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The Effect of Young Oceanic Regions on Frequencies and Damping of Free Oscillations of the Earth *

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Abstract. Long-period records of great earthquakes during 1972–1980 are analyzed. Several of the travel paths include an appreciable proportion of young oceanic regions. We include first results from a new long-period seismometer STS installed at the Saint-Sauveur Seismological Observatory. Using the vertical component we have estimated the quality factor Q and phase velocity C from the damping and frequencies of spheroidal oscillations. An effect of lateral heterogeneities on the different paths is displayed, and the variations of the two sets of values are well correlated. The contribution of young oceans in the source-receiver great-circle paths seems to have the greatest influence, compared to the effect of the other regions. A scheme of regionalization gives an estimation of the corresponding pure-path dispersion, with phase velocities low by 1% in the range 150–350 s.

Key words: Free oscillations – Regionalization – Phase velocities – Q quality factor

Introduction

Accurate attenuation measurements of seismic energy will provide important information about the anelastic properties of the Earth's interior; studies of attenuation data often show great scatter due to difficulty in estimating amplitudes. Some progress has been made in Q estimations, allowing enhanced resolution (Bolt and Brillinger, 1979). Indeed, estimations of periods and damping of free oscillations show large variations, which may be partly caused by lateral inhomogeneities in the Earth, to which the amplitudes of mantle waves would be particularly sensitive (Jobert et al., 1978).

By now, global average Earth models constructed from global observations, including Q^{-1} of mantle waves, are well developed (Zharkov et al., 1974; Deschamps, 1977; Nakanishi, 1981; Sailor and Dziewonski, 1978; Anderson and Hart, 1978 and more recently the Preliminary Earth Model (PREM) of Dziewonski and Anderson (1981)).

A further step is the search for lateral inhomogeneities and the maximum depth at which they may exist. By determining the response of an earth with a laterally heterogeneous anelasticity, Dahlen has established in a recent report (1981) that the apparent attenuation of free modes depends only on the average attenuation structure underlying the source-receiver great-circle path. Thus regionalization of Q of free modes has a theoretical basis, in the same sense as that of velocities.

Global studies of great-circle velocities C have suggested that several "pure-path" regions can be distinguished (Wu, 1972, Okal, 1977; Lévêque, 1980; Jordan, 1980; Silver and Jordan, 1981).

The purpose of the present study is to test the sensitivity

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Table 1. Events, stations and percentages P_n of great-circle paths lying in each of four structural regions: 1 "young ocean" 2 "old ocean" 3 "shield and platform", 4 "tectonic" (after Lévêque, 1980; see text for fuller explanation)

	Location	Date	Station	P_1%	P_2%	P_3%	P_4%
1	Sumbawa Islands	19. 08. 77	CMO (IDA)	5.8	25.8	18.8	49.6
2	Sumbawa Islands	19. 08. 77	HAL (IDA)	6.3	15.4	37.5	40.8
3	New Britain	27. 02. 80	SS (IPG)	7.5	22.1	23.3	47.1
4	Celebes Sea	11 06. 72	MLS, SS (IPG)	14.2	23.7	17.5	44.6
5	Argentina	23. 11. 77	RAR (IDA)	14.2	28.3	17.9	39.6
6	Argentina	23. 11. 77	KIP (IDA)	19.2	50.0	10.4	20.4
7	Sumbawa Islands	19. 08. 77	RAR (IDA)	22.1	33.7	21 7	22.5
8	Philippines	02. 12. 72	MLS, SS (IPG)	15.4	21.2	19.2	44.2
9	Sumbawa Islands	19. 08. 77	GAR (IDA)	22.1	20.8	24.6	32.5
10	Sumbawa Islands	19. 08. 77	VA (IPG)	20.0	23.8	25.4	30.8
11	Mexico	29. 11. 78	HAL (IDA)	25.2	40.8	10.8	23.2
12	Macquarie Islands	07. 02. 80	SS (IPG)	30.4	35.0	18.3	16.3
13	Mexico	30. 01. 73	SS (IPG)	34.2	37.0	7.1	21.7

