MOBILITY AND IMMOBILITY OF MID-OCEAN RIDGES AND THEIR IMPLICATIONS TO MANTLE DYNAMICS

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ABSTRACT

In the past two decades, the mobility of mid-ocean ridges relative to the mantle (absolute migration) have been correlated with major observable features, such as, spreading asymmetry and asymmetry in the abundance of seamounts. The mobility of mid-ocean ridges is also thought to be an important factor that influences the diversity of ridge-crest basalts. However, the mobility of mid-ocean ridges have not yet been defined and mapped. The absolute migration of global mid-ocean ridges since 85 Ma has been computed and mapped. Global mid-ocean ridges have migrated extensively at varying velocities during that period. Presently, the fast-migrating ridges are the Pacific-Antarctic, Central Indian Ridge, Southeast Indian Ridge, Juan de Fuca, Pacific-Nazca, Antarctic-Nazca, and the Australia-Antarctic ridges, migrating at velocities between 3.3 and 5.5 cm/yr. The slow-migrating ridges are the Mid-Atlantic and the southwest Indian ridges migrating at velocities between 0.3 and 2.0 cm/yr. Comparison of these results with mantle tomography results shows that the slow-migrating ridges have deeper depth of origin than the fast-migrating ridges suggesting a correlation between the absolute migration velocity and the depth of origin of ridges. Furthermore, the southwest Indian ridge appears to be tapping the same portion of mantle as did the Central Indian ridge. These results have important thermo-chemical implications, such as variations in the extent of melting and mineralogicalcomposition of the mantle beneath different ridges, which may influence mantle dynamics.

INTRODUCTION

Mid-Ocean ridges are important features on Earth for several reasons: in plate tectonics they are boundaries of plates and play a key role in driving them; in geophysics they are locations along which new seafloor is created. Absolute migration of mid-ocean ridges have been correlated with major observable features of the ridges. For example, Stein *et al.* (1977) correlated spreading asymmetry with migration rate, and Davis & Karsten (1986) explained asymmetry in seamount abundance by absolute ridge migration. Ridge migration rate is also thought to be an important factor that influences the diversity of ridge-crest lavas and the compositional uniformity of ridge-crest basalts (Davis & Karsten 1986). Although absolute migration of mid-ocean ridges has been linked with many features, its influences to mantle dynamics have not yet been investigated. In the present paper, the absolute migration of global mid-ocean ridges since 85 Ma was computed and its possible influence to mantle dynamics investigated.

METHODS

Magnetic lineations form concurrently with new seafloor on mid-ocean ridges when molten magma passively upwells into the narrow space between two diverging plates. Magnetic domains/minerals in the magma are align in the direction of the prevailing geomagnetic field, thus recording the age of the new seafloor. Fifteen ridge segments were selected (Fig. 1), with their corresponding magnetic lineation segments on both sides. Their paleopositions since 85 Ma to present were reconstructed by rotating identified magnetic lineations back to their former positions (Masalu & Tamaki 1994), using the models of absolute motion of plates (sensu Mueller *et al.* 1993, Duncan & Clague 1985). The absolute migration velocities for each respective ridge were then computed.

Locations of identified magnetic lineations were obtained from a CDROM of digital data of locations of global magnetic lineations (Cande *et al.* 1989). Ages were assigned to identified magnetic lineations based on a recent geomagnetic polarity time scale for the Late Cretaceous and Cenozoic times (Cande & Kent 1992).

The assumption in my method was that plates remained rigid over the past 85 m.y. This is certainly not completely correct because both inter- and intra-plate deformation is known to exist. Errors may also arise from incorrectly identified magnetic lineations. There are also inherent errors from the use of models of absolute plate motions. Notwithstanding the possibility for these errors my results present first overview of global motion of mid-ocean ridges.

