BULLETIN OF THE EARTHQUAKE
RESEARCH INSTITUTE
Vol. 58 (1983), pp. 571-589

23. *Surface Wave Polarization Anisotropy in the West Pacific as Revealed from Group Velocities and Synthetic Waves.*

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(Received July 25, 1983)

Abstract

Multi-mode Love waves across the west Pacific have been analyzed in detail, to investigate the surface wave polarization anisotropy. From the inversions of group velocities and wave forms of observed and theoretical seismograms, it is found that the shear wave velocity in the low velocity zone under the regions corresponding to the ocean-floor age of 90~150 m.y. is 4.43 km/sec, which is 2~3% higher than values estimated from Rayleigh waves. This discrepancy is caused by the existence of partially molten materials and by the preferred orientation of crystal axes of olivines within the asthenosphere. From the wave form analyses two types are found in the wave forms of Love waves. One forms isolated waves and the other merely oscillated waves showing no clear normal or anomalous dispersions. The latter type presents a few peculiar dispersion curves with exceptionally high and low group velocities of 4.9 and 4.1 km/sec respectively around a period of 70 seconds.

1. Introduction

The azimuthal dependence of group and phase velocities of surface waves was discovered in the east Pacific (FORSYTH, 1975), in which the maximum group and phase velocities of both Rayleigh and Love waves are nearly parallel to the direction of the ocean-floor spreading. This anisotropic pattern is consistent with the one discovered in P_n velocities in the oceanic upper mantle (*e.g.*, HESS, 1964; SHIMAMURA and ASADA, 1978; CHRISTENSEN and SALISBURY, 1979).

On the other hand, a discrepancy is discovered in the velocities of SV and SH in the same direction of surface wave propagation (polarization anisotropy). The former is obtained from the inversion of Rayleigh waves while the latter from Love waves. The small discrepancy between the velocities of SV and SH was found by AKI and KAMINUMA (1963) for Japan, SAITO and TAKEUCHI (1966) for the transition regions between continents and oceans, HAMADA (1972) for the tectonic areas over the earth, and YOSHIDA and SATÔ (1976) for the south Pacific. A large discrepancy of 8% for the United States was reported by MCEVILLY (1964). In an oceanic earth model, designated as *OC*-1 (MIZUTANI and ABE, 1972), a small polarization anisotropy of 0.7% in the low velocity zone (*LVZ*) is incorporated. Some evidences of polarization anisotropy in the upper mantle beneath Eurasia were also discovered by CRAMPIN and KING (1977).

However, THATCHAR and BRUNE (1969) suggested the possibility that the velocity discrepancy between *SV* and *SH* might be caused from observational errors of Love waves, since the fundamental Love waves are significantly contaminated by higher modes. YOSHIDA (1983a) studied the excitations and velocities of multi-mode Love waves and emphasized that the first higher mode cannot be disregarded for the analyses of oceanic Love waves.

The present paper aims to search rigorously for evidences of surface wave polarization anisotropy in the west Pacific through the group velocity inversions and the wave form analyses of Love waves. Theoretical seismograms of the fundamental and higher modes will be generated for the help of the resolution.

2. Earthquake data

Seven earthquakes with focal mechanism already known were selected for the present study and are listed in Table 1, together with other seismic information reported by *USGS*. Focal mechanisms of *No. 1* were determined by STAUDER (1968a), *Nos. 5, 6* and *20* by STAUDER (1968b), *Nos. 15* and *16* by KATSUMATA and SYKES (1969), and *No. 18* by ICHIKAWA (1971). Those events were used by LEEDS (1975) for the determination of Rayleigh wave phase velocities. The *WWSSN* stations used are listed in Table 2. Table 1 shows that the magnitude of earthquakes ranges from 6.1 to 6.5, with focal depths

Table 1. List of earthquakes.

Number	Date			Time (h	m	s)	Lat.	Long.	Focal Depth	Magnitude
1	7	August	1966	02	13	04.7	50.6°N	171.2°W	39	6.5
5	1	October	1965	08	52	04.4	50.1°N	178.2°E	32	6.3
6	29	July	1965	08	29	21.2	50.9°N	171.4°W	23	6.4
15	10	February	1966	14	21	11.2	20.8°N	146.4°E	43	6.2
16	12	November	1965	17	52	27.6	30.6°N	140.4°E	40	6.6
18	29	March	1965	10	47	37.6	40.7°N	143.1°E	33	6.1
20	4	July	1966	18	33	37.1	51.9°N	179.8°E	13	6.2

Table 2. Observation stations.

Code	Station	Region	Latitude	Longtiude
AFI	Afiamalu	Samoa Is.	13°54′33.6″S	171°46′38.1″W
GUA	Guam	Mariana Is.	13°32′18.0″N	144°54′42.0″E
KIP	Kipapa	Hawaii	21°25′24.0″N	158°00′54·0″W
RAR	Rarotonga	Cook Is.	21°12′45.0″S	159°46′24.0″W

