RECENT RESULTS ON THE STRUCTURE OF BAY OF BENGAL AND INDIAN OCEAN FROM THE SURFACE WAVE DISPERSION STUDIES

D. D. SINGH
National Geophysical Research Institute, Hyderabad 500 007.

ABSTRACT– *Here we review the recent work on the structure of Bay of Bengal Fan and Indian Ocean, which has been done using the surface wave dispersion studies of fundamental and higher modes. The dispersion studies have been made across various propagation paths of Bay of Bengal Fan, Arabian Sea, Indian Ocean across Ninetyeast Ridge and off the ridge axis. For the Bay of Bengal Fan, high frequency S_n propagation data have also been considered in addition to the higher and fundamental mode surface wave data and PL wave. Brief results on these studies are presented here.*

INTRODUCTION

The Indian Ocean is one of the largest oceans in the world. As compared to other oceans, very few seismological studies have been carried out for this ocean. Its evolution has great geological importance. To understand its evolution and tectonics, geophysical studies are essential. In the present studies, we review the recent seismological investigations carried out by us and other workers in the world for Indian Ocean. These studies include the crust and upper mantle structure using the surface wave dispersion data for Bay of Bengal and Indian Ocean. This will help in better understanding of the tectonics and origin of Indian Ocean.

Bay of Bengal Fan

Brune and Singh (1986)[1] have used the fundamental and higher mode Rayleigh and Love waves in addition to PL wave across various propagation paths (figure 1) of Bay of Bengal Fan. The whole data set is labeled A through D. The data set A corresponds to waves arriving from south–southeast to Kodaikanal (KOD). It has a crustal thickness of about 18 km; only a few kilometers thicker than the normal oceanic structure. The path B corresponds to waves arriving roughly from the east at stations Madras (MDR) and Kodaikanal (KOD) (at about 10° N). This shows a crustal thickness of 21.8 km. Data set C corresponds to waves arriving from the east and southeast at stations Hyderabad (HYB) and Vishakhapatnam (VIS) (about 15° N) and gives a crustal thickness of about 28 km. Data set D corresponds to waves arriving at Howrah (HOW) and Shillong (SHL) from the south–southeast and gives a crustal thickness of 36 km. The sedimentary thickness is estimated using the higher mode Rayleigh and Love wave data. The correction for the continental path has been made.

Brune and Singh (1986)[1] have used the fundamental and higher mode Rayleigh and Love waves in addition to PL wave across various propagation paths (figure 2) of Bay of Bengal Fan. Observed dispersion of fundamental and higher mode Love and Rayleigh wave (figure 2) across the Bay of Bengal to eastern margins of India suggests an increase in crustal thickness northward, from an approximately 15 km thick oceanic crust to an approximately 25 km thick at 20° N and over 35 km at the northern most part of Bay of Bengal Fan (figure 3). Sedimentary thickness varies from 5.5 km to 12 km. Brune and Singh (1986)[1] have explained this increase in crustal thickness due to several reasons, such as:

- The change in Moho represents dynamic isostatic adjustment such as phase change boundary, which is lowered because of temperature or pressure perturbations from sedimentary blanket or pressure perturbations of plate collision.
- The collision has underthrust a wedge of low-velocity material beneath the oceanic crust.

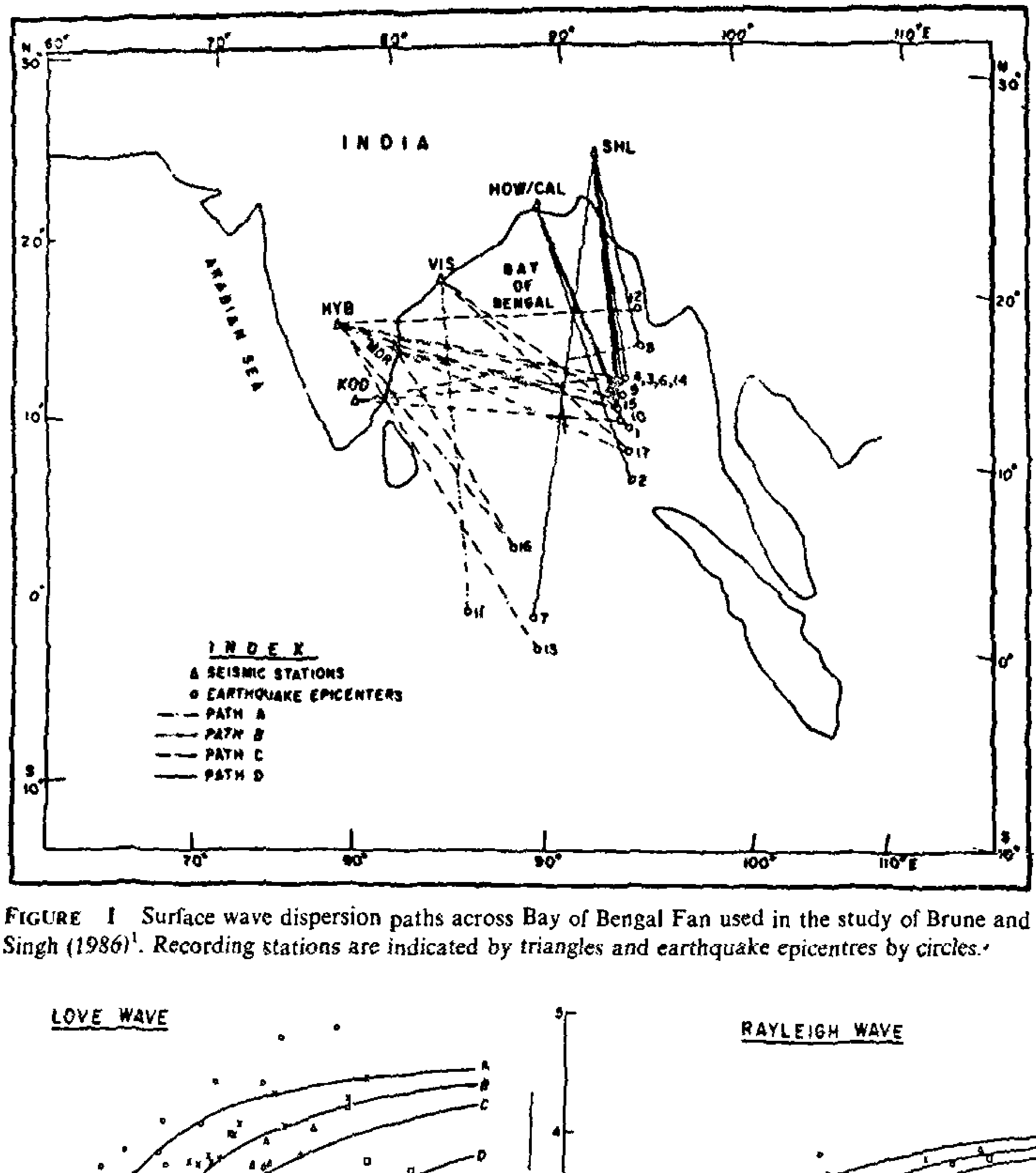


FIGURE 1 Surface wave dispersion paths across Bay of Bengal Fan used in the study of Brune and Singh (1986)[1]. Recording stations are indicated by triangles and earthquake epicentres by circles.

