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Research note

Observed very long period Rayleigh-wave phase velocities across the Canadian shield

Emile A. Okal *Seismological Laboratory, California Institute of Technology, Pasadena, California 91125, USA*

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Summary. The recent Indonesian earthquake (1977 August 19; $M_s = 8.0$) makes possible a direct determination of Rayleigh-wave phase velocities at very long periods (200 to 300 s) over a pure shield path (College, Alaska–State College, Pennsylvania) by the two-station method. Results are in good agreement with previous models derived by regionalization of great-circle phase velocities and discussed in a previous paper (Okal, Paper I). Great-circle phase velocities computed at College and State College are correctly predicted by the models derived in Paper I, and further substantiate one of its main conclusions: no substantial structural differences between oceans and continents at depths greater than 240 km, are necessary to account for the presently available seismic data.

1 Introduction

In a recent paper, Okal (1977, hereafter called Paper I) discussed the regionalization of oceanic and continental Rayleigh-wave phase velocities at periods of 200 to 300 s, taking into account the intrinsic oceanic lateral heterogeneity brought up by the variation of lithospheric thickness with the age of the plate. Theoretical values obtained from Leeds' models of oceanic lithosphere (Kausel, Leeds & Knopoff 1974; Leeds, Kausel & Knopoff 1974; Leeds 1975) were checked against experimental values obtained directly from the two-station method over a few 'pure-age' oceanic paths. This method uses Rayleigh-wave records at two stations separated by a homogeneous path, on the same great circle with the epicentre, in a direction favourable to the radiation of Rayleigh waves. Unfortunately, in the case of shields, it was not possible at the time of Paper I, to find any such pair of records over the lifetime of the WWSSN network. (The use of standard stations is necessary to eliminate the uncertainty on the phase response of the instruments.) However, such an alignment was obtained for the recent Indonesian earthquake (1977 August 19), between College, Alaska (COL) and State College, Pennsylvania (SCP).

The goal of the present paper is two-fold: in Section 2, we report the experimental determination of Rayleigh-wave phase velocities over a shield path. We then compare these values with the theoretical ones obtained by 'regionalization' or 'pure-pathing' of great-circle phase velocities (Kanamori 1970; Dziewonski 1970; Paper I), and with oceanic velocities, both experimental and theoretical. We conclude that shield velocities do indeed fall within the range through which oceanic velocities vary with the age of lithosphere, as expected from the conclusion of Paper I. In the third section, we compute great-circle phase velocities from the records at COL and SCP, and use them as an independent check of the models derived in Paper I. The agreement is found to be excellent.

2 Pure shield Rayleigh-wave phase velocities

2.1 DATA

The Indonesian earthquake of 1977 August 19 (Origin Time 06:08:52 GMT) was located by the National Earthquake Information Center at 11.13° S; 118.40° E, southwest of the island of Sumba. The magnitude measured at Pasadena was $M_s = 8.0$. Strong Rayleigh waves were observed at COL and SCP, these two stations being separated by only 2.6° in azimuth. Fig. 1 shows the geographical layout of the great circle linking the two stations and the epicentre. Table 1 gives the details of the seismic phases used in this study. A clock correction of −500 ms was applied to the records at SCP. The calibration pulses were digitized, filtered at $T \geqslant 150$ s, and checked to be identical at both stations.

Seismograms were digitized at 2 s intervals and Fourier analysed at the five standard periods used in Paper I (292.57, 256.00, 227.55, 204.80 and 186.18 s). For the wavetrains used (R4 to R8), spectral amplitudes are usually peaked between 200 and 300 s. We eliminated all spectral components whose amplitude was less than one-half the maximum spectral amplitude in the corresponding record. These components appear as asterisks (*) in Tables 2 and 3. The phase velocities were then computed from the difference in phase at the two stations (see Paper I, equation 1).

2.2 RESULTS

These are listed in Table 2, and plotted on Fig. 2, which is adapted from Fig. 3 of Paper I. The error inherent to the method is on the order of twice the digitizing unit (2 s) in the time

Table 1. Summary of records and stations used in this study.

Code	Station	Epicentral distance (km)	Azimuth (°)	Time correction (ms)	Digitizing window starts (GMT)	Digitizing window ends (GMT)
COL	College, Alaska	11298.1	25.7	0		
	R3				09:56	10:16
	R4				11:08	11:33
	R5				13:00	13:25
	R6				14:06	14:42
	R7				16:11	16:35
SCP	State College, Pennsylvania	16353.7	23.1	−500		
	R4				10:42	11:11
	R5				13:17	13:46
	R6				13:46	14:22
	R7				16:24	16:54
	R8				16:54	17:26