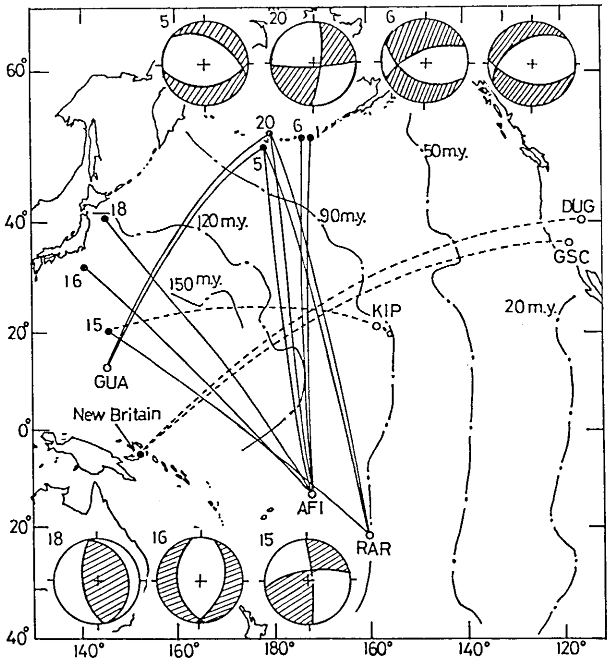


Fig. 1. Map of epicenters (solid circles) and stations (open circles). Great circle paths are shown by solid or dotted lines, together with isochrons of 20, 50, 90, 120 and 150 m.y. of the ocean-floor age. Earthquake mechanism diagrams are given in the upper and lower parts of the map in the equal area projection (lower hemisphere). Numbers (5, 20, 6, etc.) in the figure correspond to earthquake numbers in Table 1.

less than 43 km. Although all the events are located at extremely shallow parts, the fundamental mode of Love waves is expected to be contaminated by higher modes, from a theoretical viewpoint (YOSHIDA, 1983a).

Map of the epicenters, stations, great circle paths, and mechanism diagrams for the seven earthquakes is shown in Fig. 1. Isochrons of the ocean-floor age, as inferred from geomagnetic lineations (ATWATER and MENARD, 1970; LARSON and CHASE, 1972), are also denoted. We can see from the figure that the great circle paths indicated by solid lines cover the western Pacific. According to the mechanism diagrams, earthquakes of *Nos. 1, 5, 6* and *16* are the normal faulting, and the fault motion of *Nos. 15* and *20* is close to that of the strike-slip. Assuming a nodal plane having a sharp dip angle as the fault plane, the motion of *No. 18* can be interpreted to be the dip-slip type.

3. Wave forms and group velocities of observed Love waves

As an example of oceanic Love waves which form *'G waves'* and constant group velocities, wavetrains observed at *DUG*, Dugway, Utah and *GSC*, Goldstone, California are presented in Fig. 2. The waves are excited by an earthquake near New Britain Island located in the northeastern part of the Solomon Sea, on February 22, 1966 (see in detail YOSHIDA and SATÔ, 1976). We notice from Fig. 2 that group

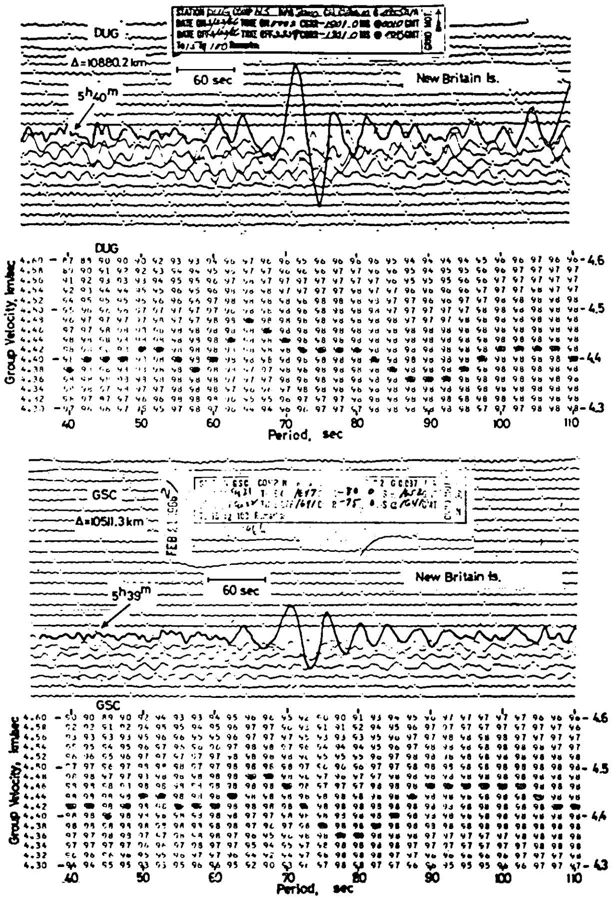
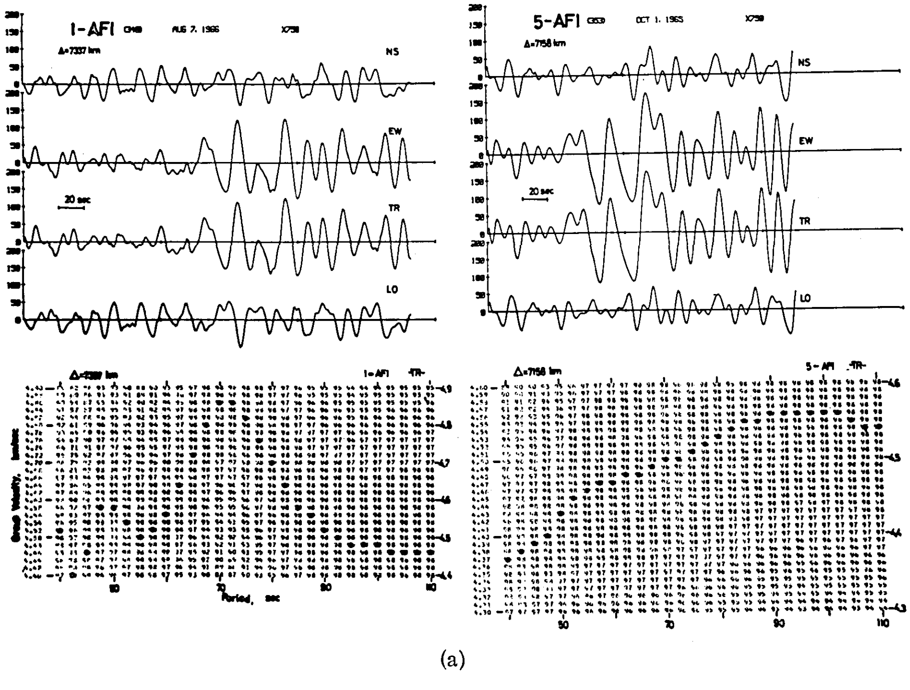
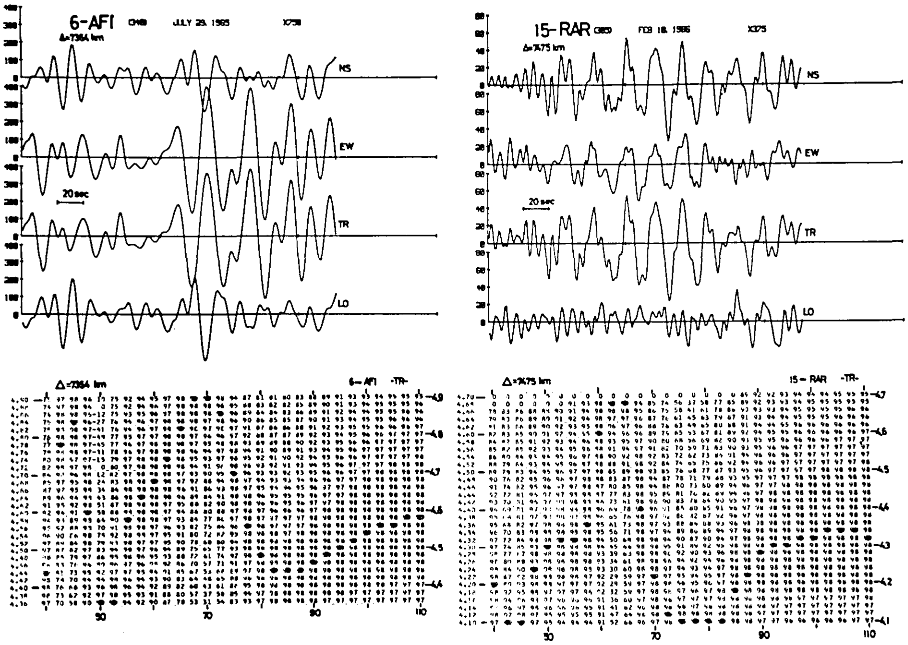