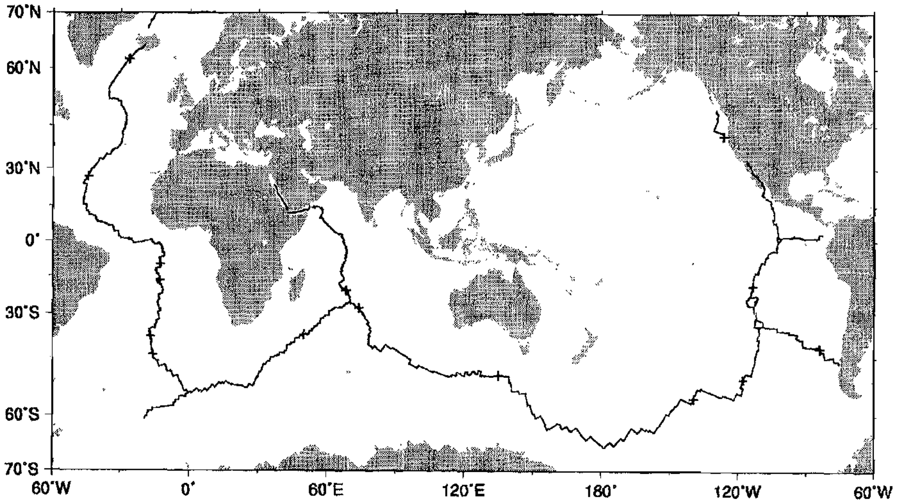

Fig. 1: Global mid-ocean ridge

RESULTS

Migration of global mid-ocean ridges

It is apparent that global mid-ocean ridges migrated extensively in the past 83 m.y. (Table 1 and Fig. 2). All ridges appear to be migrating; the East Pacific Rise (EPR) appears to have rotated clockwise for about 50° since 83 Ma (Fig. 2i). The South Mid Atlantic Ridge (SMAR) shows small lateral migration but indicates extensive longitudinal migration toward north (Fig. 2ii). Similarly, the northern EPR and the Juan de Fuca ridge segments appear to have migrated northerly at least since about 83 Ma (Chron 34) to Present (Fig. 2i).

Table 1: Migration of global mid-ocean ridges

Identifier	Ridge	Distance Migrated (km)	Time to Present (M. Yrs)
JUAN	Juan de Fuca	3900	83
PacAnt	Pacific-Antarctic	2400	73
PacNazca	Pacific-Nazca	200	12
AntNaz	Antarctic-Nazca	1010	20
SMAR	South Mid-Atlantic Ridge	1300	83
CMAR	Central Mid-Atlantic Ridge	1200	83
NMAR	North Mid-Atlantic Ridge	1550	83
SEIR	Southeast Indian Ridge	3900	83
CIR	Central Indian Ridge	3100	83
SWIR	Southwest Indian Ridge	1250	64
AustAntar	Australia-Antarctic	1400	43

The SMAR runs between several hotspots located relatively close to it on both sides which probably played a role in limiting its lateral migration (Uyeda & Miyashiro 1974).