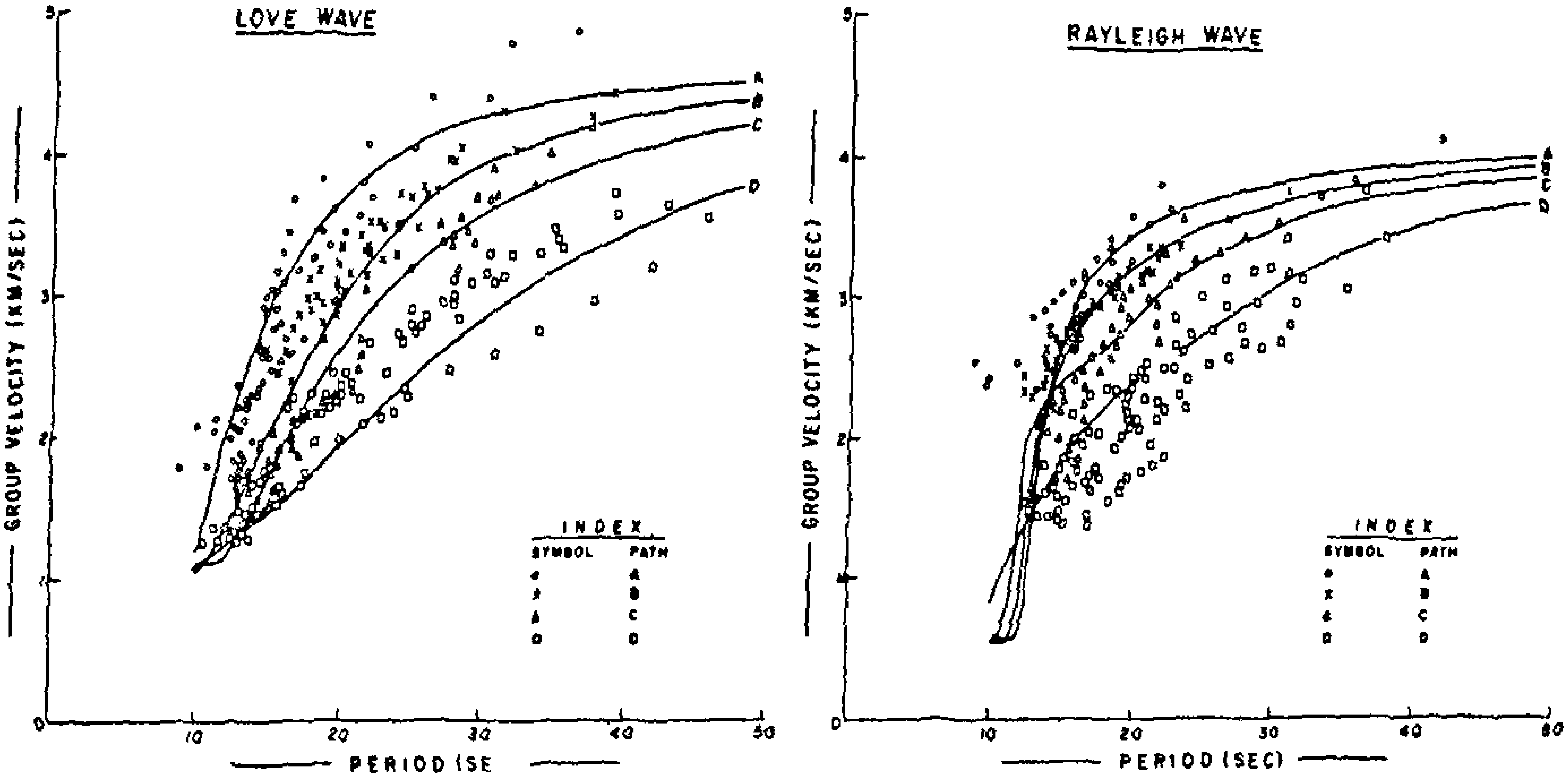


FIGURE 2 Group velocity results for various propagation paths across Bay of Bengal Fan numbered A, B, C and D are shown with approximate theoretical curves of Love and Rayleigh waves.