Fig. 2. Love waves which traversed the north Pacific, excited by the New Britain Island earthquake of Feb. 22, 1966, and observed at *DUG* and *GSC*. Group velocities are shown by solid circles in the numerical graph.

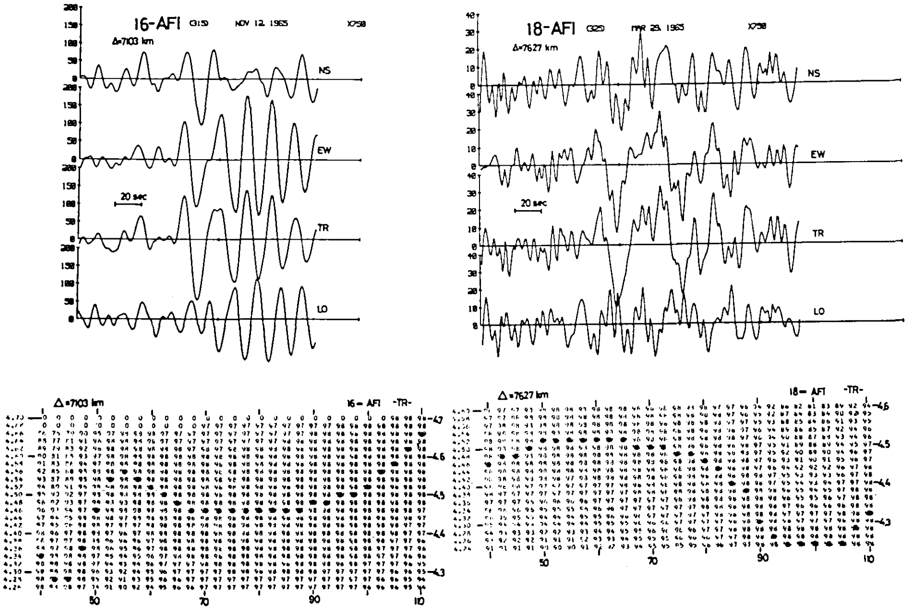

1-AFI
AUG 7, 1965
Δ=7337 km
5-AFI
OCT 1, 1965
Δ=7158 km
NS
EW
TR
LO
20 sec
Group Velocity, km/sec
Period, sec
5-GUA
OCT 1, 1965
Δ=5056 km
5-RAR
OCT 1, 1965
Δ=8193 km
-TR-

(a)

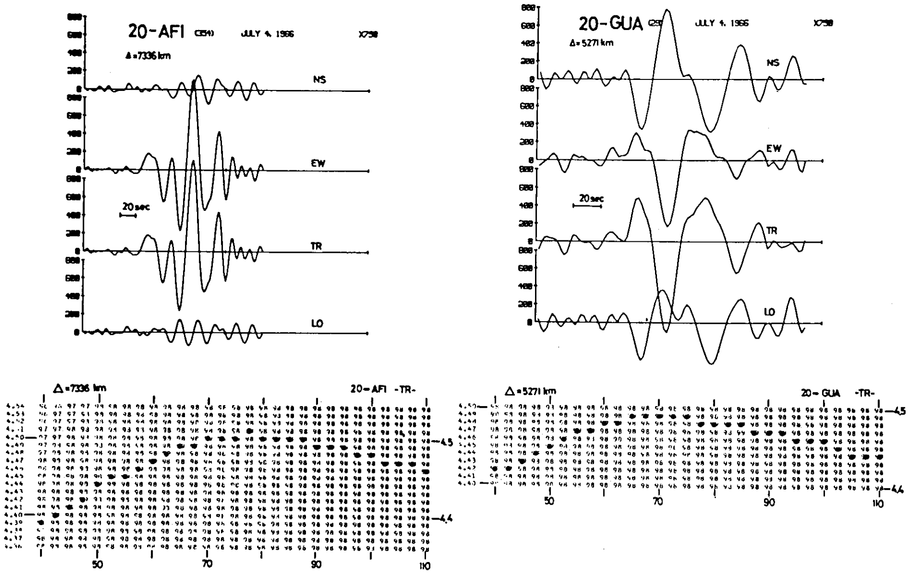
(b)