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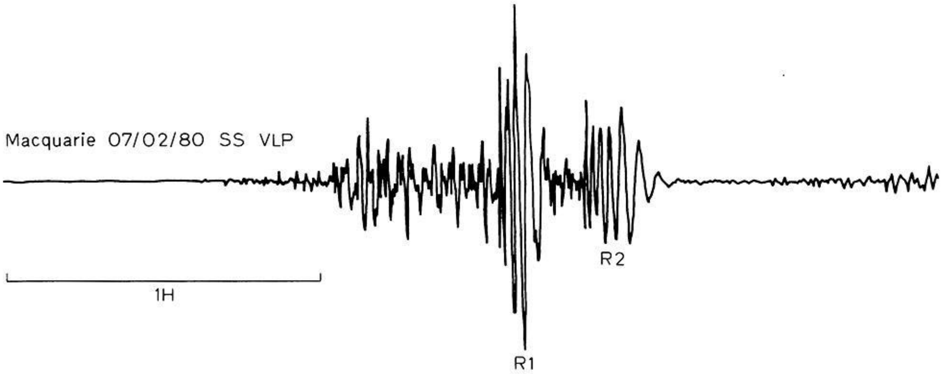

Fig. 1. Record of Macquarie islands earthquake (7 February 1980) at Saint-Sauveur Badole (French station) with the STS seismometer