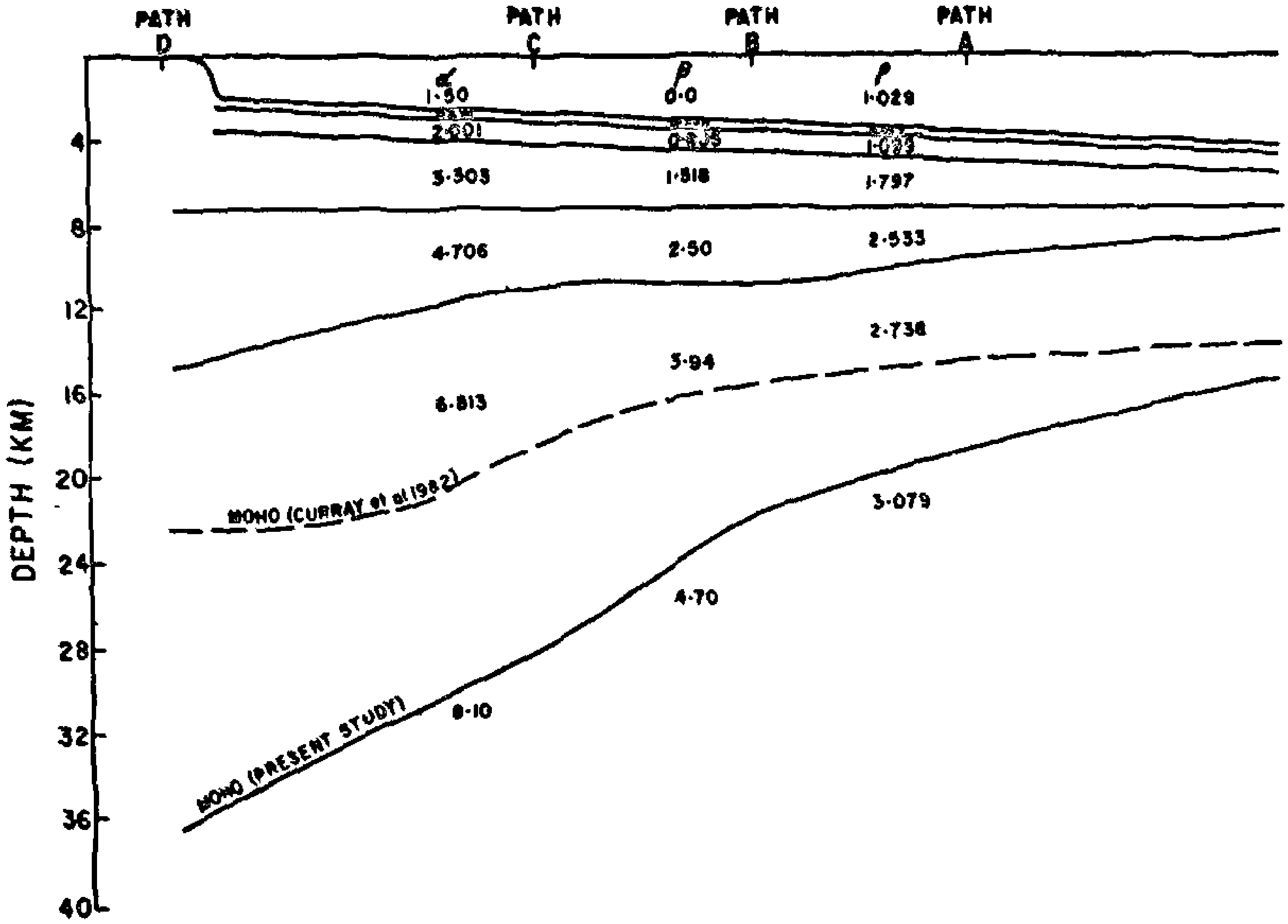


FIGURE 3 Schematic north-south cross section of crustal structure beneath Bay of Bengal Fan comparing Moho location indicated by Curray et al. (1982)[2] and Moho location inferred from surface wave dispersion results obtained in the study of Brune and Singh (1986)[1].

- The northern Bay of Bengal is actually fortuitious continental, or continent-like, possibly as a result of the influence of the 90 E ridge (especially in the northern part).
- The blanketing effect of sediments, with consequent temperature rise, has brought about differentiation of basalt, with increase in crustal thickness.

Recently Brune *et al.* (1990)[3] have found a super thick (20 km) sedimentary basin under the northern Bay of Bengal from various geophysical and geological data like surface wave dispersion, seismic refraction, S_n propagation data and found a cold upper mantle beneath the Bay of Bengal; which is against any mechanism requiring high temperatures there. Brune *et al.* (1990)[3] have found the maximum sedimentary thickness beneath the Bangladesh shelf of about 22 km.

Arabian Fan

Singh (1988a)[4] has used the fundamental and higher modes Love and Rayleigh waves generated by 31 earthquakes and recorded at the western margins of India and Pakistan (*figure 4*) to determine the crustal structure beneath the Arabian Fan sediments. The observed dispersion data (figure 5) suggest an increase in crustal thickness northward, from an approximately 16 km crustal thickness at the southern tip of India to an approximately 28 km crustal thickness at the regions of 20° N and above latitude, with an overlying 6 km sedimentary thickness (figure 6). This gradual increase in crustal thickness in the northward direction and attaining of quasi-continental oceanic structure beneath the Arabian Fan sediments suggest that the Mohorovicic discontinuity may have resulted from a change in crustal structure due to an increase of pressure and it is not a phase change. The same material exists beneath Moho, and it does not represent the boundary between two different material. The transition has given rise to crustal thickening in the northward direction. Another possible explanation is that the increase in hydrostatic pressure due to the load exerted by a large sedimentary column together with horizontal pressure caused by the collision of Indian and Eurasian plates has given rise to an increase in temperature near the Moho. Because of the thermal blanketing effect of this large sedimentary column, an inferred rise in temperature may have either changed the upper mantle material into material with crustal like velocity or may have given rise to metamorphism of earlier existing sedimentary rocks.