6-AFI
JULY 25, 1965
Δ=7364 km
NS
EW
TR
LO
20 sec
15-RAR
FEB 18, 1966
Δ=7475 km
-TR-
50
70
90
110

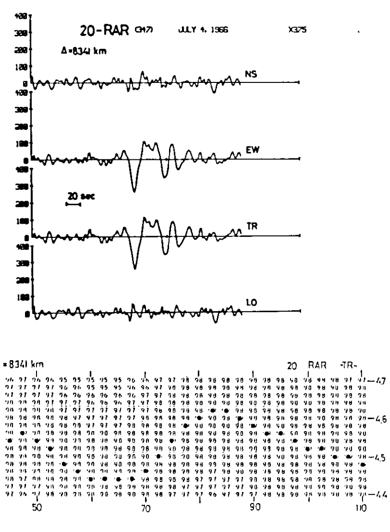
(c)


16-AFI
NOV 12, 1965
Δ=7103 km
NS
EW
TR
LO
20 sec
18-AFI
MAR 25, 1965
Δ=7627 km
-TR-
50
70
90
110

(d)



(e)



(f)

Fig. 3. Observed Love waves of *NS* and *EW* components, and synthesized transverse (*TR*) and longitudinal (*LO*) components. Numerals in the ordinate indicate the displacement in a scale of 1 mm=10, Group velocities (solid circles) determined for the waves of the *TR* component are presented below the seismograms. The maximum magnification of the seismograph is given in the top line as *X*750.

velocities for *DUG* and *GSC* are close to 4.4 km/sec for the periods from 40 to 110 seconds, with a velocity variation less than 0.12 km/sec.

In Fig. 3 Love waves analyzed are shown together with group velocities, as calculated by using the filtering techniques carried out by YOSHIDA (1982). For the velocity calculation the wavetrains of transverse components are employed. Observed waves from the seven earthquakes at stations *AFI*, *GUA*, and *RAR* can be grouped into two types of the wave form (Hereafter we indicate the wave path by the designation of the earthquake number and station code). One group (*Group A*) is oscillated waves such as for *1-AFI*, *5-AFI*, *5-RAR*, *6-AFI*, *15-RAR*, *16-AFI*, *18-AFI*, and *20-RAR*, and the other (*Group B*) is isolated waves, such as for *5-GUA*, *20-AFI*, and *20-GUA*. The oscillated waves in *Group A*, especially those for *1-AFI*, *6-AFI*, *15-RAR*, *16-AFI*, and *18-AFI*, seem to have been strongly interfered by the higher mode, since the calculated group velocities are fluctuating in the period range from 40 to 110 seconds.

It is interesting that the waves observed at *AFI* seem to be most severely disturbed by higher modes. According to Fig. 1 the wave paths to *AFI* or *RAR* from the seven earthquakes are travelling rather parallel to the isochrons of the ocean-floor age. On the other hand the waves forming the isolated waves are well observed at *GUA*, and the paths *5-GUA* and *20-GUA* are traversing nearly normal to the isochrons in the western Pacific. Effects of reflection, refraction and diffraction of higher modes seem to be serious on the wavetrains forming *Group A*.

Love waves in *Group B*, for *5-GUA* and *20-GUA*, have relatively uniform group velocities of about 4.53 and 4.45 km/sec respectively. This velocity difference seems to be caused by the difference in the medium structures near two seismic sources, since the high heat flow of 1.9×10^{-6} cal/cm sec and the high thermal conductivity of 2.35×10^{-3} cal/°C cm sec (LANGSETH and HERZEN, 1968) are observed in the region of the marginal sea near earthquake *No. 20*. The wavetrains of the transverse component for *5-GUA* are in good agreement with the polarity inversed ones for *20-GUA*, except short period components of about 20 seconds for *20-GUA*. This relation is similar to the one found by YOSHIDA (1983a) that the wave forms at the station azimuth 90° from left lateral strike-slip source are inversely traced, compared with those at the azimuth 45° from the thrust fault.

Love waves in *Group A*, for *6-AFI* and *15-RAR*, have peculiar dispersion curves with unusual group velocities of 4.4 to 4.9 km/sec and 4.1 to 4.7 km/sec, respectively. The group velocity variation reaches 0.5 or 0.6 km/sec in the period range from 40 to 110 seconds.

Comparing these values with the usual velocity variation of 0.12 km/sec of oceanic Love waves given in Fig. 2, this is a surprising phenomenon and may be caused by the contamination of the fundmental mode by higher modes.

From Fig. 1 we see that the paths *5-GUA*, 15-*KIP*, *16-KIP*, and *18-KIP* are preferable for the study of surface waves propagated over the western Pacific, since these paths cover the region with the ocean-floor age of 90～150 m.y. or more. In the present analyses the Love waves for *15-KIP* were not available due to the lack of the *WWSSN* seismograms, and those for *16-KIP* and *18-KIP* could not be analyzed because of noisy signals. Hence Love waves for *5-GUA* are analyzed in detail in later sections. The paths from earthquakes *Nos. 15*, *16*, and *18* to *AFI* and *RAR* traverse the oldest portion of the Pacific. However, the Micronesia region belonging to the partially submerged continental area, which is separated from the Pacific basin by the andesite line (Kuo *et al.*, 1962; Santo, 1963), is partly involved in those paths. Therefore they are not superior to the path *5-GUA*.

