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SURFACE WAVE DISPERSION IN BRAZIL, EAST OF THE ANDES.

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Abstract

This paper presents the results of a study of the dispersion characteristics of fundamental mode surface waves propagating in Brazil, east of Central Andes in particular, the continental crust and upper mantle structure. The occurrence of several large earthquakes in South America from 1965 to 1974 permits a reconnaissance study of the continental crust and upper mantle structure of Brazil, east of the Andes using surface wave dispersion. Data from WWSSN stations NAT and LPA were used to measure fundamental mode group velocity of Rayleigh and Love waves. The average S- velocity in the lower crust was found to be 4.40 km/sec. in Brazil, east of the Andes, which is typical of stable continents. The average S-velocity beneath the upper mantle is 4.66 km/sec, a typical value for cold platform areas. Other seismological data support this observation.

***Keywords*:** Surface waves, dispersion, continental crust, upper mantle, Brazil.

1: Introduction

Several earthquakes with surface wave magnitude $M_s \geq 5.5$ occurred in South America from 1965 to 1974. The seismograms were obtained from the World- Wide Standardized Seismograph network (WWSSN). Little geophysical data is available from South America and it is an area of considerable current interest. Any indication of crustal structure would be valuable. These factors, as well as the availability of data from WWSSN stations encouraged us to attempt to measure surface wave dispersion in Brazil, east of Central Andes. The purpose of this study is to present the dispersion characteristics of Rayleigh wave (18 ─ 80 s) and Love wave (18 – 60 s) propagating across South America. We used seismograms recorded by long-period instruments at the stations shown in Figure 1. The main motivation for the study is that the group-velocity provides new constraints on the shear-velocity structure of the crust and upper mantle beneath Brazil as well as the location of the internal boundaries such as the Moho

There have been vigorous efforts to produce new information about the structure of the South American crust and lithosphere. These efforts have concentrated largely on the use of data from several temporary regional seismic networks. However, seismic methods are either very expensive or limited in the determination of deep crustal structure, owing to the necessity of a large energy source to obtain information about both intermediate and lower parts of the crust. Data from these networks have provided new information about the crust [1-2], lithosphere [3] refraction [4], teleseismic studies [5]. Even with these efforts, the seismic structure of the crust and upper mantle underlying South America remains poorly characterized as a whole

Surface wave dispersion has been successfully used in the determination of crustal and upper mantle parameters in many different places around the world in recent times. More recently phase and group velocities have provided valuable information about crustal parameters in different regions [6]. The principal goal of this study is the determination of a shear wave velocity model beneath the continental crust and upper mantle of Brazil, east of the Andes using Rayleigh and Love wave group velocities obtained at the Brazilian seismological station of the World-Wide Standardized Seismograph Network (WWSSN)

2: Data and Methods of Analysis

We used seismograms recorded by the long-period instruments at the World Wide Standardized Seismograph Network (WWSSN). We used only well recorded earthquakes, rejecting small events with a poor signal-to-noise ratio and large events which were distorted. The selected seismograms were digitized at irregular intervals and a sampling interval of 1.0 s

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was then obtained by linear interpolation of the digitized points. The horizontal components were rotated to separate radial and transverse ground motions and a time series of 512 point centered on the surface wave of interest were selected. No filtering was applied to the WWSSN data. No tapering was applied since the time series always started before the arrival of the fundamental surface waves and extended past the time of the large surface wave amplitude. The earthquakes used as sources for this study are listed in Table 1. Source data were taken from the monthly listing of Preliminary Determination of Epicenters published by the National Earthquake Information Service of the U.S. Geological Survey.

The multiple filter technique of [7] was used to determine group arrival time for a range of periods. A system of Gaussian filters with constant Q yielded constant resolution on a long period scale. Instrumental responses were removed using theoretical values for WWSSN instrument responses. Standard errors of ± 0.025 km/sec in resulting group velocity are estimated from possible errors in earthquake source location, timing errors, errors in instrument response correction and resolution of the multiple filter techniques.

The group velocity of the surface waves recorded at the stations NAT and LPA is given by [8]

$$U(\omega) = \frac{\Delta_1 - \Delta_2}{t_1(\omega) - t_2(\omega)} \quad (1)$$

in equation (1) where Δ_1 and $t_1(\omega)$ are the distances and group travel time (at a given frequency ω) for a Brazilian event recorded at NAT, Δ_2 and $t_2(\omega)$ are the same values for the event of March 26, 1971. This technique has the advantage that it identically removes all influences of instrumental group delay or instrumental group delay corrections which are hidden in the terms t_1 and t_2 since both waves are recorded by the same instrument. The high quality of the data recorded at NAT allowed determination of the Rayleigh wave group velocity from 18 to 80 sec. The same technique was used to estimate group velocities for Love waves as for the Rayleigh waves. The surface wave group velocity measurements for paths across Brazil recorded at the stations NAT and LPA are listed in Tables 2 and 3