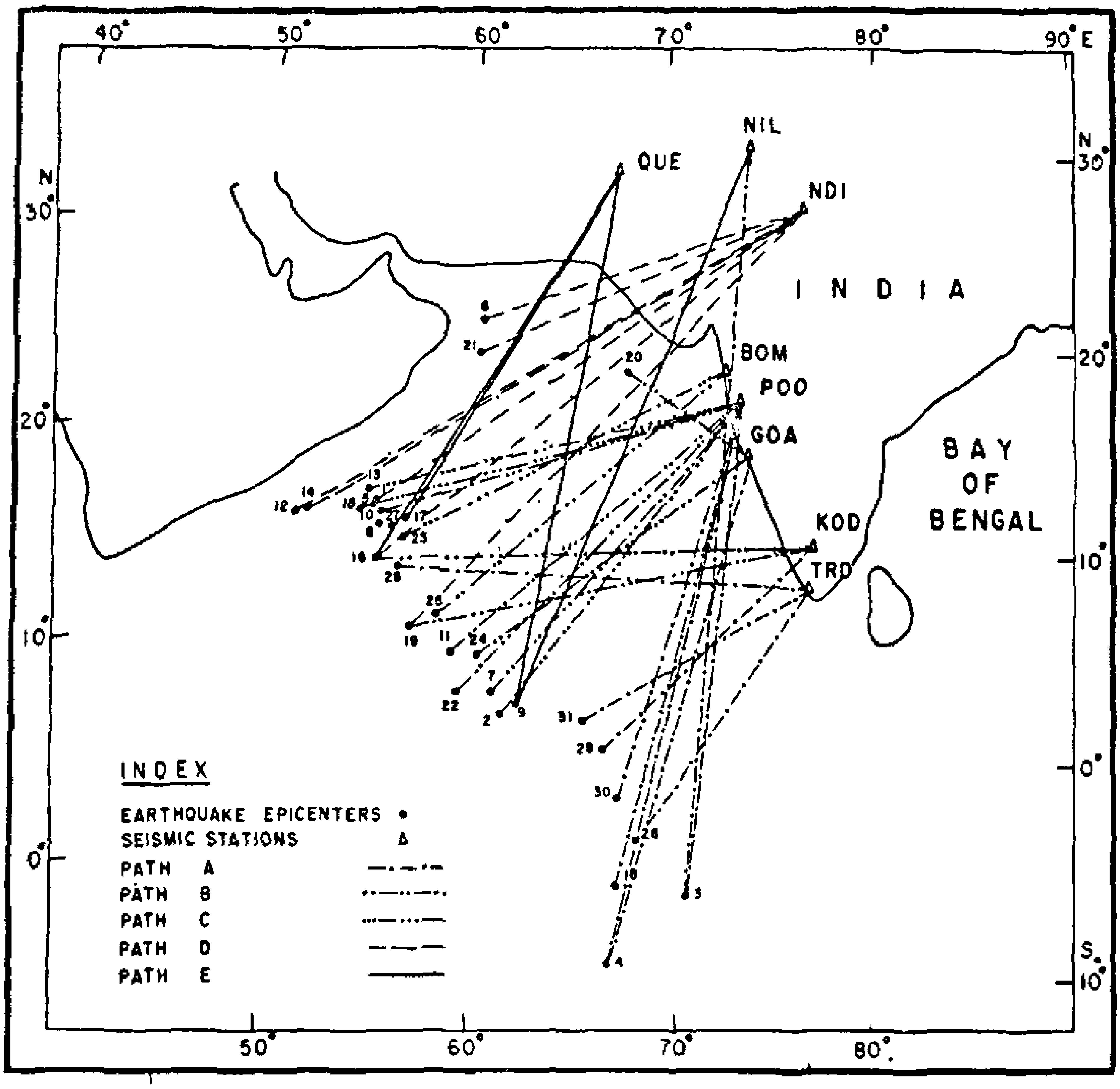


FIGURE 4 Surface wave dispersion paths across Arabian Fan used in the study of Singh (1988 a)[4]. Recording stations are indicated by triangles, and earthquake epicentres by circles.

Indian Ocean

Singh (1988b)[5] has determined fundamental mode Rayleigh and Love wave phase and group velocities using surface waves generated by nine earthquakes, which occurred in central Indian Ocean and recorded at seven WWSSN station of central Asia (figure 7). The Rayleigh and Love wave group velocities are determined at the period of 14 to 54 second. Similarly, the Rayleigh and Love wave phase velocities are determined at the time period of 15 to 100 second at 5 second time interval. The dispersion data of Rayleigh and Love waves show a thick crust of 23 km thickness across Ninetyeast Ridge. This anomalous crustal thickening, having quasi-continental oceanic structure, may be explained by assuming the gradual transformation of top mantle material into material having either crustal like velocity or slightly lower than Moho velocity (P-wave velocity 7.72 km/sec, S-wave velocity 4.45 km/sec). The velocity structure down to a depth of 200 km is estimated across north and central Indian Ocean. A low velocity zone of 90 km thick with P-wave velocity of 7.85 km/sec and S-wave velocity of 4.37 km/sec (figure 8) is estimated to be centered at a depth of 78 km from surface. This low shear velocity in the mantle may be caused by the partial melting and elevated temperature (1100°–1200°C) there. The observed dispersion data for Rayleigh and Love wave that cross the Ninetyeast Ridge are characterised by lower phase and group velocities, as compared to waves having paths in a more western direction than this ridge axis. Our observed dispersion data support that a model which gives serpentinization of peridotites (chemical differentiation in upper mantle), may explain the origin of Ninetyeast Ridge. The present result does not support the hypothesis that Ninetyeast Ridge was formed on hot, relatively weak lithosphere, which is essential with formation at or near an oceanic