4. A model *PC-L43*

For the determination of an upper mantle structure under the western Pacific, theoretical seismograms for *5-GUA* were generated following the same procedure as carried out by Yoshida (1983a) on the basis of surface wave excitation theory (Saito, 1967). As a starting model, an oceanic upper mantle *8099-80* (Yoshii, 1975) was used. The seismograms of the fundamental, first, second, and third higher modes, for the periods 10～350, 10～320, 10～260, and 10～220 seconds respectively, were obtained by computations of torsional oscillations. In the synthesis of the waves source parameters reported by Stauder (1968b) were employed.

It is known from group velocity partial derivatives of Love waves (Yoshida, 1983b) that the influence of the density and P-wave velocity is very weak on the group velocity variation for the periods considered here. Therefore, in the synthesis, attention was paid to the shear wave velocity in the *LVZ*. By comparing the observed Love waves for *5-GUA* with synthesized ones, the best model *PC-L43* (Fig. 4) was constructed.

4.1 Phase and group velocity characteristics

The model *8099-80* explains the group velocity dispersion of Rayleigh waves propagated through the western Pacific for the period range from 40 to 90 seconds. In Fig. 4 the phase and group velocity

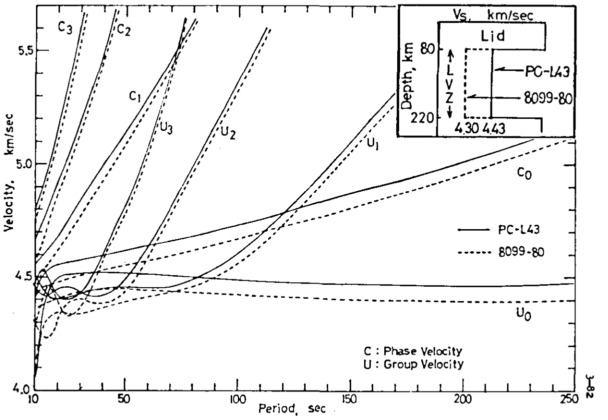


Fig. 4. Phase and group velocities calculated for the models *PC-L*43 and 8099-80. Shear velocity structures for the two models are schematically inserted in the upper right.

curves of the first four modes of Love waves calculated for *PC-L43* and *8099-80* are shown, together with structures of shear wave velocity for the two models. The shear wave velocity in the *LVZ* for *8099-80* is 4.3 km/sec, and that for *PC-L43* is 4.43 km/sec, which is 0.13 km/sec (3%) higher than the value for *8099-80*. The group velocity difference of the fundamental mode between the two models is about 0.07 km/sec in the period range from 50 to 150 sec, and the phase velocity difference is about 0.06 km/sec for the same period range. The wavelength of the fundamental mode at 300 seconds is about 1500 km, and the *LVZ* is extended at the depth 220 km. Hence we can infer that the polarization anisotropy may be effectively influenced on the fundamental Rayleigh and Love waves of periods less than several hundred seconds. For the entire period range in which multi-mode Love waves were synthesized, the velocity characteristics for *PC-L43* are shown in Fig. 5.

4.2 Wave forms of multi-mode Love waves

The theoretical seismograms of the fundamental and three higher modes calculated for the two models *PC-L43* and *8099-80*, corrected for the instrumental characteristics, are shown in Fig. 6. We see from the figure that the wavetrains for *PC-L43* are arriving considerably faster at *GUA* than those for *8099-80*, especially in the fundamental mode. As was understood in the study by Yoshida (1983a), the *WWSSN* seismograph records effectively the higher modes of oceanic Love waves composed of short periods of about 50 seconds or less. The amplitude spectra of the theoretical seismograms for *PC-L43* are shown in Fig. 7, indicating that the multi-mode waves have two

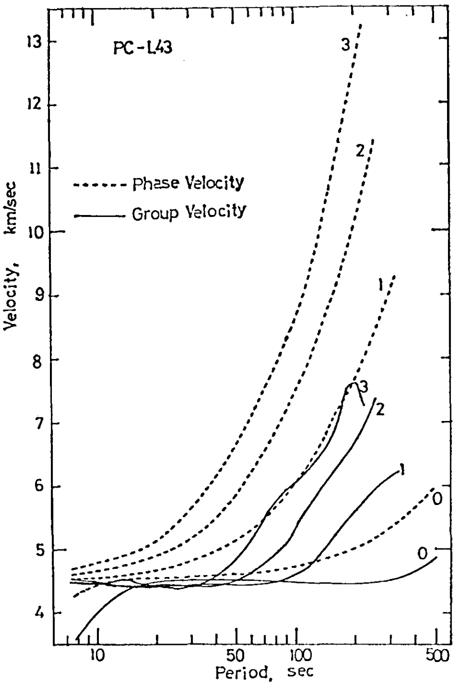


Fig. 5. The dispersion characteristics of phase and group velocities calculated for the model *PC-L*43. For the range in which the dispersion curves are given, synthetic waves are made. Numbers attached to the curves signify the mode number.