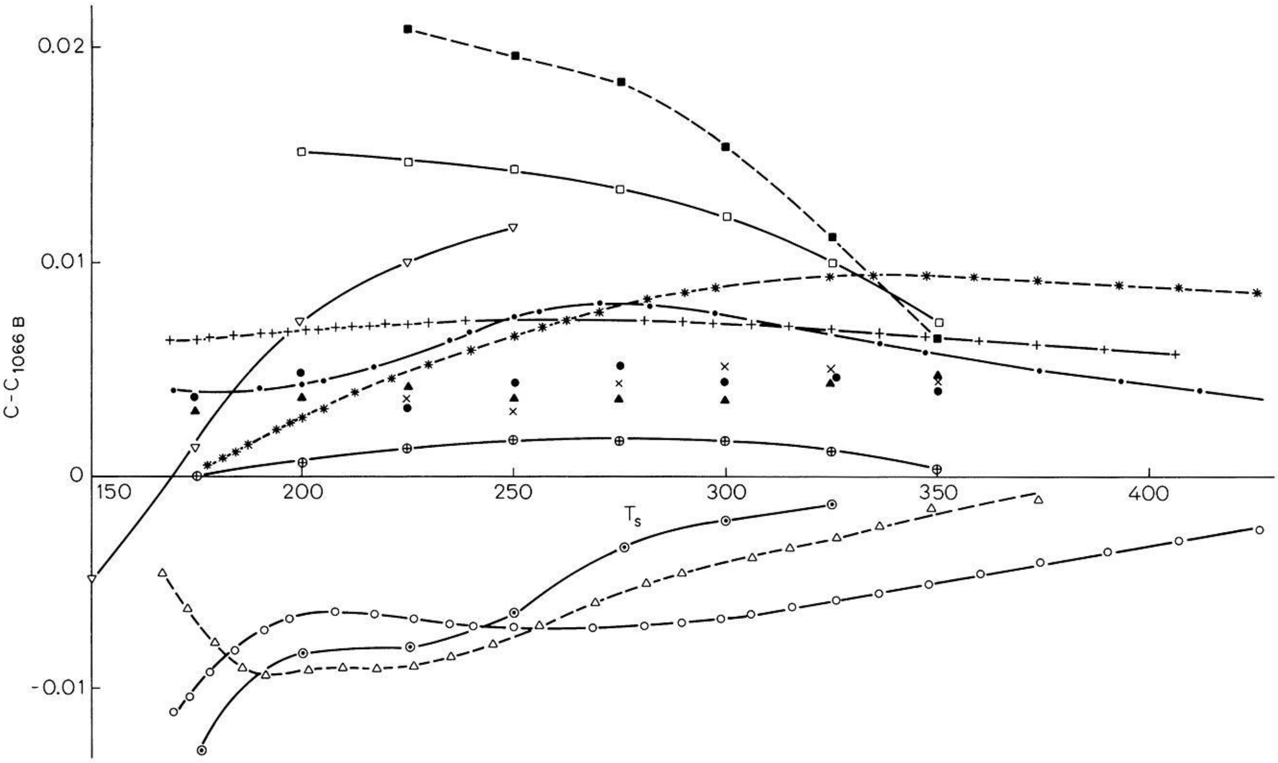

Fig. 2. Deviations in km/s of the observed spheroidal phase velocities from theoretical ones for model 1066B, for different earthquakes, after smoothing of the data and ellipticity correction.
■ Sumbawa 1977 August 19 (CMO) □ Sumbawa 1977 August 19 (HAL) ▽ Celebes Sea 1972 June 11 (MLS, SS) * New Britain 1980 February 27 (SS) • Argentina 1977 November 23 (RAR) + Argentina 1977 November 23 (KIP) ● Philippines 1972 December 2 (VA, MLS, SS) × Sumbawa 1977 August 19 (RAR) ▲ Sumbawa 1977 August 19 (GAR) ⊕ Sumbawa 1977 August 19 (VA) ⊙ Mexico 1973 January 30 (SS) ○ Mexico 1978 November 29 (HAL) △ Macquarie Islands 1980 February 7 (SS)

of the observed *C* and *Q* to such tectonic models, searching for the existence of a correlation between the two sets of determinations and determining the regions whose influence is predominant in the period range considered (150 s–350 s).

Data and Methods

Our digital data are those of the I.P.G.P. long period data acquisition system (Blum and Gaulon, 1971) and of the free mode channels of the stations of the IDA network (Agnew et al., 1976). Locations of events and stations are shown in Table 1.

The vertical seismometer constructed by E. Wielandt and G. Streckeisen (Wielandt, 1975; Wielandt and Streckeisen, in press 1982), was tested for one year in our Saint-Sauveur Badole station and gave us remarkable records, being able to detect ultra long-period signals (up to 600 s). Three channels are recorded at a sampling interval of one second; the "Very Long Period" VLP channel is particularly interesting for studying surface waves and free oscillations. The record of the Macquarie Islands earthquake of 7 February 1980 is given in Figure 1. The high sensitivity and very good signal to noise ratio allows us to identify on records of earthquakes of magnitude 6.5 the successive groups of surface waves up to the ninth. This recording channel has a flat response to ground acceleration at a gain of $4.5-10^6$ V m^{-1} s^2 in the period range 100–600 s.

In this report only vertical components are used, and data windows for the spectral analysis are chosen to minimize the effect of spectral leakage and mode interference. When several modes interfere, enhancement of the fundamental is performed by using a time variable filtering technique (Cara, 1973) with

