Reports

Sediment Distribution on the Mid-Ocean Ridges with Respect to Spreading of the Sea Floor

Abstract. *An abrupt change in sediment thickness between the crests and flanks of the mid-ocean ridges can be interpreted as a major discontinuity in the rates either of spreading of the sea floor or of accumulation of sediment. The preferable interpretation of the data is that the process of spreading of the sea floor is intermittent and that the present cycle of spreading commenced around 10 million years ago, following a long period of quiescence during which most of the observed sediments were deposited.*

In an earlier paper (*1*) that describes certain features of the sediment distribution in the North Atlantic Ocean, an attempt was made to reconcile the pattern of accumulation with the hypothesis of a spreading sea floor as proposed by Hess (*2*) and Dietz (*3*). It was noted that although the virtual absence of sediment in a strip 160 to 240 km (100 to 150 miles) wide along the crest of the mid-Atlantic ridge supported the hypothesis of spreading, a relatively uniform sediment cover on most of the ridge flank seemed to require a uniform age for the flanks rather than a progressively greater age away from the crest. Accordingly, the suggestion was made that the spreading that has produced the strip of thin sediments on the crest is relatively recent and that it had been preceded by a long period of quiescence during which the flank sediments had accumulated.

Recent papers by Vine (*4*) and Pitman and Heirtzler (*5*) have given strong support for the hypothesis of spreading by demonstrating close agreement between the patterns of the magnetic anomalies of the crest and the known reversals of the earth's field. From this evidence they have calculated spreading rates for several areas and have tentatively extrapolated these rates to date specific anomalies out to several hundred kilometers from the ridge axes. Patterns of the anomalies of the crest have indicated spreading rates of the order of 4 cm/yr for the Pacific, 1 to 2 cm/yr for the North Atlantic, and 2 to 3 cm/yr for the South Atlantic and Indian oceans. We have examined the patterns of sediment accumulation on several seismic profiler traverses of the mid-ocean ridge system in the light of these rates of spreading to ascertain what can be concluded about the temporal variation of sedimentation rates, or conversely, about the variations in spreading rates.

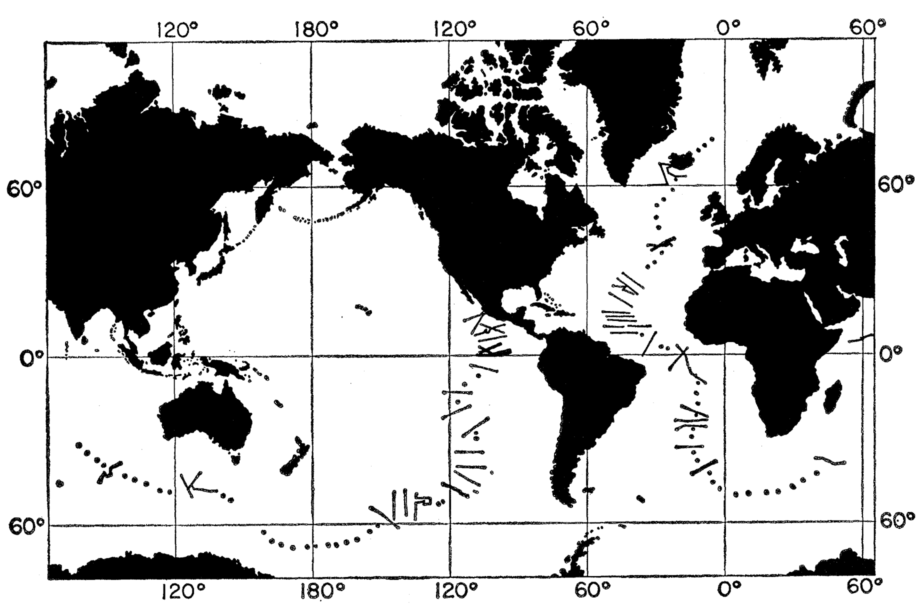

Fig. 1. Seismic profiler traverses of the mid-ocean ridge system. Heavy lines indicate traverses illustrated in Figs. 2 and 3.

