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Surface Wave Dispersion and Crustal Structure in the Indian Ocean

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ABSTRACT. Dispersion of Rayleigh waves along several paths in the Indian Ocean have been studied by means of records from Shillong. From the observed group velocity data it was found that the average thickness of the crust under the Indian Ocean is about 5-10 km. It was also found that the bottom of the Indian Ocean is likely to be covered by a series of ridges.

1. Introduction

In Seismology, methods for the determination of crustal structure may be classified into two groups —(1) those using direct, reflected and refracted compressional and shear waves from near earthquakes or explosions and (2) those based on earthquake surface waves. Refraction methods provide more detailed information on crustal structure than any other technique. Surface wave studies indicate the average properties of the crust, of course in much less detail between the earthquake epicentre and the seismograph station, a distance usually consisting of continental or oceanic regions or a mixed path of both. Surface wave methods are particularly useful in the study of the structure of remote oceans, not covered by refraction surveys. From a study of the crustal structure under continents and oceans as revealed by the Rayleigh and Love wave dispersion data, Press and Ewing (1955) concluded that oceanic Rayleigh wave dispersion results are not only consistent with the known ocean depths, the sedimentary thickness and crustal layering found in refraction measurements, but also indicate that the technique can be used as an exploration method in its own right.

In recent years, although many seismologists have successfully utilised the surface wave dispersion data for the exploration of Pacific, Atlantic, Arctic and many other oceans, very little or practically no attempt has so far been made by any author to study the sub-oceanic structure of the Indian Ocean. As part of the I.G.Y. Programme, the California Institute of Technology operated a seismograph station at Wilkies in the Antarctica. The seismograms obtained from this station were utilised by Kovach and Press (1961) for a study of the crustal structure of the Indian Ocean.

In 1963, through the co-operation of the United States Coast and Geodetic Survey, three components of Press-Ewing long period type seismographs were installed in the Central Seismological Observatory at Shillong, India. These instruments form a matched system with a seismometer period of thirty seconds and galvanometer period of one hundred seconds. The magnification is around three thousand for a period of thirty seconds. Long period seismic waves at fairly long distances are generally well recorded by these seismographs.

2. Study

In the present communication it is proposed to study the sub-oceanic crustal structure of the Indian Ocean from a study of the Rayleigh wave dispersion data obtained from the seismograms of Shillong.

The epicentre, date and origin time of the earthquakes which have been used in this study were taken from the monthly bulletins published by the U.S.C.G.S. and are shown in Table 1. Typical examples of seismograms, which have been studied, are shown in Fig. 1.

The shocks were well recorded by the long period seismographs of Shillong. The epicentral distances of the shocks being fairly long, the dispersion of the Rayleigh waves could be measured from the seismograms with precision and the results obtained were rather independent of small errors in the determination of epicentral distances and origin times. Fig. 2 is an index map showing the epicentres, waves paths and the recording station. From the figure, it may be seen that the wave paths are not entirely oceanic, especially for earthquakes Nos. 4, 5 and 6, wavepaths of which pass rather close to the coast line. The percentage of continental paths were determined for all the shocks and has been shown in Table 1. For the portion of the path of known continental character, *i.e.*, 1000 fathom line used as boundary, a correction was applied using the continental Rayleigh wave-velocity curve of Brilliant and

TABLE 1

Epicentre Lat.	Epicentre Long.	Date	Origin Time (GMT) h m s	Path No.	Percentage of oceanic path
34·6°S	81·5°E	5 Jun 1963	05 32 09	1	90·7
37·9°S	78·0°E	6 Jun 1963	12 04 15	2	86·8
27·5°S	66·0°E	28 Jun 1963	02 28 51	3	82·5
12·8°S	66·0°E	20 Dec 1963	15 14 45	4	71·5
8·4°S	67·6°E	10 May 1963	11 09 42	5	56·0
44·7°S	37·5°E	25 Feb 1964	00 34 32	6	78·5