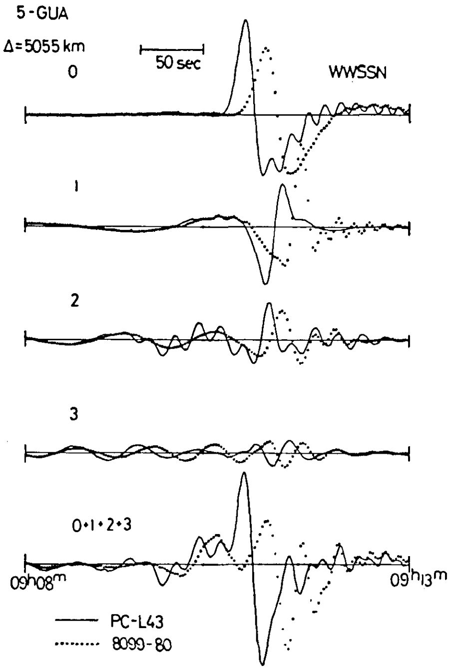


Fig. 6. Synthetic seismograms for earthquake No. 5, observed at *GUA*. The waves are obtained for the medium models *PC-L*43 and 8099-80, showing the motion as recorded by the *WWSSN* long-period seismograph. Numerals indicate the mode number.

spectral peaks at periods of 40 and 100 seconds. The spectral peak appearing at 40 seconds seems to be caused by the higher mode interference.

For the study of the *LVZ* below the lithosphere, waves longer than 50 seconds seem to be more important. So short-period waves less than 50 seconds were eliminated, and the high-cut filtered waves of the first four modes were compared with those of transverse component observed at *GUA*. In Fig. 8 the observed and two synthesized Love waves for *PC-L43* and *8099-80* are shown. According to the figure two synthesized waves are very different, and it should be noted that this difference is caused only by the difference in the upper mantle structures. The synthesized waves for *PC-L43* explain the observation much better than those for *8099-80*, from a viewpoint of the wave form fitting.

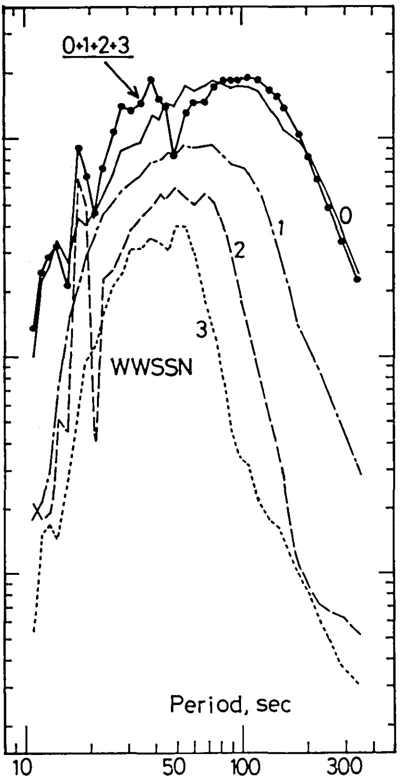


Fig. 7. Fourier amplitude spectra of the wavetrains given in Fig. 6.

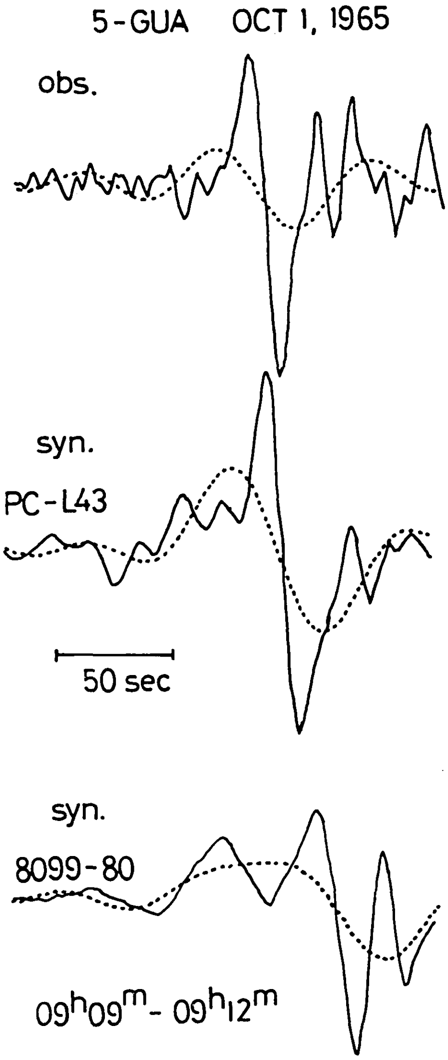


Fig. 8. High-cut filtered waves with a cut-off frequency 1/50 Hz at *GUA*. Top: Observed waves. Middle and Bottom: Synthetic waves composed of the fundamental, first, second, and third higher modes calculated for *PC-L*43 and 8099-80 respectively. Dotted lines are high-cut filtered waves with a cut-off frequency 1/50 Hz.

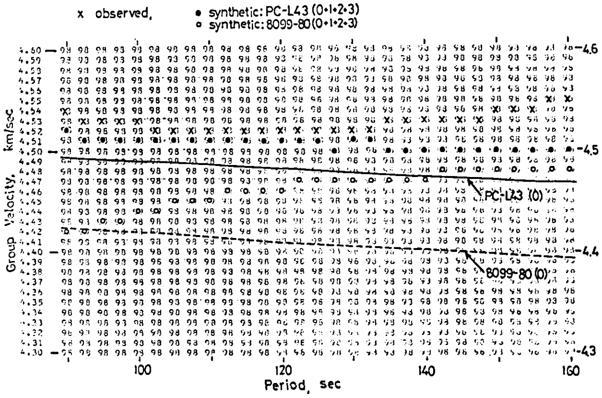


Fig. 9. Group velocities of observed waves and synthetic waves composed of the first four modes which are calculated for *PC-L*43 and 8099-80. The velocities of synthetic waves are determined for the high-cut filtered waves. Group velocities of the fundamental modes for the two models are shown for reference by solid and dotted lines. Numerals indicate the mode number.