Although we have about 50 profiler crossings of the ridge system (Fig. 1), many of them are not satisfactory for this study, either because of the extreme paucity of sediments or because of insufficient resolution, particularly in much of the earlier work. In the traverses where the sediments are sufficiently thick and the resolution high (several of which are indicated by heavy lines in Fig. 1), the pattern of accumulation may be described in the following way. At the axis of the ridge sediments are so thin that the thickness cannot be resolved in our profiler records. Sediment coring and underwater photography frequently reveal exposed basement rock in this region. The sediments thicken gradually toward the flanks out to a distance of 100 to 400 km from the axis where there is an abrupt or discontinuous increase in thickness. The distance between the discontinuity and the ridge axis varies geographically and appears to be closely associated with the rates of spreading determined from the magnetic anomaly pattern. The rate of increase in sediment thickness between the ridge axis and the discontinuity also varies geographically and appears to be associated with sedimentation rates. Beyond the discontinuity the flank sediments are of almost constant thickness or thicken only slightly with increasing distance from the ridge crest. A traverse is shown in Fig. 2 to demonstrate the pattern described above. The large variation in sediment thickness occurs well above the present level of carbonate compensation and therefore cannot be attributed to differential solution. In Fig. 3 the sediment thickness along this profile and that for four other profiles is plotted as a function of distance from the ridge crest. The data are somewhat smoothed by plotting average thickness for each 10 km of traverse.

In each of the examples of Fig. 3 it is clear that the pattern of sediment thickness cannot be explained by a constant rate of accumulation on a steadily spreading crust. Under those conditions, the end result would have been a sediment layer that thickens uniformly from the ridge crest out at least to the point where carbonate solution becomes effective. Therefore, we must conclude that there has been a marked change in the rate either of accumulation or of spreading. Dividing the half-width of the thin sediment strip by the spreading rate determined by the magnetic anomaly pattern gives a date approximately 10 million years ago for the discontinuity in all areas, whether the spreading has been fast or slow. Thus it appears that the initiation of the spreading cycle occurred in many parts of the world at the same time.

The significant features of the sediment distribution are shown in Fig. 4, which is a generalized sketch of sediment thickness versus distance from the ridge crest. To explain the sediment pattern by accumulation on a continuously and uniformly spreading sea floor requires that for a relatively short period of time, roughly 10 million years ago, the accumulation rate was orders of magnitude higher than the rates before or after.

Alternatively, we can account for the pattern by a discontinuity in spreading. We suggest that the following sequence of events best accounts for the observed sediment accumulation.

1) An earlier cycle (or cycles) of spreading occurred, possibly that during which Gondwanaland and Laurasia were broken up and the pieces moved approximately to their present locations. The spreading during this cycle was extensive enough to sweep all of the Paleozoic sediments from the Pacific floor. Its duration was probably considerably shorter than the following period of quiescence. Reversals of the earth's magnetic field were recorded as bands of anomalies symmetrical about the ridge axes, as postulated by Vine and Matthews (*6*).

2) The early spreading cycle terminated probably in the Late Mesozoic or Early Cenozoic and was followed by a period of quiescence, during which most of the observed sediments were deposited on a static crust.

3) A new spreading cycle commenced about 10 million years ago, which has generated the pattern of the magnetic anomalies of the crest and has produced the strip of thin sediments. The ridge axes of the latest cycle follow those of the preceding one with remarkable accuracy.

This hypothesis is based on the assumption that the magnetic anomaly pattern is continuous from the ridge crest out to the point corresponding approximately to the 10-million-year isochrone where it joins the pattern generated during the previous spreading cycle. A marked change in the magnetic anomaly pattern in this vicinity is characteristic of the profiles shown by Vine (*4*) and by Pitman and Heirtzler (*5*). It is also worthy of note that Vine deduced a change in spreading direction in the northeast Pacific within the past 10 million years, which we attribute to local divergence between the axes of the spreading cycles.

If our knowledge of sedimentation rates during the Tertiary were more exact, we could calculate the duration of the quiescent period from the sediment thickness on the ridge flanks. Lacking this information we can only estimate the duration from comparison of the thicknesses on each side of the discontinuity. In many places the flank sediments are three or four times as thick as those between the crest and the discontinuity; so if we assume that the latter accumulated in 10 million years and also assume that sedimentation rates did not change during the Tertiary, the estimated duration of the quiescent period is of the order of 30 to 40 million years. In other places, notably *Eltanin 19* (Fig. 3), at about

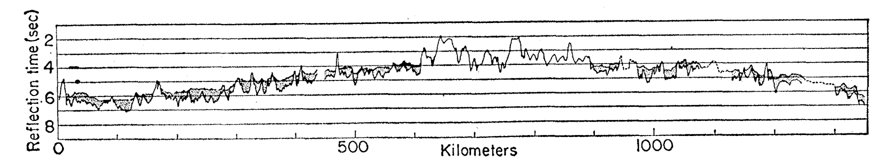

Fig. 2. Tracing of seismic profiler records made during a crossing of the mid-Atlantic ridge at about 40°N. The azimuth of this traverse is about 30° from perpendicular to the axis of the ridge, hence the true width of the thin sediment strip is about 250 km.