TABLE 2

Path	Percentage of oceanic path	Period	Group vel. without correction	Group vel. after correction
1	90·7	20	3·31	3·34
		21	3·34	3·37
		23	3·36	3·39
		24	3·44	3·47
		25	3·47	3·50
		26	3·49	3·52
		27	3·51	3·55
		29	3·57	3·61
		30	3·69	3·63
2	86·8	19	3·47	3·55
		21	3·50	3·57
		23	3·58	3·66
		24	3·64	3·72
		25	3·66	3·74
		26	3·72	3·81
		30	3·80	3·89
3	82·5	20	3·34	3·41
		21	3·36	3·43
		22	3·42	3·50
		23	3·47	3·55
		24	3·53	3·62
		25	3·55	3·64
		26	3·60	3·69
		27	3·67	3·78
		29	3·70	3·80
4	71·5	20	3·26	3·37

Path	Percentage of oceanic path	Period	Group vel. wsthout correction	Group vel. after correction
4	78·5	21	3·30	3·41
		22	3·35	3·47
		23	3·40	3·53
		24	3·42	3·55
		25	3·49	3·63
		26	3·55	3·71
		27	3·58	3·75
		28	3·61	3·78
		29	3·65	3·82
		30	3·74	3·95
5	56·0	20	3·24	3·44
		21	3·29	3·50
		22	3·32	3·54
		24	3·37	3·58
		25	3·47	3·73
		27	3·50	3·76
		28	3·58	3·89
		30	3·67	4·02
6	78·5	20	3·53	3·68
		22	3·62	3·78
		23	3·66	3·82
		24	3·70	3·86
		25	3·71	3·87
		26	3·75	3·91
		27	3·77	3·94
		28	3·78	3·96
		29	3·81	3·97
		31	3·83	3·99

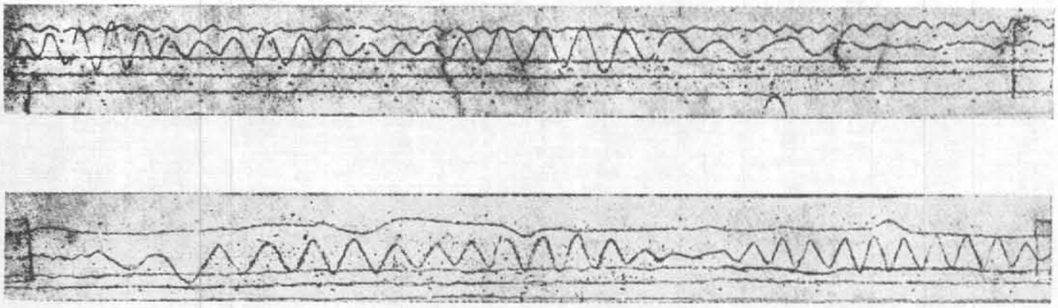

Fig. 1. Section of Shillong seismograms for the earthquake of 6 June 1963 (above) and 28 June 1963 (below)