4.3 Group velocities of observed and simulated multi-mode Love waves

Group velocities of the observed and synthesized waves are shown in Fig. 9, together with those of the fundamental mode calculated for *PC-L43* and *8099-80*. We notice that the group velocity of about 4.53 km/sec of the observed waves for *5-GUA* is close to that of the synthesized waves composed of the first four modes for *PC-L43* for the period range from 90 to 150 seconds. The velocities of the synthesized waves for *8099-80* are very low near the period 90 seconds compared with those observed, and the velocities of the fundamental mode calculated for *8099-80* are also much lower near the period 160 seconds than those observed. Strictly speaking the observed group velocities are higher than those of the synthesized waves for *PC-L43*. However, for the periods less than 150 seconds, the error is small, converging within 0.03 km/sec. An error of 0.05 km/sec near the period of 150 seconds seems to arise from the short signal length of the analyzed waves.

5. Discussion

Regional classifications of Love wave velocity have been recently studied by YU and MITCHELL (1979). They divided the Pacific into four areas belonging to the ocean-floor ages of 0–20, 20–50, 50–100, and 100 m.y. or more. In Fig. 10 group and phase velocities of the fundamental mode Love waves for *PC-L43* and *8099-80* are compared with their results. They interpreted the lower velocities for greater ages by a large influx of mid-plate volcanism in the western Pacific during the Cretaceous period. The velocities of the fundamental mode for *PC-L43*, which has been constructed for the region of 90-150 m.y. or more, are in good harmony with the velocities reported by them, since the group and phase velocities for *PC-L43* are, on the whole, higher than *Region 4* (100 m.y. or more) and lower than *Region 3* 50-100 m.y.) for the periods from 50 to 110 seconds. If the Melanesia region, which is remarkably different from the normal oceanic basin and is partly involved in *Region 4*, can be excluded from analyzed areas, the velocities for the *Region 4* seem to become higher than the values presented in Fig. 10, showing good agreement with the velocities for *PC-L43*. The velocities for *8099-80*, which well explains the Rayleigh wave disperion, are too low to explain Love wave velocity.

The model *PC-L43* is also supported by the phase velocity data (SCHLUE and KNOPOFF, 1977) for the path *15-KIP*, though in the present analysis Love waves for this path were not available. In Fig. 11 the phase velocities of Love waves calculated for *PC-L43* and *8099-80* are compared with their data. A good agreement is seen between

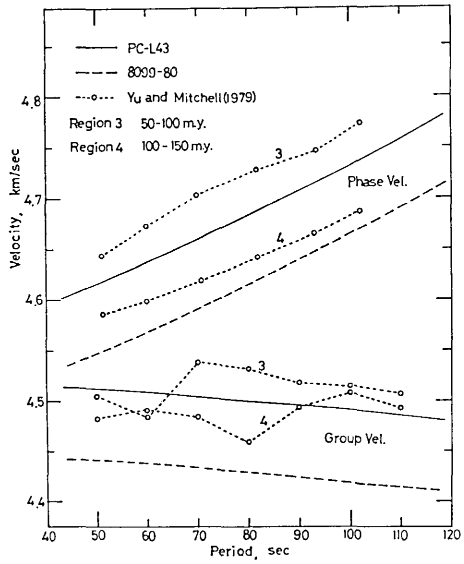


Fig. 10. Comparison of theoretical phase and group velocities of the fundamental modes for *PC-L*43 and 8099-80 with observed velocities associated with the ocean-floor ages of 50-100 m.y. (*Region* 3) and 100-150 m.y. (*Region* 4).

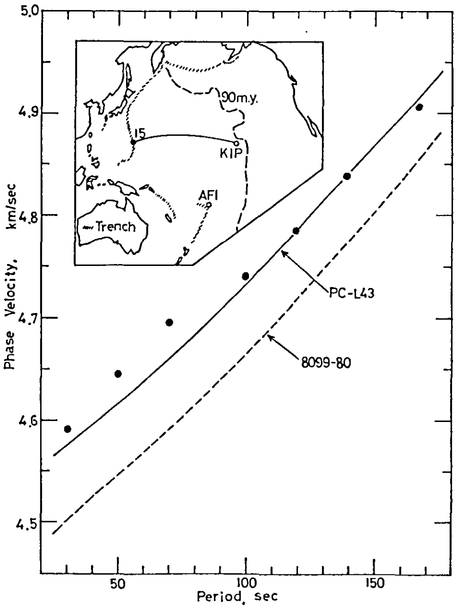


Fig. 11. Phase velocities of the fundamental modes calculated for *PC-L*43 and 8099-80 and observed ones (solid circles) in SCHLUE and KNOPOFF (1977) along the path 15-*KIP* (solid line) shown in the inserted map.

PC-L43 and the observation in the period range from 30 to 170 seconds. For the periods longer than 100 seconds the consistency is quite satisfactory, suggesting that the shear velocity 4.43 km/sec in the *LVZ* under the western Pacific is a reasonable value. Phase velocities calculated for *8099-80* are also lower than the observation by 0.08, 0.07 and 0.06 km/sec near the periods of 50, 100 and 150 seconds, respectively. Namely, the model constructed from Rayleigh waves cannot explain the Love wave dispersion. Fig. 11 shows clearly the existence of the polarization anisotropy.

It has been recently reported that the oceanic lithosphere varies with the ocean-floor age not only in thickness but also in shear wave velocity. YOSHIDA (1978) has presented a high shear velocity model varying with age for explaining the observed group velocities of Rayleigh waves near the periods of 40 or 50 seconds. The increase of shear wave velocity with age seems to be produced by a cooling mechanism of the oceanic lithosphere (McKENZIE, 1967), as well as the increase of the thickness of the oceanic plate. On the other hand, the existence of the azimuthal anisotropy of body waves and polarization anisotropy of surface waves in the oceanic plate (YU and MITCHELL 1979) may be primarily influenced by the motion of the Pacific plate. There is a possibility that the preferred orientation of crystal axes in upper mantle minerals such as peridotite is formed in the stress field within the lithosphere.