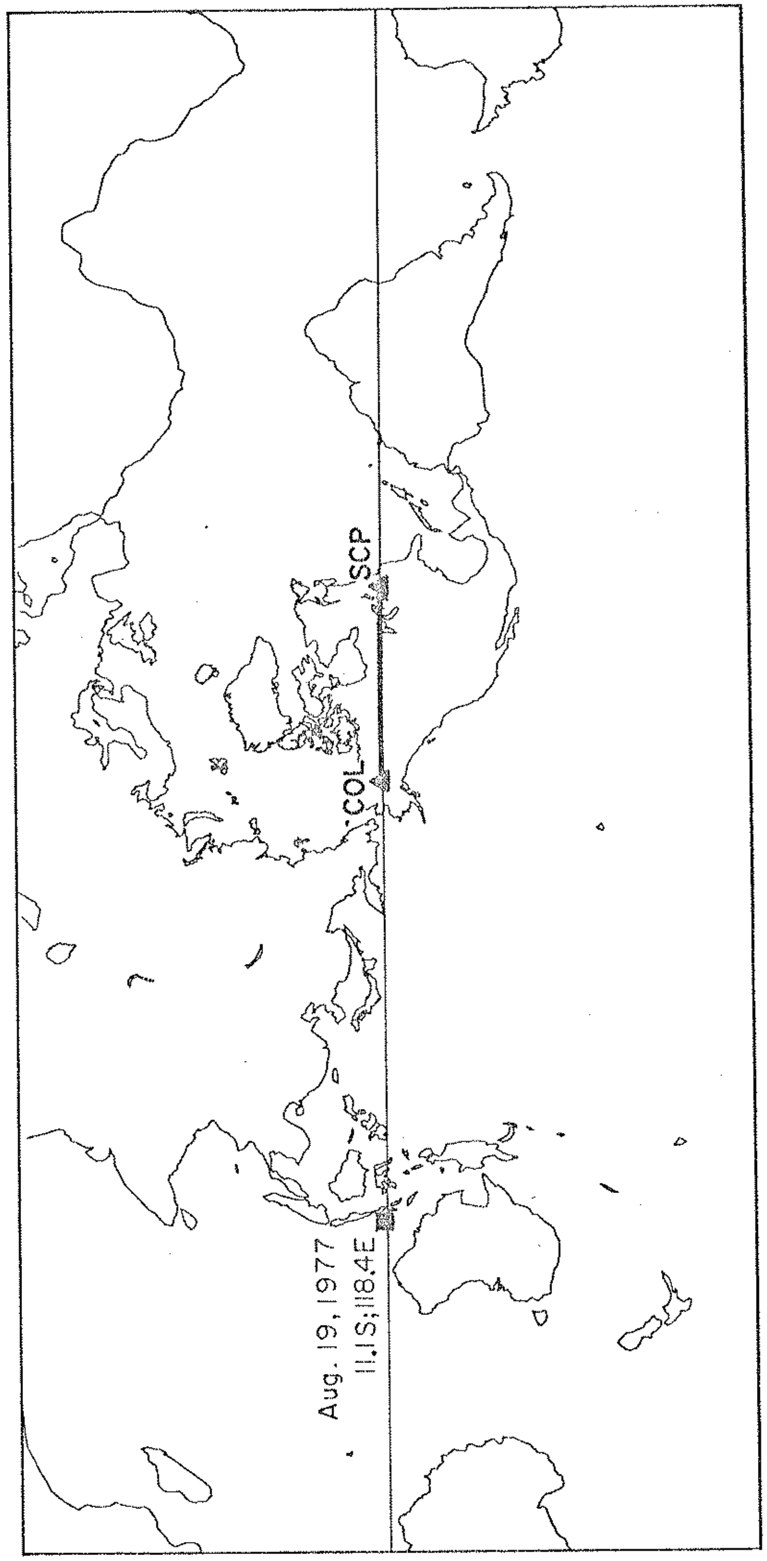

Figure 1. Map of the world showing the epicentre (black square) and stations used in this study. This Mercator projection uses the great circle through COL, SCP and the epicentre as its baseline, in order to minimize distortion along the path under study.

Table 2. Experimental values of Rayleigh-wave phase velocities (km/s) obtained by the two-station method between COL and SCP.

Period (s)	292.57	256.00	227.55	204.80	186.18
R4	*	*	*	*	4.496
R5	*	5.005	4.777	4.649	*
R6	5.226	4.983	4.726	4.561	4.546
R7	*	4.906	4.779	*	*

* No substantial energy in the records at this period.

Table 3. Rayleigh-wave phase velocities (km/s) along the great circles Sumba–COL and Sumba–SCP.

Period (s)	292.57	256.00	227.55	204.80	186.18
(a) Experimental values from the present study					
COL R3–R5	5.227	4.953	4.756	4.600	*
COL R5–R7	5.234	4.968	4.764	4.607	*
COL R4–R6	*	*	4.735	4.652	4.514
SCP R4–R6	5.256	*	4.775	4.631	4.507
SCP R5–R7	*	4.955	4.764	*	*
SCP R6–R8	5.251	4.964	4.770	4.620	*
Average	5.242	4.960	4.760	4.622	4.511
(b) Theoretical values obtained from the models derived in Paper I.					
Sumba–COL	5.242	4.965	4.761	4.609	4.494
Sumba–SCP	5.241	4.964	4.760	4.608	4.494

* No substantial energy in the records at this period.

domain, or 0.02 km/s for c. This figure is larger than for the oceanic case reported in Paper I, because of the shorter path between the two stations. The corresponding error bars are shown as arrows on Fig. 2. Fig. 2 shows that these experimental values are in good agreement with the dispersion curves obtained through regionalization of great-circle data (Kanamori 1970; Dziewonski 1970; Paper I), given the uncertainty on the present data (shown by the error bars) and the accuracy of least-squares regionalization (the values listed in Table 5d of Paper I had a root mean square residual on the order of 0.5 per cent).