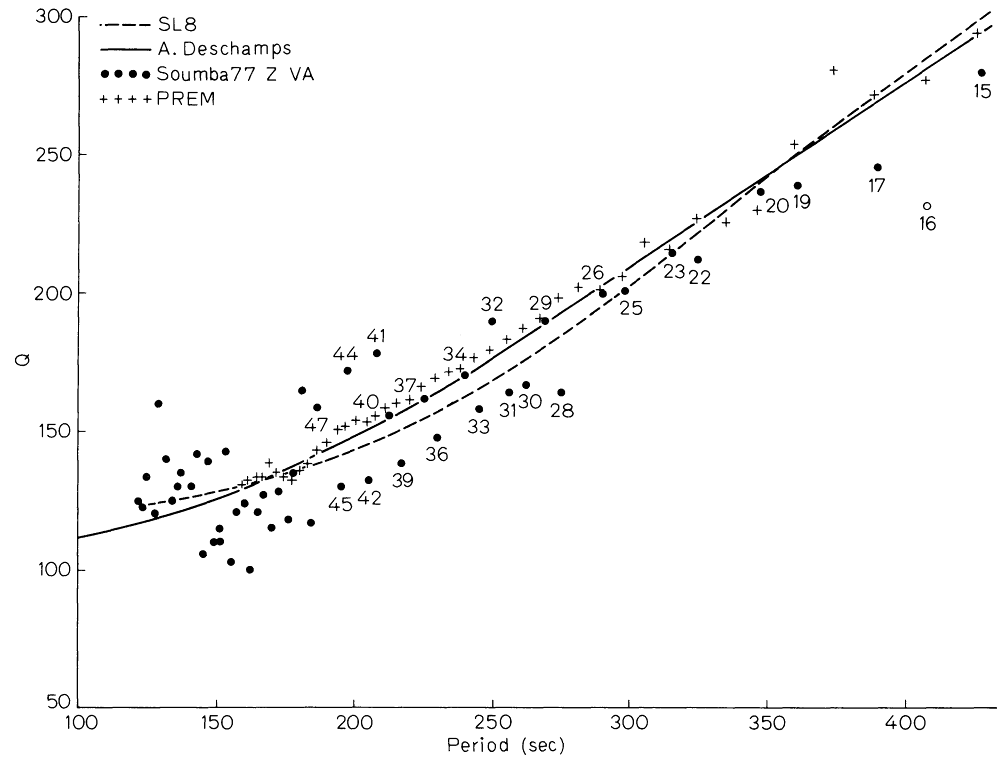

Fig. 3. *Circles* are Q data versus the period obtained from the record of Sumbawan earthquake (19 August 1977) at the French station of Villiers-Adam (vertical component). *Solid curve* is Anne Deschamps' inverted model (1977). *Dashed line* corresponds to Anderson and Hart's SL8 Q model (1978). *Crosses* are Dziewonski and Anderson's mean Q values (1981)