In the westernmost part of the Pacific, 15° discontinuities of *P*-wave travel time are found from the ocean bottom seismographic observations (NAGUMO, OUCHI, KASAHARA and KORESAWA, 1983). This discovery suggests the existence of several zones composed of partially molten materials in the upper mantle. The partially molten materials in the *LVZ* can produce the discrepancy between the velocities of *SV* and *SH* (*e.g.*, SHIMOZURU, 1963) by considering the media containing volume fraction of liquid pockets by 10%. Recently the low seismic velocities and high attenuation of the *LVZ* are interpreted in terms of the thermally activated processes involving viscous grain boundary relaxation and dislocation-impurity interactions (GUEGUEN and MERCIER, 1973), or in terms of the presence of thermally activated point defects (SHAW, 1978) without the necessity of melting. However, in the models proposed from the theory of activated processes the existence of polarization anisotropy in the *LVZ* is not established yet. The polarization anisotropy in the *LVZ* found in the present study is partly the effect of the partial melting and is partly under the influence of the preferrential alignment of olivine crystals due to horizontal shear flow in the asthenosphere associated with the mantle convection. Under the process of the convection the glide plane becomes parallel

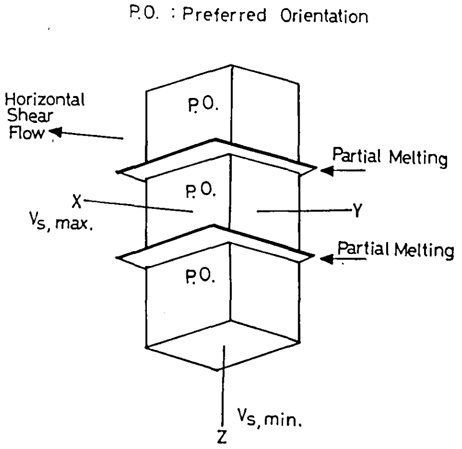


Fig. 12. Geometry of the direction of shear flow in the asthenosphere and the probable glide plane in dunites.

to the direction of currents in olivine fabrics.

Fig. 12 shows a preferred orientation of olivine crystallographic axes which produces the discrepancy in the velocity of seismic waves between the vertical and horizontal components, the velocity in the *X* direction being maximum and that in the *Z* direction minimum. This preferred orientation of velocity can be inferred by accepting the experimental or observation results found by Verma (1960), Hess (1964) and Kasahara *et al.* (1968). Oguchi (1979) found the polarization anisotropy in the orthogonal anisotropic media whose symmetric axis is inclined in arbitrary directions, with elastic constants being under constraints of $C_{44}<C_{66}$. These constraints were previously assumed by Kaminuma (1966) for explaining the polarization anisotropy of surface waves. So far we have discussed surface wave polarization anisotropy in the *LVZ* comparing the model *PC-L43* with the model *8099-80*, showing a discrepancy of about 3% in shear velocities. However, according to the study of first higher mode of oceanic Rayleigh waves (Yoshida, 1983c) the vertical shear velocities in the *LVZ* for the west Pacific are about 4.35 km/sec. For the vertical shear velocity of 4.35 km/sec surface wave polarization anisotropy of about 2% is produced there.

6. Conclusions

From the group velocity inversions and the wave form analyses of multi-mode Love waves in the long period range from 40 to 180 seconds, a regional upper mantle model *PC-L43* for the west Pacific has been constructed. The model well explains Love wave dispersions for that area and has a feature with a high shear velocity of 4.43 km/sec in the *LVZ*, 2∼3% higher than the values which are adequate for explaining Rayleigh wave dispersion; namely the horizontal shear wave velocity is much higher than the vertical one. This phenomenon of surface wave polarization anisotropy is caused by the existence of partially molten materials and by the preferred orientation of crystal axes of olivines in the *LVZ* due to the horizontal shear flow of asthenosphere.

It has been found that the wave forms of multi-mode Love waves which propagate in the west Pacific can be classified into two types. One forms isolated waves, and the other oscillated waves which, however, show no normal or anomalous dispersions. The former type is observed on the waves traversing normal to the isochrons of the ocean-floor-age, and the latter on the waves travelling mainly from north to south, nearly parallel to the isochrons. The oscillated waves show a few peculiar dispersion curves with unusual group velocities of 4.9 and 4.1 km/sec around the period of 70 seconds, which might be caused by higher mode interference.

Acknowledgments

The author wishes to thank Profs. T. Usami, T. Maruyama and Dr. R. Yamaguchi for their valuable discussions. He is also grateful to Prof. S. Nagumo for his valuable suggestions and to Prof. M. Mizoue for his encouragement. He is indebted to Prof. M. Saito, Kobe University, for his helpful suggestions and discussions.

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23. 郡速度及び合成波から明らかにされた西太平洋における表面波異方性

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表面波異方性を研究する為に，西太平洋を伝播した基本及び高次モードラブ波を詳しく解析した．観測された波と理論記象の波形，及び群速度のインバージョンから次の事が明らかになった．即ち，海底年代が九千万年から一億五千万年に相当する地域の低速度層のS波速度は4.43 km/secであり，これはレイリー波から求められている値より2～3%高い．この食い違いはアセノスフェア内における部分溶融相の存在と橄欖石等の結晶軸の定向性によって生じている．波形解析よりラブ波の波形には二つの形状がある事が見い出された．一つは孤立波であり，他の一つは正分散も逆分散もせず単に振動している波群である．後者のタイプでは，周期70秒付近で群速度が4.9 km/secとか4.1 km/secとか例外的に高い値や低い値をもつ異常な分散曲線を示すものが若干みられた．