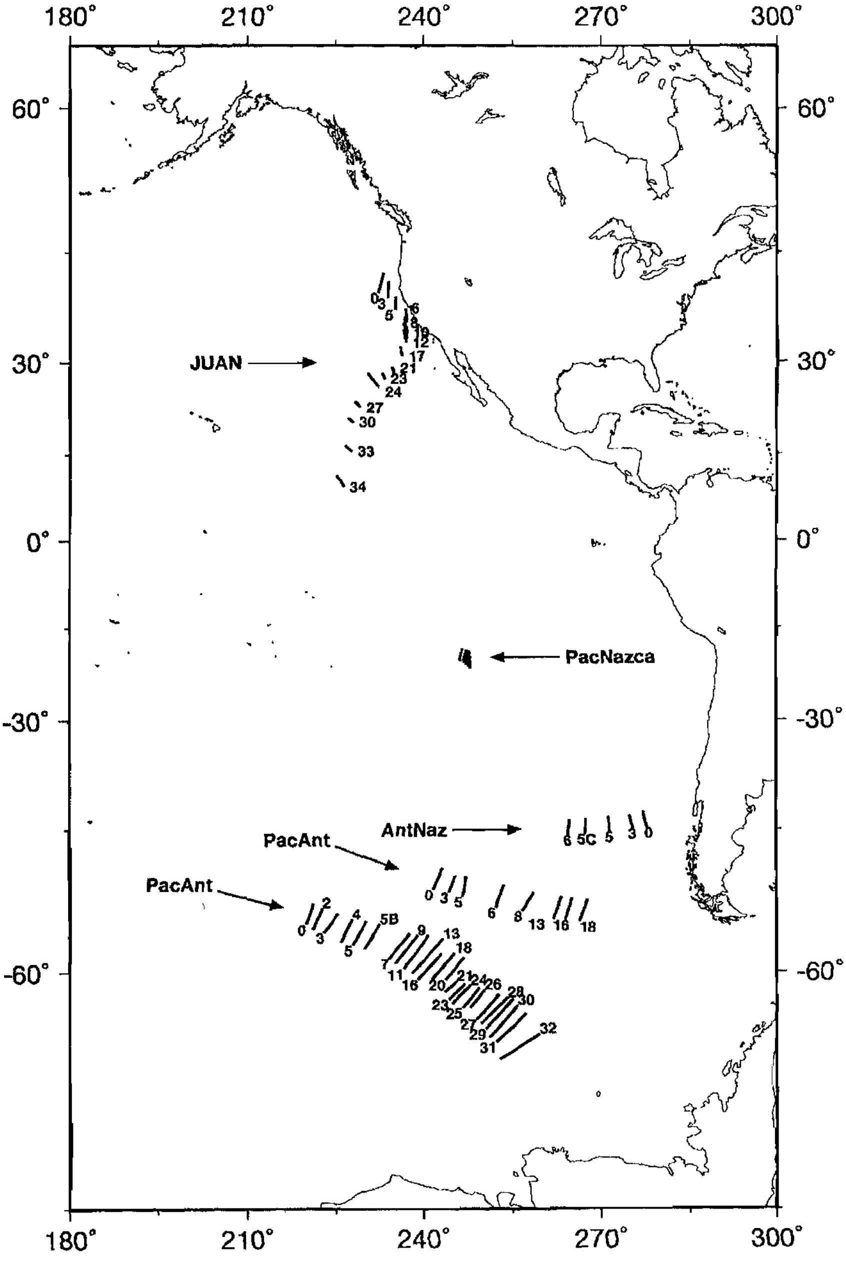

Fig. 2 (i): Pacific ridges (Juan de Fuca and South Pacific ridges.