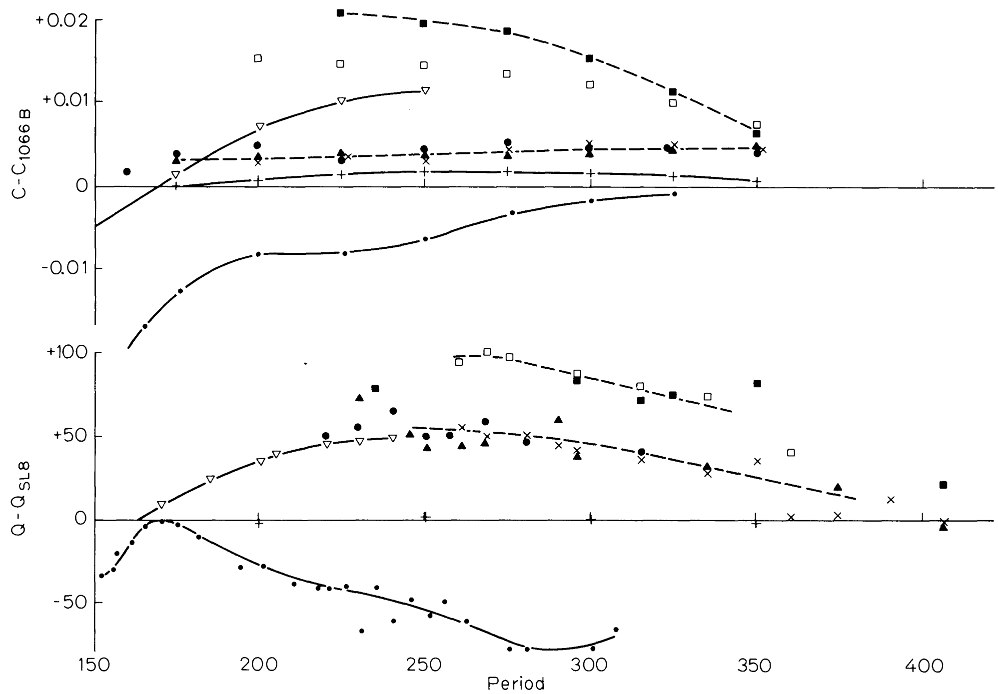

Fig. 4. Differences between the observed C (km/s) and Q values, after smoothing, and the corresponding reference models versus the period, for different earthquakes
■ Sumbawa 1977 August 19 (CMO, IDA) □ Sumbawa 1977 August 19 (HAL, IDA) ▽ Celebes Sea 1972 June 11 (Moulis, St Sauveur) ● Philippines 1972 December 2 (MLS, SS, VA) × Sumbawa 1977 August 19 (RAR, IDA) ▽ Sumbawa 1977 August 19 (GAR, IDA) + Sumbawa 1977 August 19 (Villiers Adam) • Mexico 1973 January 30 (St Sauveur)

a window adapted to the dispersion, allowing a better identification of spectral peaks and a better estimation of the corresponding periods and damping. The variable time filtering has been checked for the absence of systematic errors. For the vertical IDA and VLP records such filtering was not necessary, especially for the IDA records in which the first arrival R1 could not be used.

To obtain Q values we use the technique of observing the time rate of decay of an individual peak in the amplitude spectrum (Roult, 1974; 1975; Jobert and Roult, 1976); we take successive time intervals (about nine hours) with a tapering by the window function $w(t)=(1-t^2/L^2)^2$ as in Connes et al., 1962. We determine the mean energy for some particular spectral peaks, and plot the log of these values multiplied by the period of oscillation versus time. The Q factors are determined from the slopes of straight lines fitted to the data points by a least-square method.

Results

Periods of free oscillations derived from the spectra are collected, and after a correction for ellipticity perturbation (Dahlen, 1975)

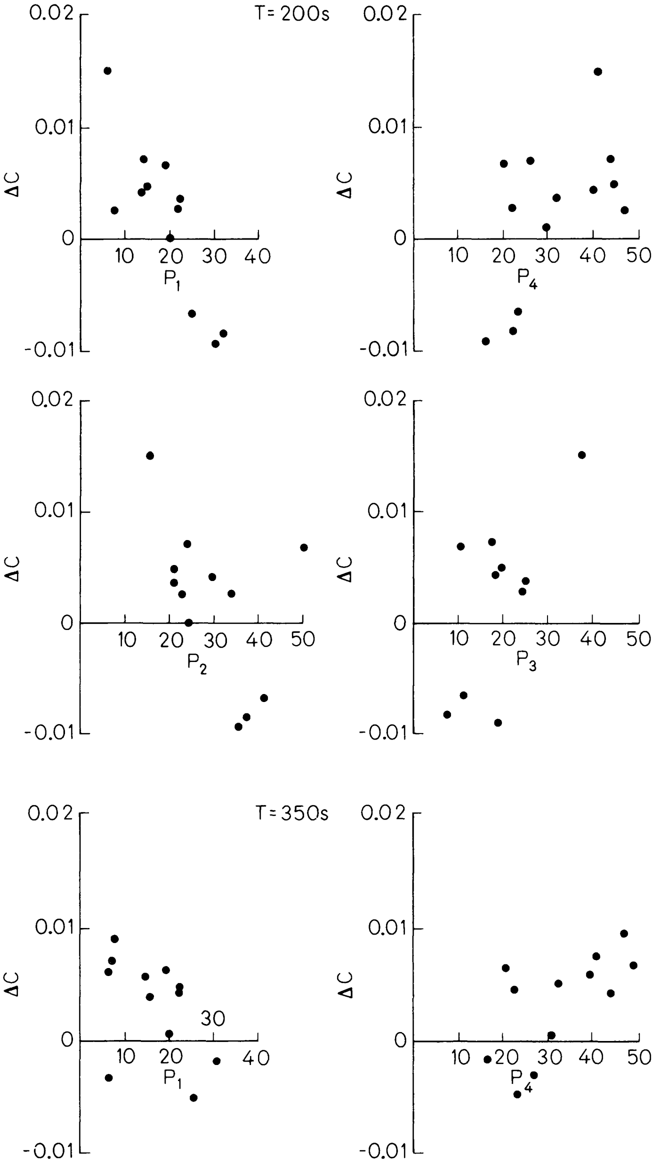

Fig. 5. ΔC phase velocitiy differences (in km/s) versus percentages (Lévêque's regionalization) of "young ocean" region (P_1), "old ocean" region (P_2), "shield and platform region" (P_3) and "tectonic" region (P_4)