Furthermore, comparison of the present data with the experimental curves for the pure-age oceanic paths KIP-SOM and KIP-GUA (see Paper I: Fig. 1) brings an immediate *experimental* confirmation of one of the main conclusions of Paper I; the shield phase velocities lie within the range of variation of oceanic velocities with age; in the range 200–300 s, the average shield velocity (the thick trace on Fig. 2) is indeed very comparable to average oceanic velocities at similar periods. Thus, any model of continent–ocean heterogeneity predicting strong differences in phase velocities at very long periods is incompatible with experimental data.

3 Great-circle phase velocities

The digitized records used in Section 2 provide an independent experimental check of the phase velocities obtained through regionalization in Paper I: we computed great-circle phase velocities, making use of the various phases listed in Table 1, both at COL and SCP. Results

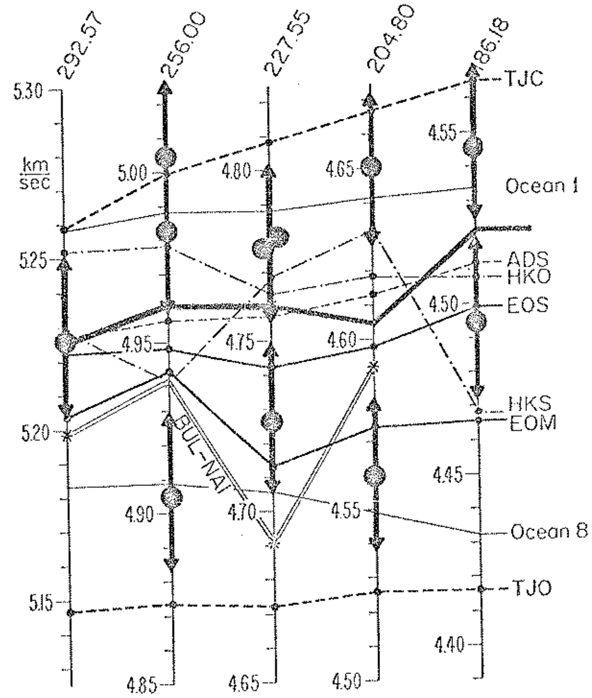

Figure 2. Experimental Rayleigh-wave phase velocities obtained over the pure shield path COL–SCP. This figure is adapted from Paper I, Fig. 3, to which the reader is referred. The big individual dots are the values from Table 2 of the present paper; the vertical arrows centred on them are error bars. The thick trace across the figure is the resulting average experimental shield velocity. Other curves include regionalized phase velocities obtained in Paper I for shields (EOS) and mountainous areas (EOM), Dziewonski's shield model (ADS), Kanamori's shield (HKS) and ocean (HKO) models, and Jordan's oceanic (TJO) and continental (TJC) models, uncorrected for Q. Models 'Ocean 1' and 'Ocean 8', derived in Paper I, Section 1, show the range of variation of oceanic velocity with lithospheric age.

are listed in Table 3a. This time, the error bars are on the order of 0.003 km/s, due to the much longer path travelled by the wave. Table 3b gives the theoretical values obtained from the models derived in Paper I (and listed in Tables 5a and b of Paper I). Because of the slight difference in azimuth between COL and SCP, the two great circles through these stations are not exactly identically regionalized into the seven regions used in Paper I, and the theoretical values are very slightly different. Nevertheless, the agreement between the average values measured over the great circles and those expected from these models is excellent and fits well within the standard error accompanying the results of inversion.

Such a direct computational test by independent data is a very desirable confirmation of any model obtained by an inversion technique: In addition to providing a least-squares fit to the 29 records used in the inversion, models T (trench areas), M (mountainous areas), and S (shields) derived in Paper I correctly predict the dispersion along this new great-circle path.

Conclusions

Direct experimental determination of Rayleigh-wave phase velocities over a pure shield path confirms the similarity between shield velocities and oceanic ones at periods of 200 to 300 s.

Furthermore, the present data are entirely compatible with models achieved independently by great-circle dispersion analyses.

Conclusion (iii) from Paper I is confirmed experimentally: Rayleigh-wave phase velocities for shields fall within the range of oceanic models, and the difference between average oceanic and continental velocities is on the same order of magnitude as the variation within the oceanic plate due to its age.

Conclusion (iv) can be extended to include direct determination of very long-period Rayleigh-wave phase velocities: Dziewonski's shield model S2 reconciles all presently available seismic data without any substantial structural difference below 240 km with the average oceanic model O1.

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