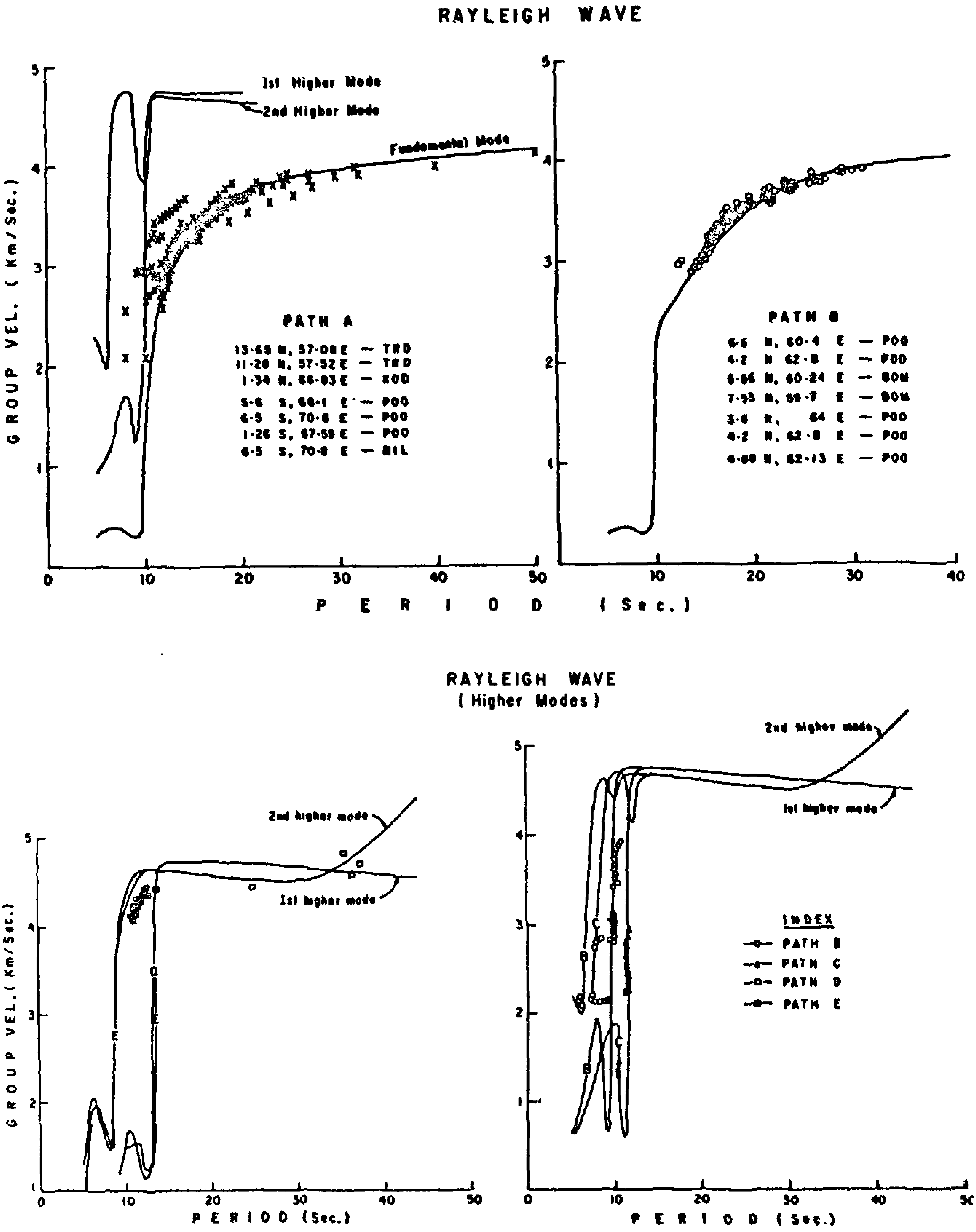
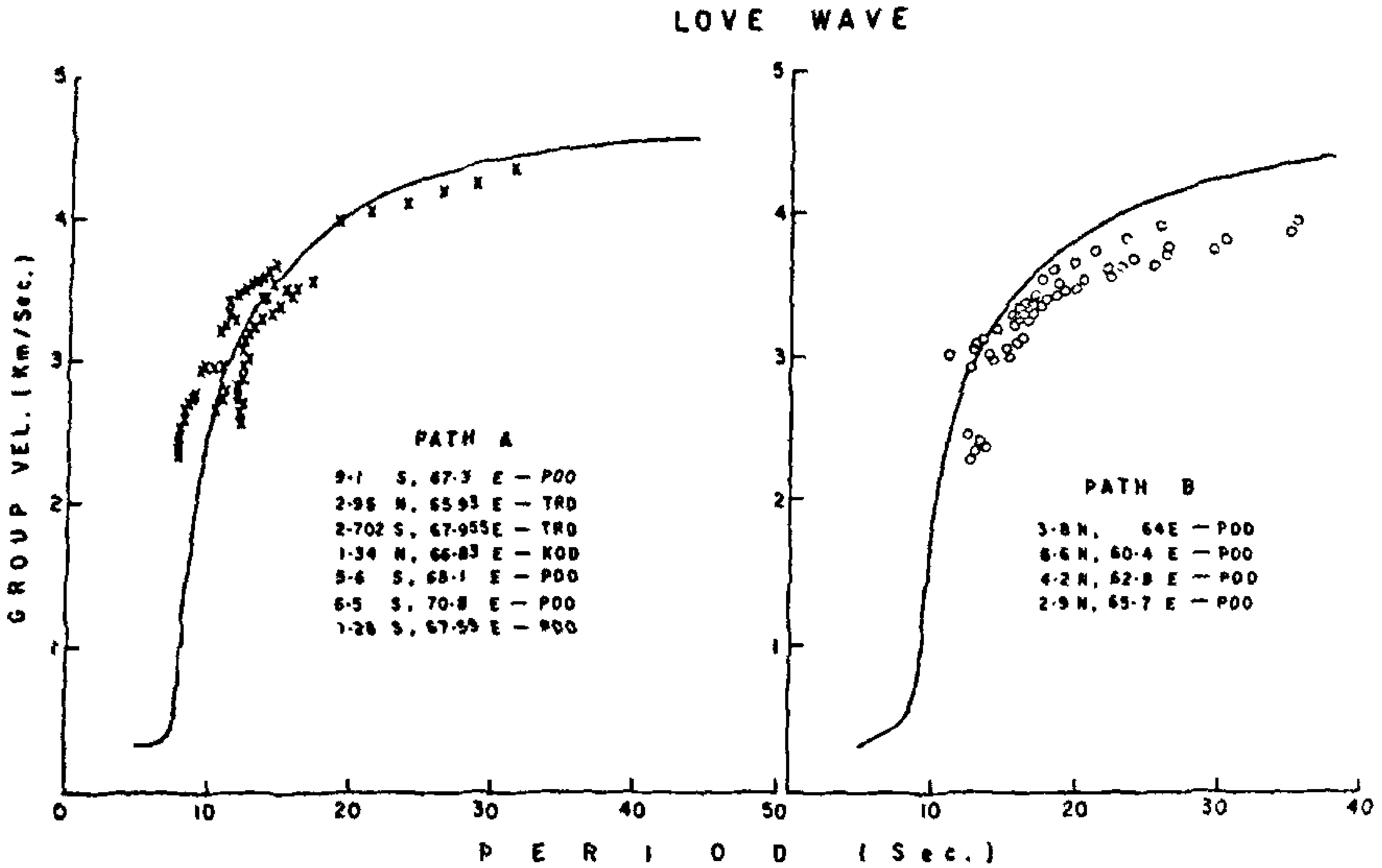


FIGURE 5 Observed fundamental and higher mode Rayleigh and Love wave group velocities (symbols) for various propagation paths across Arabian Fan numbered A to E are shown with their corresponding theoretical curves (continuous line) for the Arabian Fan.