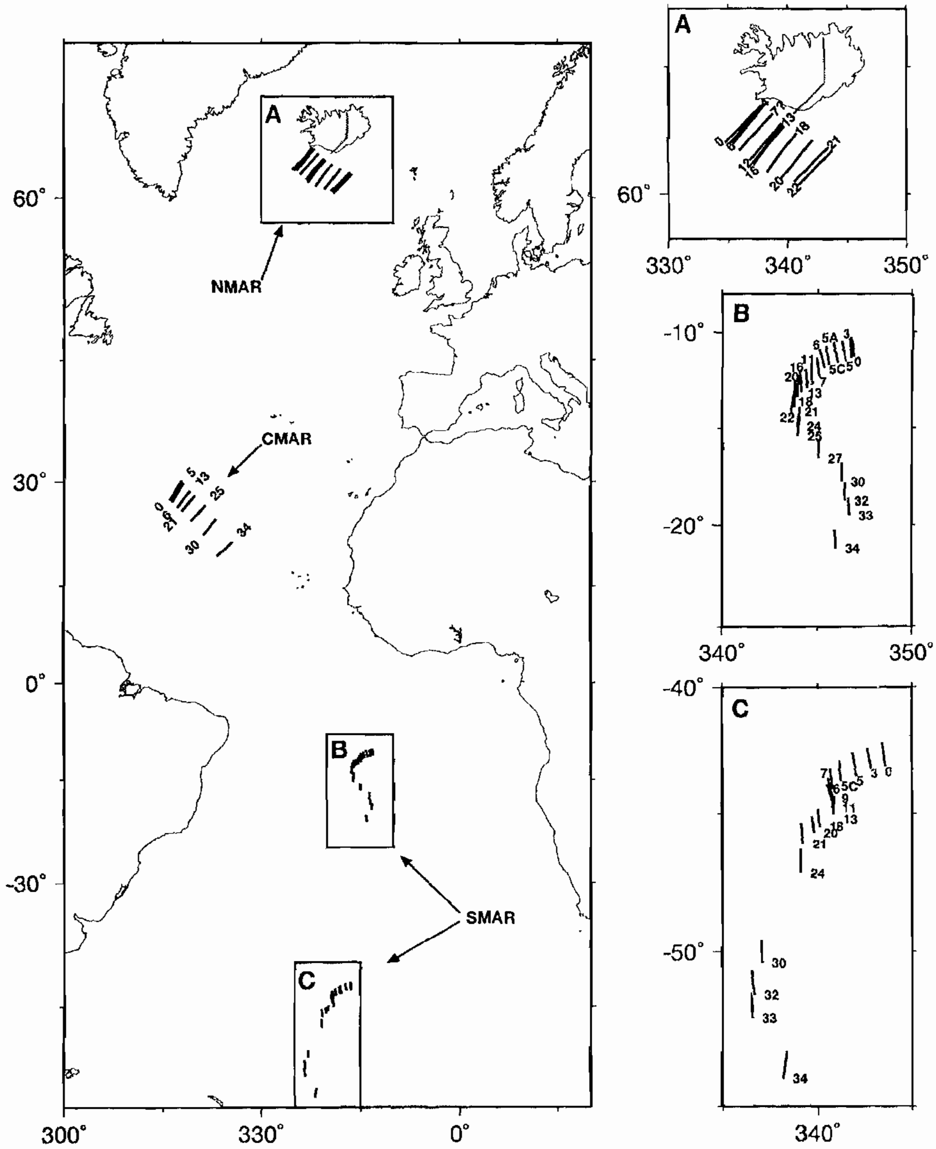

Fig. 2(ii): Atlantic ridges (SMAR, CMAR and NMAR)

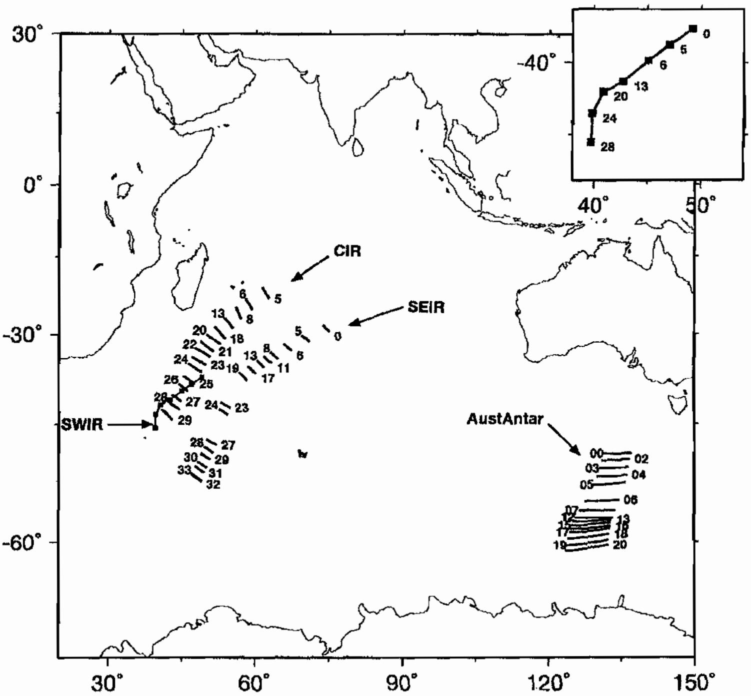

Fig. 2 (iii): Indian Ocean ridges (CIR, SEIR and AustAntar). Note that the CIR and SWIR (line connecting solid squares on the figure, and inset) sampled the same locality at different times