phase velocities are computed in the period-range 150–400 s, using a smoothing process according to the precision estimated for the values of the frequencies.

The scattering of the observed values is used as an estimate of the error in the data in the smoothing process (about 0.25 per cent). The observed scattering does not appear as a random error, but is rather correlated with the distance through the spectral amplitudes (Roult, 1974). The smoothing is assumed not to have a systematic effect on the data as will be shown below.

The global Earth model 1066B of Gilbert and Dziewonski (1975) is used as a reference model; we plot in Figure 2 the differences between the observed values and the phase velocities of this reference model.

The model SL8 of Anderson and Hart (1978) seems perfectly appropriate as an average representation of the observed Q; the differences ΔQ from the values of Deschamps (1977) or from the values of Dziewonski and Anderson's PREM model (1981) are very small, these two last models giving almost identical results (Fig. 3). Figure 3 shows Q data determined from the Sumbawan earthquake (19 August 1977) recorded in France for which the great-circle path corresponds to percentages of the different regions very near the global average. We will take SL8 as a reference.

The small fluctuations ($\Delta Q \sim 20$) observed in Figure 3 in Q values for orders higher than 50 are due to the uncertainties of the measurements (rms error about 10%). These fluctuations are systematic for periods higher than 200 s; this effect has also been observed on phase velocities before smoothing (see discussion before).

Regional differences, much larger than the estimated uncertainties appear in both phase velocities and Q quality factors: from the simultaneous analysis of the differences ΔQ between the observations and the reference values (Fig. 4) we can draw the conclusion that the events for which the observed phase velocities are low also show a large attenuation of Rayleigh waves. C and Q data are strongly related to the corresponding great-circle paths, and particularly sensitive to the percentages P_1 of young oceans (the corresponding regionalization will be presented in the next section). A small variation in that percentage has a large effect on both C and Q; other regions seem to be of less importance as can be seen in Figure 5 and 6.

A correlation appears between ΔC or ΔQ and chiefly P_1, less marked with increasing period. Such a correlation is less apparent for the percentages of the "old ocean" region (P_2) or the "shield and platform" region (P_3).

Regionalization

We first divide the earth's surface into four regions, following the regionalization of Lévêque (1980): a "young ocean" region (age less than 30 m.y.), an "old ocean" region (age greater than 30 m.y.), a "shield and platform" region and an inhomogeneous region called a "tectonic region" including both mountains and subduction zones.

Using the pure-path velocities determined by Lévêque for each of these regions, we computed the theoretical phase velocities according to the percentages of each of the provinces represented in our great-circle paths. Phase velocities computed with these regional velocities do not show a good agreement with the observed values; the lowest phase velocities corresponding to events 11, 12 and 13 are not explained. It seems that pure-path velocities for young regions are not low enough to fit the data.

Seismological studies of aspherical heterogeneity led Silver and Jordan (1981) to construct a global tectonic regionalization with three oceanic regions defined by their crustal age and three continental regions according to their tectonic behaviour during the Phanerozoic (Jordan, 1980). Pure-path velocities corresponding to these six provinces have been computed from the parameters estimated from Jordan's data set. We also computed the theoretical values we can expect with such a pattern, but they do not fit the observations well. As in the preceding scheme the young oceanic region is not slow enough.

Since our data were not correctly interpreted using the pure-path velocities estimated from Lévêque and by Silver and Jordan, we attempted to regionalize our observations, knowing their lack of resolution for regions other than young oceans. We used Lévêque's regionalization.