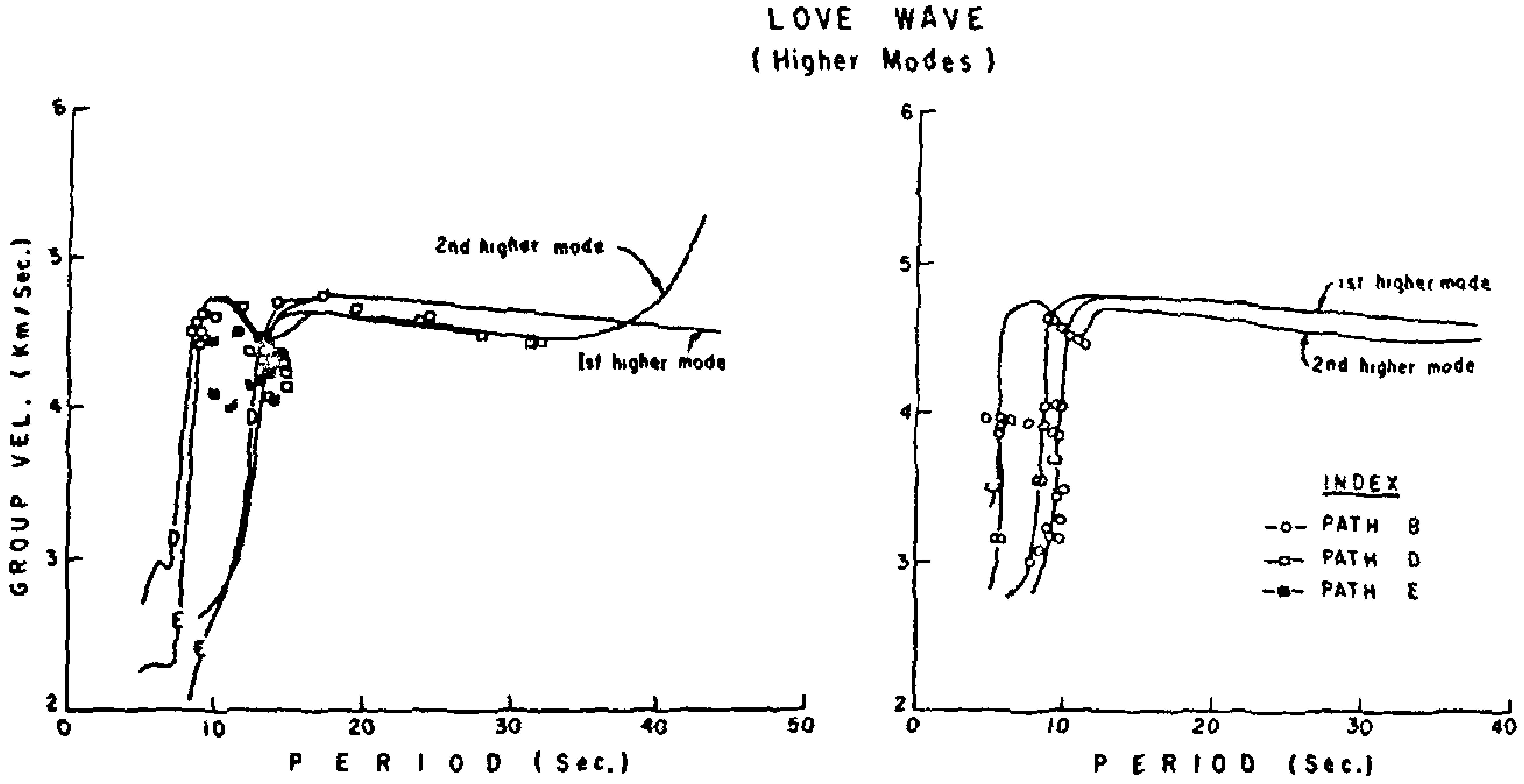


FIGURE 5 (continued).

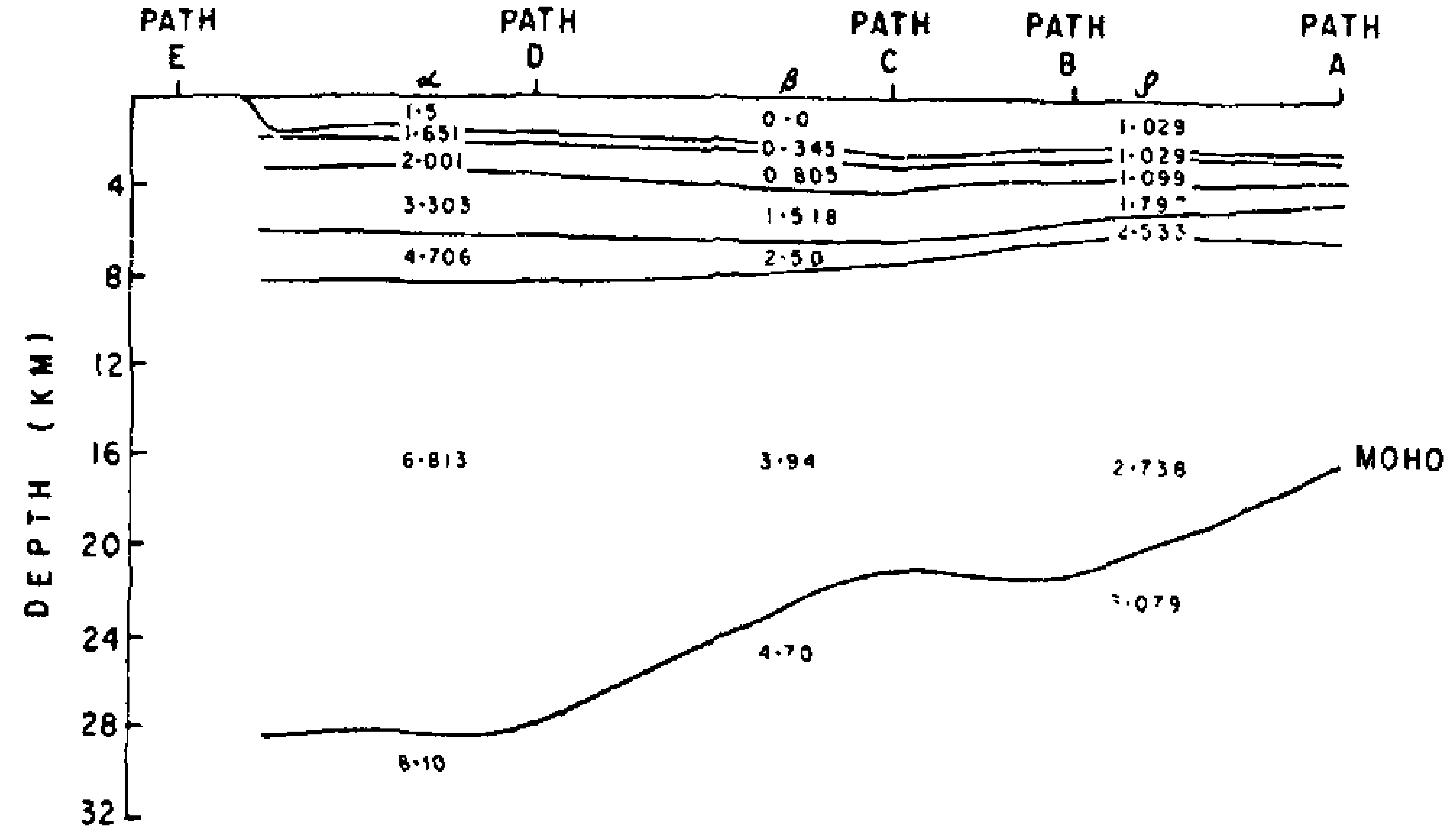


FIGURE 6 Schematic cross-section of crustal structure beneath Arabian Fan from southern most India (Trivandrum) to northern most end (Central Pakistan). Moho is inferred from surface wave dispersion results obtained in the study of Singh (1988 a)[4] for different propagation paths.