3: Inversion for Earth Structure

The results of the surface wave group velocity computed are summarized in Tables 2 and 3 Both Rayleigh and Love wave dispersion were measured on two paths from events 1, 2, 3, and 4 to station LPA and from events 5, 6, 7, 8, and 9 to station NAT. The Rayleigh and Love wave fundamental mode group velocity dispersion curves are shown in Figures 2 and 3. At most periods group velocities on the indicated path to station LPA were slower and group velocities on the indicated path to NAT were faster, both for Rayleigh and Love waves. Rather than attempt to invert all the observed group velocities to estimate crustal and upper mantle structure only the two indicated paths to LPA and NAT were used to estimate the crustal and upper mantle structure. Not only are both Rayleigh and Love wave dispersion available for these paths, providing better constraints on structure than is possible with one wave type. Since the dispersion in these two cases spans virtually all the observed dispersion, the related crustal models will give an indication of the range of crustal structure across the entire study area.The technique of [9] was used in this study to calculate the surface wave dispersion parameters from flat –layered earth models.

Corrections for sphericity are incorporated in Love wave dispersion calculations but are not used in Rayleigh wave dispersion calculations. Corrections for Rayleigh wave group velocity for sphericity may be neglected for the period range used here [10]. Layer parameters were derived from mantle model parametric earth Models (PEM-C) [11]. Starting values of P and S wave velocity and density were derived from previous studies of continental structure using surface waves [12-13]. The same values of density were used in all models, after preliminary adjustments. Poisson's ratios of 0.26 and 0.31 were used for the crust and upper mantle, respectively [14]. The values of density below 40 km were all taken from PEM-C. No changes in layer thickness were employed. S wave velocity was varied to fit Love wave dispersion and then P wave velocity was varied to fit Rayleigh wave dispersion, under the constraint that Poisson's ratio remained within the bounds expected for the layer in question.

Considerable effort was made to incorporate the most recent features of seismic and chemical studies of the crust [15-17]. These new crustal models include such details as low velocity zones at depths near 10km, low velocity zones near the base of the crust and rapidly increasing P velocity with depth in the lower crust, in place of models of one or two homogeneous layers for the lower crust and rapidly increasing P velocity with depth in the lower crust, in place of models of one or two homogeneous layers for the lower crust, Models were tested to find an Earth model which produced Rayleigh and Love wave group velocity matching the data on the path across Brazil to NAT and LPA stations. The final model is listed in Table 4. The group velocities differ from the observed values by less than 0.04 km/sec for both Rayleigh and Love waves. Poisson's ratio in each layer is considered satisfactory. The average density of the crust is 2,830 kg/m^3, the average P velocity through the crust is 6.40 km/sec and the average S velocity through the crust is 3.63 km/sec. These are considered acceptable values for continental structures [16-17].

4: Discussion

We used Rayleigh wave and Love wave group velocity dispersion curves with paths passing through Brazil, east of the Andes. The model of the crust determined for Brazil, east of Central Andes in this study is similar to models of continental structure elsewhere.[18]. It was found that there were low shear wave velocities in the mantle: 4.55 km/sec in the lid and 4.50 km/sec in the low velocity zone.

Other studies indicate low shear wave velocities under eastern Brazil. Low velocity anomalies appear in the western Caribbean and far eastern Brazil on the 20 s Love wave and appear to be associated with the western Caribbean and Maranhao Basins. [19]. The low shear wave velocities indicate unusually high temperatures in the mantle in Brazil, east of Central Andes. Enhanced shear wave attenuation, recent widespread volcanic activity, heat flow above normal for continents, widespread seismicity, active Cenozoic crustal tectonics, high electrical conductivity in the mantle and crustal thinning are possible related geophysical phenomena [20]. The range province of western United States provides a well developed example of this kind of geological regime.[21].

The crustal structure indicated for eastern Brazil by this surface wave study and the crustal thickness are typical of a stable crust. Seismic activity in much of eastern Brazil is actually rather low [22] especially in the northeastern region used for inversion in this study.

5: Conclusion

We report the results of a systematic study of Rayleigh and Love wave dispersion across Brazil. east of the Andes. Determination of the crustal and upper mantle structure with surface waves can make a valuable contribution to studies of the evolution of the Brazil, east of the Andes. The surface wave dispersion suggests that the crust of Brazil, east of the Andes is typical of stable continental platforms. The S-wave velocity of 4.66 km/sec of the upper mantle beneath it is typical for stable platform areas. A technique for measuring group velocity on the path between two earthquakes has been used [8]. The technique removes the effect of instrumental response on measured group velocity.