As expected, the results in Figure 7 (with uncertainties of about 0.02 km/s) show very low velocities for the young ocean

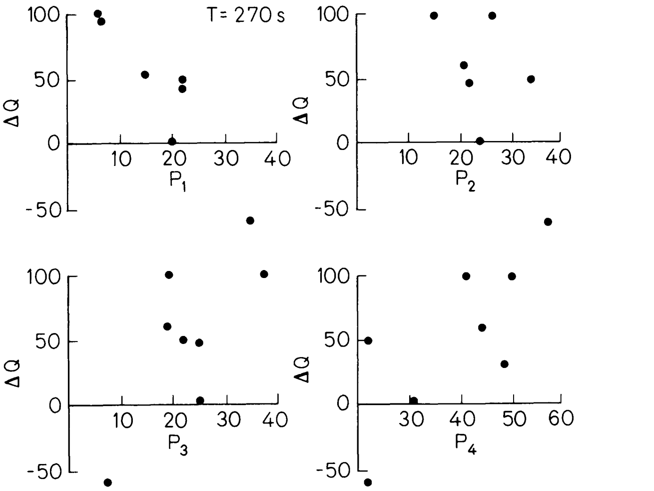

Fig. 6. ΔQ quality factor differences versus the same percentages P_1, P_2, P_3 and P_4 as in Fig. 5

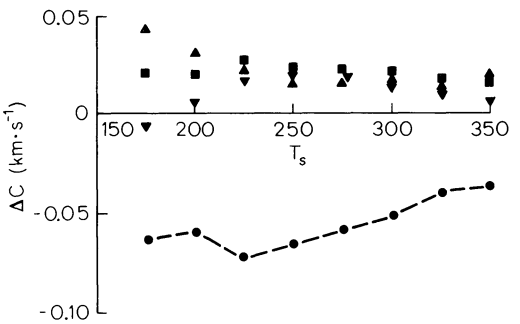

Fig. 7. Deviations of the pure-path velocities (km/s) from those of model 1066B obtained from our observations, with Lévêque's regionalization.

● young ocean region. ■ old ocean region. ▲ shield and platform. ▼ tectonic region

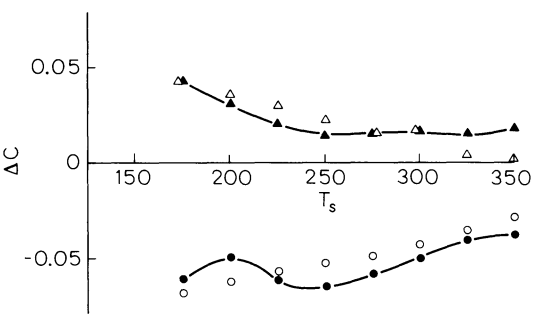

Fig. 8. *Lower curve*: comparison of our results for the "young ocean" region (●●) with the corresponding results of Dziewonski and Steim (○○)

Upper curve: comparison of our results (▲▲) for the "shield and platform" region with the corresponding results of Dziewonski and Steim (△△)

region; the distinction between the three other regions is not clear.

Figure 8 shows the comparison and the good agreement, for the young oceanic and shield regions, between our results and the recent results of Dziewonski and Steim (1981).

Such low phase velocities can be explained by a model with rather low velocities, such as in Montagner and Jobert (1981), for these regions. Another cause could perhaps be found in the existence of additional anomalous phenomena in some areas such as "slow" fracture zones (Okal and Stewart, 1982).

Conclusions

As in earlier results, estimations of free periods and damping of oscillations show large variations, clearly path dependent, due to lateral inhomogeneities of the Earth. Amplitudes of mantle waves are particularly sensitive to this effect.

Our observations lead to the following conclusions:
– The correlation between the variations of phase velocities and Q factors observed for different paths is very good.
– The most influential province corresponds to the young ocean region, for which we find particularly low velocities, lower than those presented in previous publications; differences from the 1066B model are about 0.05 km/s for periods from 150 s to 350 s.

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