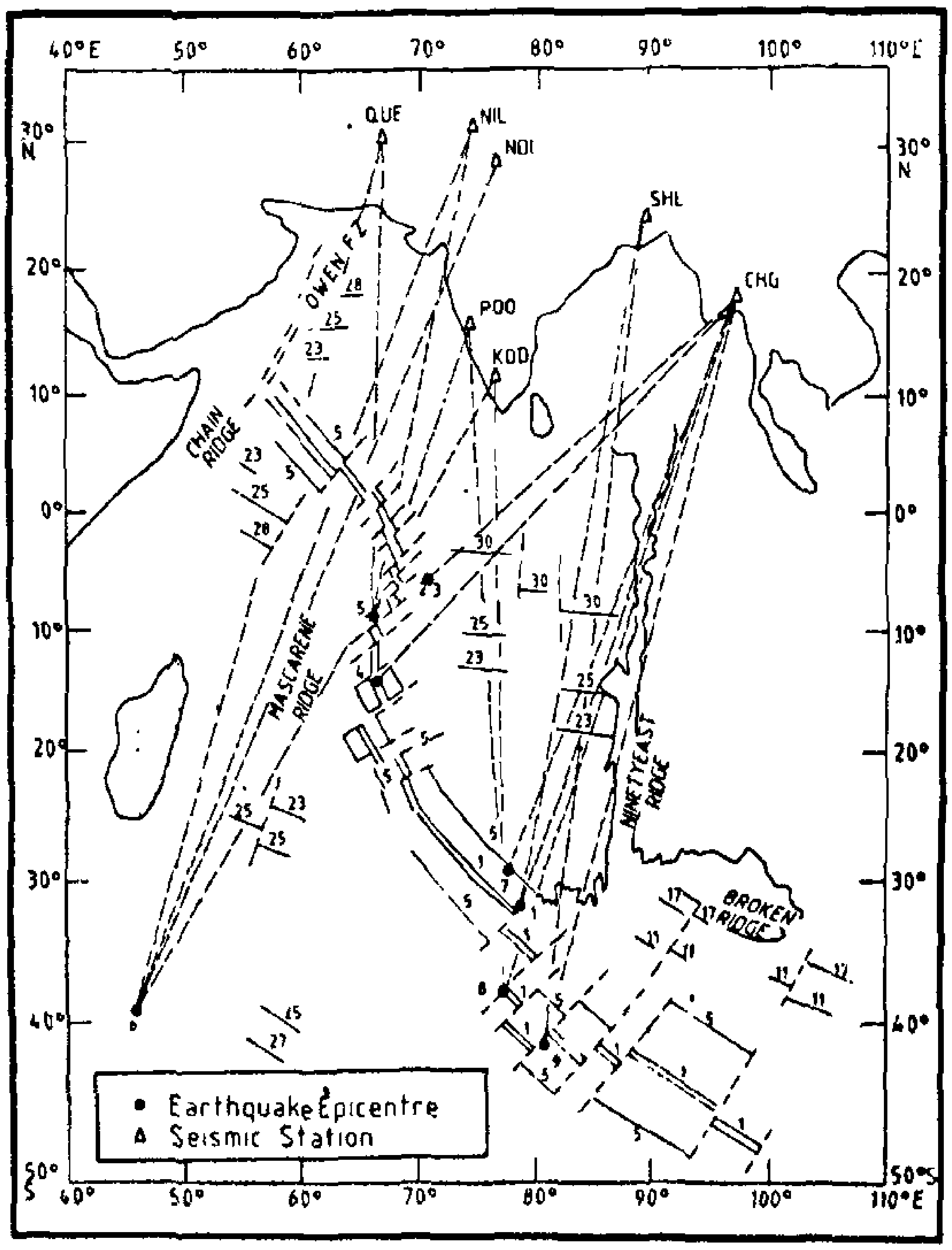


FIGURE 7 Surface wave dispersion paths for north Indian Ocean used in the study of Singh (1988 b)[5]. Recording stations are indicated by triangles and earthquake epicentre by circles. Magnetic anomalies are taken from *Heirtzler et al.* (1968)[6].

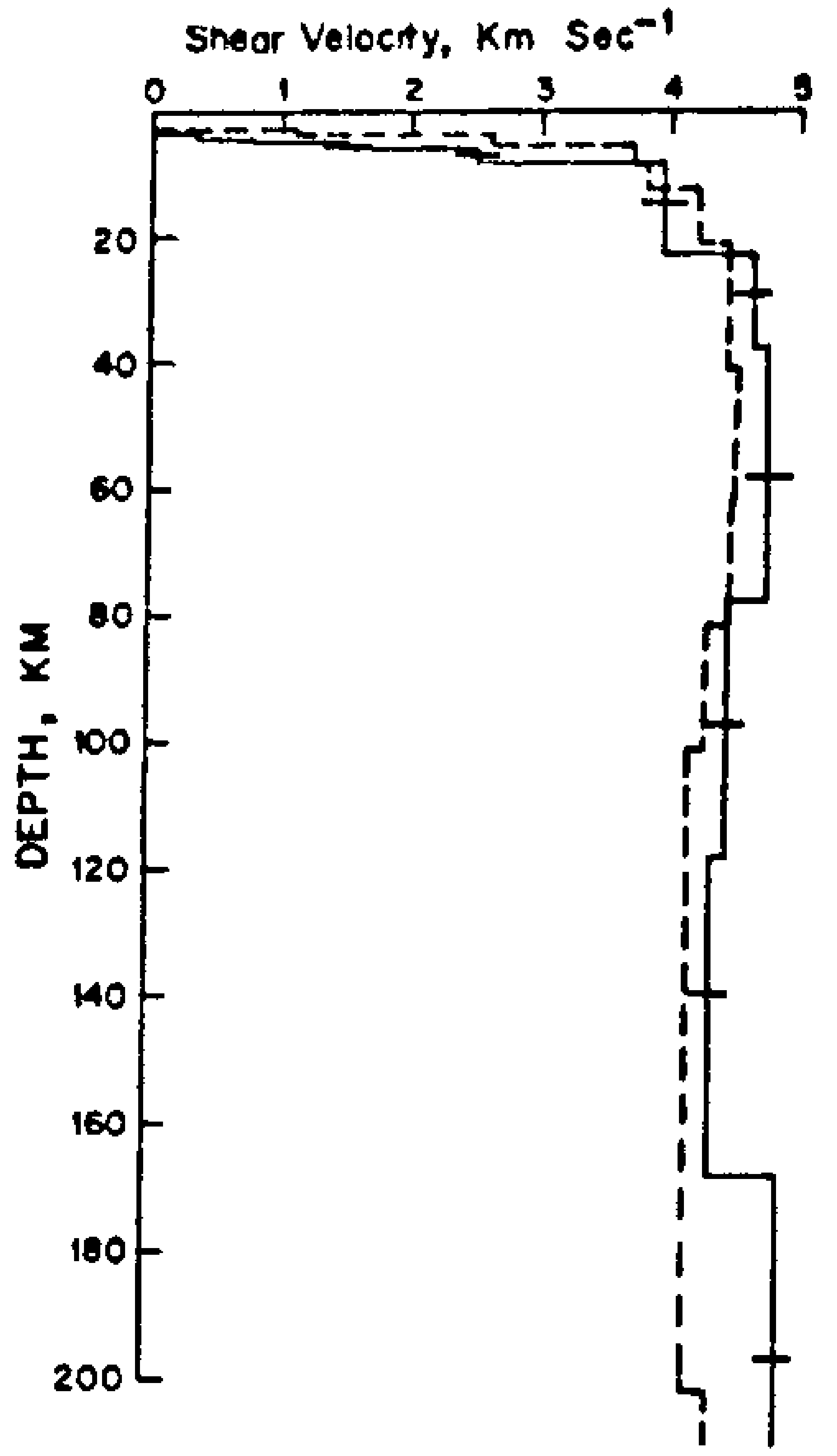


FIGURE 8 Shear wave velocity model for north Indian Ocean across the Ninetyeast Ridge. The standard deviation estimates of the shear wave velocity of the model are shown by horizontal bars for each layer. Continuous line represents the model determined by Singh, 1988 (b)[5] and broken line is obtained by Souriau, 1981[7].

spreading centre by a mantle plume or hot spot.