Table 1: Earthquake Source Data

Date	Location	Time	Depth (km)	Mag (m_b)
26/03/71	55.4S, 129.1W	9:08 : 06.6	33	5.9
05/02/72	55.4S, 128.7W	0:15 : 51.2	33	5.9
25/06/74	54.6S; 131.6W	5:05: 19.0	33	6.1
01/10/65	60.6S; 24.8W	22:34: 25.1	33	6.0
08/11/70	60.6S; 25.4W	20:10; 52.4	33	6.0
25/02/72	60.6S; 25.7W	1:17: 12.5	33	6.0
02/05/71	28.2S; 70.6W	20:52: 32.8	55	5.8

Source: World-Wide Standardized Seismograph Network (WWSSN)

Fig. 1. Location of WWSSN Seismological Stations NAT and LPA

Table 2: Observed group velocities (km/sec) for fundamental mode Rayleigh waves.

Period (sec)	NAT	LPA
18	2.88	2.76
20	2.96	2.86
22	3.01	2.95
24	3.03	2.02
26	3.09	2.10
28	3.14	2.15
30	3.18	2.19
33	3.21	3.26
35	3.25	3.35
40	3.29	3.48
45	3.33	3.61
50	3.35	3.71
55	3.37	3.73
60	3.40	3.76
70	3.43	3.83
80	3.47	3.85

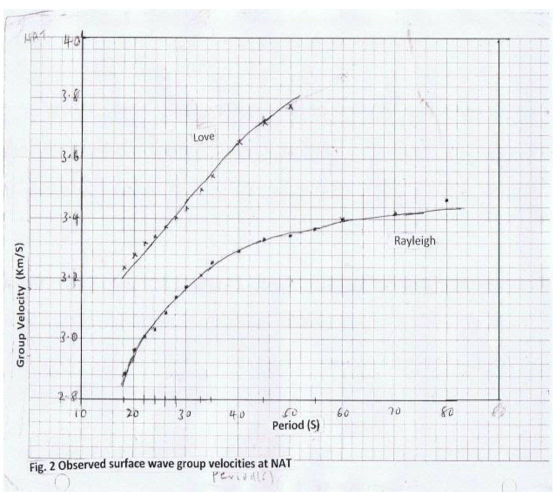

Fig. Observed surface wave group velocities at NAT.

Table 3: Observed group velocities(km/ssec) for fundamental mode Love wave.

Period (sec)	NAT	LPA
18	3.23	3.21
20	3.28	3.22
22	3.31	3.30
24	3.34	3.32
26	3.37	3.35
28	3.40	3.36
30	3.43	3.40
33	3.50	3.42
35	3.59	3.54
40	3.66	3.58
45	3.72	3.66
50	3.78	3.69
60	3.87	3.75

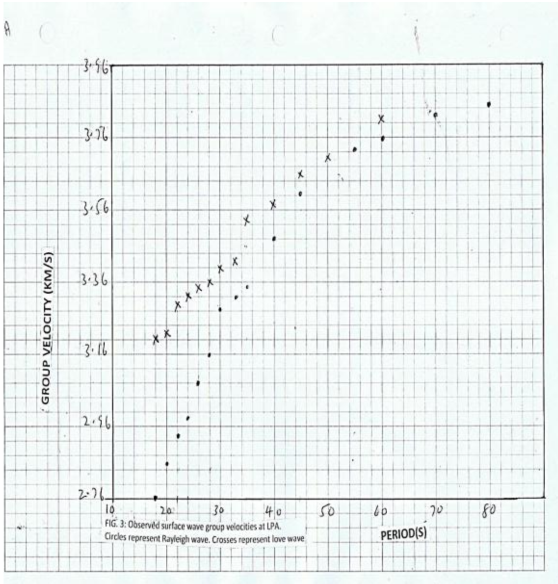

Fig 3. Observed surface wave group velocities at LPA. Circles represent Rayleigh wave. Crosses represent Love wave

Table 4: Crust – mantle model of eastern Brazil

Depth (km)	P- velocity (km/sec)	S-velocity (km/sec)	Density (km/m^3)
0.0	3.50	2.00	2200
1.0	4.80	2.85	2410
2.5	6.10	3.46	2750
10.0	6.65	3.72	2800
20.0	6.70	3.82	2900
30.0	7.00	3.95	2975
40.0	8.15	4.45	3330
70.0	8.35	4.40	3386
220.0	8.65	4.56	3447
270.0	8.79	4.63	3457
320.0	8.93	4.70	3507
370.0	9.07	4.78	3538
420.0	9.60	5.10	3799
470.0	9.70	5.18	3861
520.0	9.80	5.26	3922
570.0	9.90	5.35	3984
620.0	9.99	5.43	4046
670.0	11.01	6.15	4407
771.0	11.18	6.23	4466

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