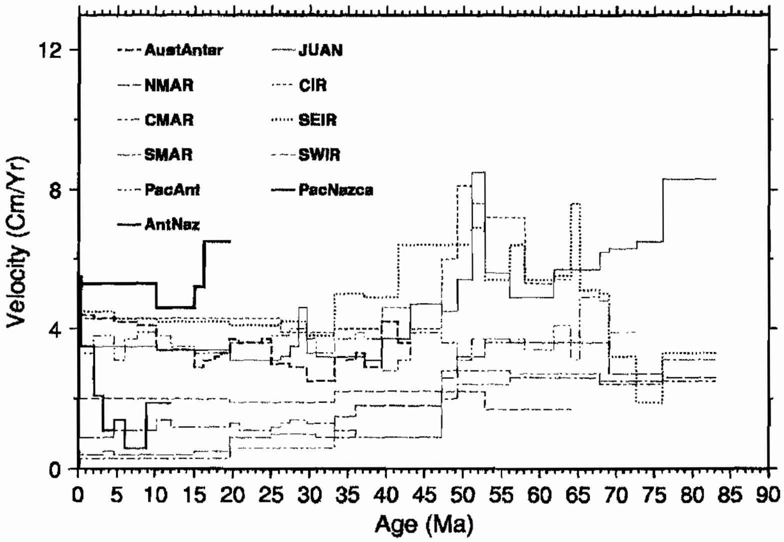

Fig. 3: Variation of migration velocities of global mid-ocean ridges. Text identifiers as in Table 1

Contrary to the SMAR, the Central Mid Atlantic Ridge (CMAR) between the equator and the 40° N latitude, and the Northern Mid Atlantic Ridge (NMAR) north of the 40° N latitude, have been migrating northwesterly since 83 Ma to Present (Fig. 2ii) suggesting existence of active deformation between the SMAR and the CMAR at least since 83 Ma. The present results may offer one explanation of the origin of tectonic complexity in the equatorial Atlantic region, an area characterized by a dense pattern of mostly medium to large offset fracture zones as well as a series of unusual ridges and troughs (Mueller & Smith 1993). Other investigators have suggested that, the equatorial Atlantic region recorded the migration of the plate boundary between the North and South American plates (Mueller & Smith 1993); and based mainly on evidence from fracture zone trends, it has been suggested that the boundary was located in the equatorial Atlantic for a significant time span between the Late Cretaceous and Late Tertiary (Roest 1987, Roest & Collette 1986).

For the Indian ocean mid-ocean ridges, the results show that paleopositions of the Central Indian Ridge (CIR) between Chron 29 and Chron 25 coincide with those of the Southwestern Indian Ridge (SWIR) between Chron 20 and Present (Fig. 2iii), implying that the SWIR may be tapping the same portion of the mantle as did the CIR between Chron 29 and 24.

Absolute ridge migration velocities and mantle tomography

The absolute migration velocities show that the ridges divide into two groups: the slow migrating ridge group including the CMAR, SMAR, NMAR and the SWIR ridges, and the fast migrating ridge group including all other remaining ridges (Fig. 3). Presently, slow moving ridges are migrating at velocities between 0.3 and 2.0 cm/yr whereas fast migrating ridges are moving at velocities between 3.3 and 5.5 cm/yr.