Souriau (1981)[7] has used Rayleigh wave group velocities (figure 9) to determine the upper mantle structure of the aseismic ridge of eastern Indian Ocean i.e. the Ninetyeast Ridge and the Broken Ridge-Naturaliste Plateau. Velocity models have been obtained down to 150–200 km for the profiles on and off Ninetyeast Ridge and down to 100 km for Broken Ridge. They reveal that, except for a thick anomalous crust, the structure beneath these ridges is quasi-oceanic. For the Ninetyeast Ridge (figure 8), the uppermost 30 km of the mantle have lower velocities. For paths off ridge no such low velocities are obtained, indicating a small lateral extension of this anomaly. According to her, a thermal origin is ruled out, while a model with serpentinized peridotites as proposed by Bowin (1973)[8], which fits gravimetric data, is able to explain the low velocities of uppermost mantle beneath the Ninetyeast Ridge.

Montagner (1986)[9] has studied the Rayleigh wave

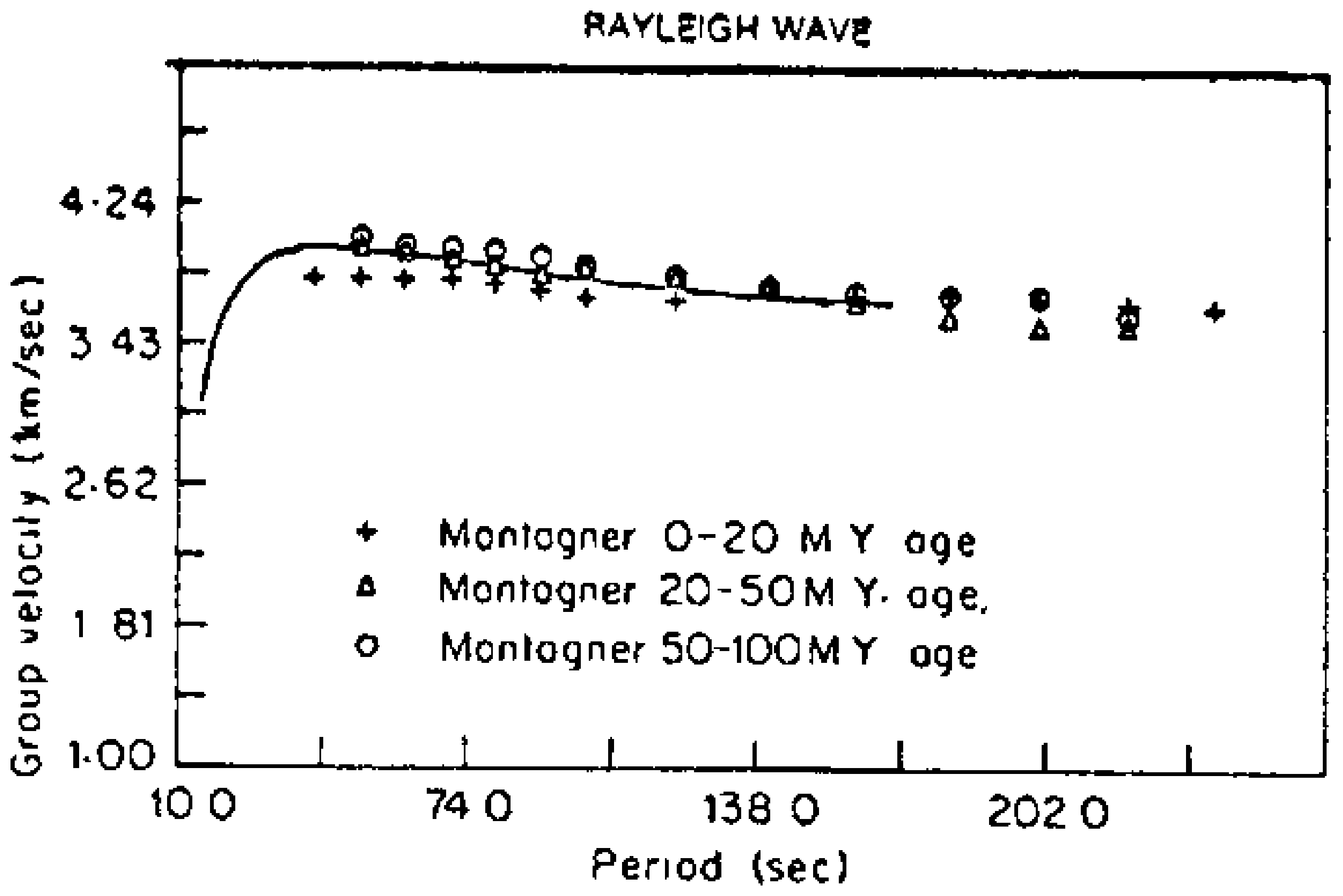


FIGURE 9 Observed fundamental mode Rayleigh wave group velocity determined by Souriau, 1981 (continuous line) and Montagner, 1986[9] (symbols) for Indian Ocean paths.

dispersion along 86 paths across Indian Ocean and surrounding regions in the period range of 40–300 second (figure 9). He used a tomographic method to compute the geographical distribution for group velocity and azimuthal anisotropy and then 3-D structure of S-wave velocity. His data can resolve a horizontal wavelength of 2000 km for velocity and 3000 km for azimuthal anisotropy. Result suggests high velocity at all depths except for the central part of South East Indian Ridge. Low velocities are found along the central and South East Indian Ridges. Velocity is found to increase with the age of sea floor and high velocities are obtained under African, Indian and Australian shields. Further, Montagner (1986)[9] found the low velocity zones under the Gulf of Aden and western part of South East Indian Ridge at greater depths and this low velocity anomaly of Central Indian Ridge is offset eastward. He interpreted the low velocity anomalies caused due to uprising material and complex plate boundary.

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