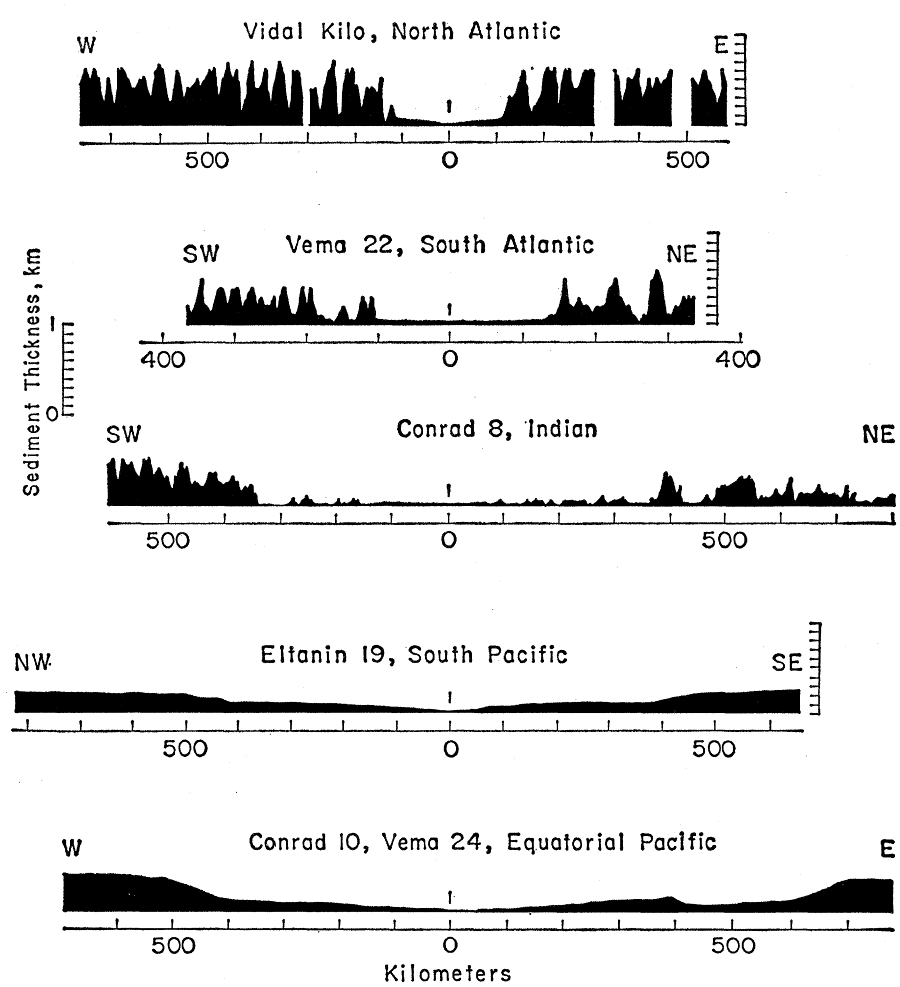

Fig. 3. Graphs of sediment thickness versus distance from the ridge crest for five traverses. The bottom one is a composite made from three traverses in the Pacific where the belt of thick equatorial sediments intersects the East Pacific Rise. On the eastern side the pattern is complicated by fractures (transform faults) or structure associated with the Galapagos Islands.

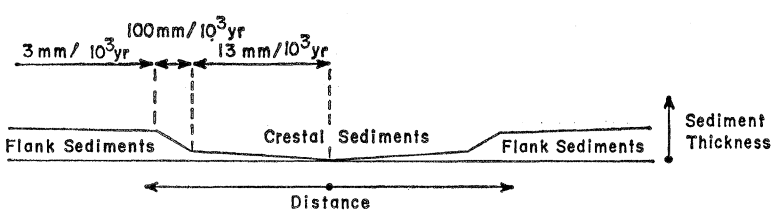

Fig. 4. Generalized sketch of crestal and flank sediment thickness based on data from the equatorial Pacific. The slopes give accumulation rates as indicated if spreading is assumed constant at 4.5 cm/yr.