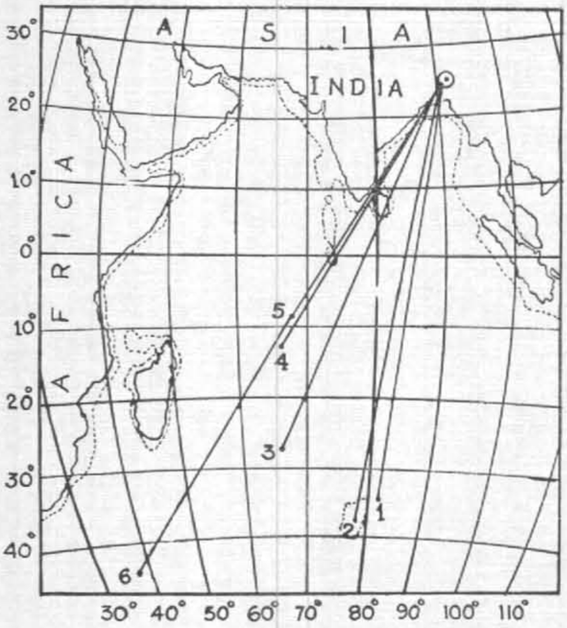

Fig. 2. Index map showing wave paths of the observed earthquakes

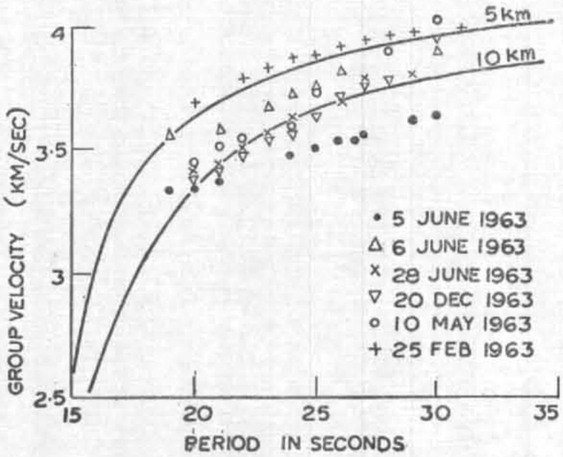

Fig. 3. Indian Ocean Rayleigh wave dispersion datawith the theoretical curves corresponding to 5 and 10 km crustal thickness

Ewing (1954). The correction was applied after Wilson and Baykal (1948), on the assumption that the observed velocity of any period is a linear function of the percentage of its path which is oceanic or continental. The observed group velocities have been shown in Table 2 together with those obtained after applying corrections for the continental paths. The dispersion curves for the Rayleigh waves were determined by graphical method by plotting the crests and troughs observed on the seismograms.

3. Results

The experimental results have been compared with a single layered crust of constant velocity underlain by a sub-crust of different velocity to arrive at a value for the thickness of the crust. The Rayleigh wave group velocities obtained from the seismograms have been plotted in Fig. 3 together with two theoretical curves for two different crustal thickness as computed and used by Officer (1955). These theoretical curves were calculated for an average crustal velocity obtained from earthquake and crustal refraction profiles elsewhere. The values of compressional and shear wave velocities α and β, density ρ and Poissons ratio σ considered by Officer for calculating the theoretical curves are : $\alpha_0=1\cdot52$ km/sec, $\alpha_1=5\cdot50$ km/sec, $\beta_1=3\cdot18$ km/sec, $\alpha_2=8\cdot10$ km/sec, $\beta_2=4\cdot68$ km/sec, $\rho_1/\rho_0=2\cdot67$, $\rho_2/\rho_0=3\cdot00$ and $\sigma=0\cdot25$.

From Fig. 3 it will be seen that the observed data lie more or less in between the two theoretical curves. The method used gives an average crustal thickness over the segments of the paths considered. Allowing for all known errors, it would seem that an average crustal thickness of 5 to 10 km may be inferred for the region under consideration. The group velocities from the earthquake No. 1 lie a little below the theoretical curve indicating that the thickness of the crust in this segment is more than 10 km. From Fig. 2 it may also be seen that 50 per cent of the path No. 5 is almost grazing the Indian subcontinent but path No. 1 is entirely in the mid Indian Ocean. This may be an indication that the crust in the mid Indian Ocean region is thicker than that on its eastern and western parts.

The way the group velocity data from the different earthquakes fit in between the two theoretical curves also suggests that the floor of the Indian Ocean is not likely to be a smooth one but rather rugged, *i.e.*, covered by ridges.

The author's observations are also in agreement with that of Santo (1960). From the surface wave dispersion data from an Indian Ocean shock recorded at Mt. Tsukuba, Santo observed that the dispersion of Rayleigh waves through the Indian Ocean is rather similar to the western Pacific Ocean. As determined by Officer, the crustal thickness in the south western Pacific (Tasman basin) is 5 to 10 km. According to Kovach and Press (1961) the thickness of the crust under the Indian Ocean is about 5 km. Their investigation was rather limited to the south and eastern region of the Indian Ocean, whereas the author's study is limited to the middle and northern region.

4. Conclusions

(1) The average thickness of the crust in the middle and northern part of the Indian Ocean is 5-10 km.

(2) The curst in the mid-oceanic region might be thicker than that in the eastern or the western part of the Indian Ocean.

(3) The thickness of the crust in the middle and northern region of the Indian Ocean is different from that in the southeastern part.

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