The results from the present study were compared with seismic velocity anomalies beneath global mid-ocean. Su *et al.* (1992) shows that seismic velocity anomalies associated with mid-ocean ridges, appear as continuous features to 300 km depth, and for the NMAR, SMAR, Pacific-Antarctic ridge (PacAnt), SWIR, and the Carlsberg ridges remain slower than normal on average down to 400 km depth, and this situation persists to 600 km depth. Except only for the PacAnt, the "deep-rooted" ridges are the slow migrating ridges (Fig. 3). Although the PacAnt, falls in the same group with fast migrating ridges, it is the slowest ridge in the group. These results suggest existence of correlation between absolute migration velocities and the depth of origin of mid-ocean ridges whereby fast migrating ridges have shallow depth of origin and slow migrating ridges have deeper depth of origin. Intuitively, this may be explained as follows: mantle from the same vertical locality beneath a ridge have more time for passive upwelling for slow migrating ridges and less time for fast migrating ridges. Slow migrating ridges allow the development of stable and deep rooted mantle convection cells beneath them, whereas fast migrating ridges probably cause some disturbances to mantle convection cells beneath them, and thus allow only the development of shallow rooted convection cells.

DISCUSSION

The observations that the SWIR may be tapping the same portion of the mantle as did the CIR, and that the correlation between absolute migration velocity and the depth of origin of mid-ocean ridges has far reaching thermal and chemical implications. One of the most important dynamic process in the Earth's interior is thermal convection in the mantle. Currently, two methods are used to study temperature variations in the upper mantle: study of major-element chemistry of basalts erupted at mid-ocean ridges which is directly influenced by the temperature of the mantle beneath (e.g. Klein & Langmuir 1987), and seismic velocity studies (e.g. Su *et al.* 1992).

Klein & Langmuir (1987, 1989) studied the chemical systematics of global mid-ocean ridges and proposed a model which explains the observed chemical systematics of global MORB (Mid-Ocean Ridge Basalts) by variations among different melting columns. According to their model a hotter parcel of the mantle (from deeper depth in the mantle) intersects the solidus at greater depth and produces a taller melting column, leading to greater mean pressures and extent of melting whereas a cooler parcel of mantle (from shallow depth in the mantle) intersects the solids at shallower depth and produces a shorter melting column, leading to lower mean pressures and extent of melting. Their model can be combined directly with the results of this study whereby fast migrating ridges correspond to ridges with cooler sources of parcels of mantle, and slow migrating ridges correspond to ridges with hotter sources of parcels of mantle. The combined result predicts that fast migrating ridges, e.g., the SEIR, will be deeper in water depth and their basalts would have relatively high $Na_{8.0}$ and SiO_2 with low $Fe_{8.0}$ and CaO/Al_2O_3, while slow migrating ridges, e.g., the NMAR, will be shallow in water depth and their basalts would have relatively low $Na_{8.0}$ and SiO_2, but relatively high $Fe_{8.0}$ and CaO/Al_2O_3. Additionally, these results suggest that the mantle beneath fast migrating ridges have undergone smaller extents of melting (melt extraction) whereas that beneath slow migrating ridges have undergone greater extents of melting (e.g. Fig. 4 of Klein & Langmuir 1989) which may influence mantle convection. Further studies are needed from different branches of geosciences to investigate whether the "deeper origin" ridges (Su *et al.* 1992) have any peculiar characteristics from other ridges.

The observation that the SWIR may be tapping the same portion of the mantle as did the CIR, suggests that different portions of the mantle have gone through different phases/history of recycling, and thus offers one possible mechanism of origin of lateral heterogeneities in the mantle. A study that will involve entire ridges may reveal more of such observations (Masalu & Tamaki 1994).

CONCLUSION

The absolute migration of global mid-ocean ridges for the past 85 m.y. and its potential role in mantle dynamics were investigated. Absolute migration velocities and depth of origin of ridges appeared to correlate whereby slow migrating ridges (migrating at 0.3 to 2.0 cm/yr) have deeper depth of origin than fast migrating ridges (migrating at 3.3 to 5.5 cm/yr). The SWIR appeared to be tapping the same portion of mantle as did the CIR, a phenomenon that may explain lateral mantle heterogeneity. Active deformation that appeared to be taking place between the SMAR and CMAR at least since 85 Ma is one possible explanation of the origin of tectonic complexity in the equatorial Atlantic.

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