50°S in the South Pacific, the flank sediments are no more than twice as thick as the crestal sediments, which indicates either a shorter quiescent period or a substantial increase in sedimentation rates during the Late Tertiary. There is evidence that in some areas, such as the equatorial Pacific, the Early Tertiary accumulation rate was lower than that in Late Tertiary and Quaternary [for example, see Arrhenius (*7*)], so it is possible that the quiescent period began as early as, or even before, Upper Cretaceous time. Sediments of the Atlantic basins, dated by studies of horizon A (*1*) as extending at least into the Mesozoic, indicate deposition during a quiescent period.

This hypothesis will be disproved if drilling fails to recover old sediments on the flanks of the ridge near the sediment discontinuity. In that event we will apparently have to accept extreme changes in sedimentation rates about 10 million years ago, that is, in Late Miocene.

The intermittent character of the convection suggested by the sediment distribution is consistent with the idea [see, for example, Vening Meinesz (*8*)] that the rate of generation of heat seems inadequate to maintain continuous convective motion. Bearing in mind the limited accuracy of our estimates of the convective phases of the last two cycles, it seems worthwhile to point out that these times agree reasonably well with the Late Cretaceous and Miocene orogenies.

The fact that high values of heat flow are concentrated within 100 km of the ridge axis in the Atlantic (*9*) and that the value is almost constant for a considerable distance beyond is consistent with a long period of quiescence followed by spreading, as specified above. The broader belt of high values of heat flow on the East Pacific rise is consistent with the higher spreading rates and wider sediment gaps found there.

Geological data around the Gulf of Aden summarized by Laughton (*10*) indicate that rifting may have commenced as early as Eocene but that major movement probably occurred in Miocene time. Seismic profiler traverses show sediments up to 800 m thick in the gulf except for a central strip 60 to 80 km wide where the thickness is only 0 to 100 m. This evidence also supports intermittent spreading.

Oliver and Isaacs (*11*) have interpreted seismological studies in the Tonga–Fiji region to indicate that the intermediate and deep earthquake foci occur in a section of the lithosphere that has been thrust 600 to 700 km into the mantle. Although the depth range of the foci may represent the limit to which the lithosphere remains unmelted it might correspond instead to the total amount of thrusting (spreading) during the present cycle.

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12. Supported by the U.S. Office of Naval Research and Bureau of Ships, and by the National Science Foundation. We also thank the British Hydrographic Service for their assistance in obtaining data abroad H.M.S. *Vidal*. Many members of the Lamont staff have assisted in obtaining the other data, in particular, J. L. Worzel, M. Langseth, C. Windisch, G. Bryan, R. Leyden, X. Le Pichon, and R. Zaunere. Lamont Geological Observatory contribution No. 1063.

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Long Base Line Interferometry: A New Technique

Abstract. *The technique of using magnetic-tape recorders and atomic frequency standards to operate two widely separated radio telescopes as a phase-coherent interferometer when the stations have no radio-frequency connecting link has been successfully tested at the National Research Council of Canada's Algonquin Radio Observatory.*

In extending conventional radio interferometry to very long base lines two major problems are encountered. The most obvious is the requirement for a phase-stable radio link, but perhaps even more important is the difficulty of compensating for the large and varying difference in arrival time of the signals at the two sites. A flexible technique which overcomes both these difficulties has been developed; it uses video tape recorders and atomic frequency standards.

For radio astronomical applications each tape recorder must have a large signal bandwidth and corresponding time-base stability. If the bandwidth is in excess of 1 Mhz the width of the cross correlation function is less than 1 μsec when the two tapes are correlated on playback. Thus the recorders must be capable of being aligned and of remaining in alignment during playback to within a fraction of a microsecond. To meet these requirements video tape recorders of the type used successfully for many years in television were chosen for the present experiment.

Each station has its own rubidium frequency standard which, during the observing period, is used to derive the frequency of the receiver's local oscillator (since no frequency synchronization between stations is provided) and to provide a time reference. The frequency spectrum of the incoming signal is shifted by the local oscillator to a band centered at zero, so that the receiver output is an undetected, low-pass waveform having a bandwidth of about 1 Mhz. Synchronizing and blanking pulses are then added (so that the composite waveform resembles a television signal without "vertical" pulses) and a recording is made.

Approximately 15 of the 90 minutes of available recording time are allowed to align the machines during playback to within 1 μsec by use of timing pulses