of the ocean floor 500 km wide can be formed without seriously distorting the shapes of the features in the surrounding area.

To reconcile the existence of motion with the ever-increasing estimates of the viscosity of the Earth's mantle which seemingly make convection improbable (Knopoff 1964) we have only three possibilities. One is to question the estimates. Another is to say that viscosity varies sharply with the depth, since after all, the large values of viscosity are inconsistent with the classical ones obtained from the rise of Fenno–Scandia caused by the unloading of the last glaciation. Finally, perhaps viscosity varies episodically as is suggested by the great outpourings of plateau basalts. A liquid low-velocity layer would well lubricate transcurrent slips.

The origin of the north–south lineated magnetic anomaly pattern is unknown although it has been hypothesized that it is linked with rising hotter mantle material under oceanic rises (Vine & Matthews 1963). The material is presumably extruded in long blocks parallel to the axis of the rise, the contrasting magnetic polarization being acquired in major part because of differences in strength and direction of the geomagnetic field at the epochs when these long bodies of rock cooled down from the Curie temperature. The elongated magnetic anomalies can be thought of as scars propagating outward in both directions (Vine & Matthews 1963; Dietz 1962). In addition to magnetic anomalies, islands (Wilson 1963) would also move away from the rise. In the northeastern Pacific the active rise is postulated to lie under western North America (Menard 1960). According to this hypothesis transcurrent faulting is caused by different amounts of extrusion.

Unfortunately this attractive mechanism is probably not adequate to account for all the facts of observation. As previously mentioned, in the eastern Pacific the lineated magnetic anomaly pattern appears to the eye to end south of 25° N latitude. Where the East Pacific Rise can actually be seen, a lineated magnetic pattern has so far not been detected by visual inspection of the magnetic records. The same is true of the Mid-Atlantic Ridge between 6 and 30° S latitude where 13 profiles failed to reveal visual evidence of magnetic and topographic features parallel to the ridge which could be correlated from one profile to the next, except for a single prominent broad magnetic anomaly which seems to form the only clearly continuous feature (Vacquier & von Herzen 1964). It has been pointed out (Backus 1964) that a spectral analysis of these records might conceivably reveal a pattern where visual inspection does not. Such an analysis has not yet been carried out. When the position of the one easily detectable magnetic anomaly is plotted on the track chart it appears as segments separated by transcurrent faults. If it be assumed that the axis of the Mid-Atlantic Ridge was once continuous, the offsets of the apex of the magnetic anomaly measure the displacement along transcurrent faults. Most of the major transcurrent faults in the Atlantic have been mapped from topography (Heezen & Tharp 1961). The displacement along these faults is measured by the offsets of the topographic crest of the Mid-Atlantic Ridge. Thus where we can observe a ridge it has been cut into sections and these sections laterally displaced by transcurrent faults. The fact that the heat flow is displaced indicates present-day activity rather than a fossil displacement. It is quite possible that a detailed survey of the flanks of the Mid-Atlantic Ridge would reveal elliptical magnetic anomalies with their long axis parallel to the ridge. Likewise in the eastern Pacific south of 25° N latitude the anomalies may be somewhat elongated in the north–south direction. However, in neither of these areas is there evidence for magnetic anomalies such as exist in the northeastern Pacific which retain their identity for hundreds of miles and which permit measuring the displacements along transcurrent faults from simple visual inspection of magnetic profiles several degrees apart in latitude. In the Atlantic the magnetic anomaly on the crest of the ridge appears to be the only reliable marker unless extensive numerical data processing should reveal others. Therefore the possibility should be kept in mind that the magnetic anomalies in the northeastern Pacific may have been generated by other mechanisms than those associated with ridges in the Atlantic and Indian Oceans (Vine & Matthews 1963).

I wish to thank Gary Gassaway for his help in constructing the illustration for this paper.

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