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#### SUMMARY OF RESULTS OF ACCOMPLISHED RESEARCH

The following is a brief summary of our research activities supported by ONR.

The study of the conversion of  $S_n$  into  $L_g$  at continental margins is published. Our recent work on South America (as will be discussed later) suggests that this conversion phenomenon is an important one in the interpretation of the propagation of high-frequency seismic phases where there are large gradients in crustal thicknesses.

ABSTRACT of the paper, "Conversion of  $S_n$  to  $L_g$  at a Continental Margin", by Bryan L. Isacks and Christopher Stephens, Bull. Seis. Soc. Am., 65, 235, 1975.

Examination of the seismic phase  $S_n$  from earthquakes in the West Indies as recorded by numerous stations in eastern North America reveals that a substantial fraction of the short-period energy carried by  $S_n$  across the suboceanic lithosphere of the Atlantic is fed into the continental crust near the continental margin and travels into North America as the crustal phase  $L_g$ . As distance within the continent increases, the  $L_g$  part of the short-period wave train becomes predominant, and can be identified at stations in northern Canada as far as  $58^\circ$  from the sources. Several estimates of the average  $Q$  for the attenuation of  $L_g$  in eastern North America agree upon values in the range of 600 to 1,400. Hydrophone recordings at Bermuda indicate an average  $Q$  as high as 4,000 for the attenuation of  $S_n$  in the suboceanic lithosphere.

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Conversion of Sn to Lg also appears to occur near the margin between the continental U.S. and the Gulf of Mexico. In this case, Sn travels northward across the Gulf from earthquakes located near the border between Mexico and Guatemala.

Our study of Sn in terms of normal modes of Love waves in an oceanic structure is also published. The most interesting results of this work are that: (1) modes with group velocity maxima near the Sn velocity are developed for a structure in which velocities in the uppermost mantle lid are constant as a function of depth; and (2) modes with periods greater than about 1.5 sec have substantial particle displacements in the low-velocity, low-Q zone in the upper mantle and are thus subject to severe attenuation. This could explain the well-observed predominance of short-period motions of Sn.

ABSTRACT of the paper, "Toward an Understanding of Sn: Normal Modes of Love Waves in an Oceanic Structure", by Christopher Stephens and Bryan L. Isacks, Bull. Seis. Soc. Am., 67, 69, 1977.

The transverse component of the seismic phase Sn is considered in terms of normal mode propagation of Love waves. Calculations of dispersion, attenuation and particle amplitude versus depth are presented for a realistic model of oceanic structure which includes the effects of sphericity and the upper mantle zone of low velocity and high attenuation. We find modes with group velocity maxima near the Sn velocity of about 4.7 km/sec, and with attenuation sufficiently low to explain the predominance of short-period (about 1 sec) motions of Sn at epicentral distances up to 35° to 40°. For these modes, the particle displacements are largely restricted to depths above the low-velocity zone of the upper mantle. These modes are found for a structure in which velocities in the uppermost mantle lid are constant as a function of depth; sphericity alone is sufficient to provide a "wave guide" for Sn. The most interesting result of the calculations is that at periods longer than about 1.5 sec, modes with group-velocity maxima near 4.7 km/sec have substantial particle displacements in the low-velocity, low-Q zone in the upper mantle and are thus subject to severe attenuation. The results therefore indicate a filtering effect, which could explain the well-observed predominance of short-period motions of Sn. The particle displacement profiles calculated for the oceanic case also help to explain the efficiency with which Sn is excited by intermediate-depth sources, and provide a basis for accounting for the conversion of Sn into Lg across a continental margin.

A detailed investigation of the propagation of the high-frequency seismic phases Pn, Pg, Sn, and Lg in the region of western South America is now completed. A preprint of the paper, which is to be published in Geophysical Journal, is enclosed.

One of the important conclusions of this research is that the relatively young oceanic Nazca plate does not transmit Sn as efficiently as the older (and hence thicker) parts of the suboceanic lithosphere of the western Atlantic and the western Pacific. It appears that Sn does not propagate beyond a certain distance within the suboceanic of the subducted Nazca plate. Observations from other oceanic regions suggest that the disappearance of Sn with distance is related to the age, and hence thickness, of the suboceanic lithosphere under consideration rather than to tectonic and structural features along the propagation path or to effects near the source or the receiving station. The disappearance of Sn occurs over a change in distance of only  $1^\circ$  in the Nazca plate, between  $15^\circ$  and  $16^\circ$  from any station. Such a sharp "cut-off" phenomenon cannot be explained by a linear Q attenuation models. In addition, clear evidence exists for the efficient conversion of Sn into Lg at regions of crustal thickening beneath the Andes. These converted phases can be easily misidentified as Sn or Lg phases.

ABSTRACT of the paper, "High-Frequency Shear Wave Propagation in Western South America along the Continental Margin, in the Nazca Plate, and Across the Altiplano", by Douglas S. Chinn, Bryan L. Isacks, and Muawia Barazangi, to be published in Geophysical Journal, 1978.

High-frequency shear waves (0.5-2 Hz) recorded at regional distances at WWSSN stations in western South America are classified according to their apparent velocity and frequency/amplitude character. For propagation paths crossing any given region, the observations are abundant and consistent.

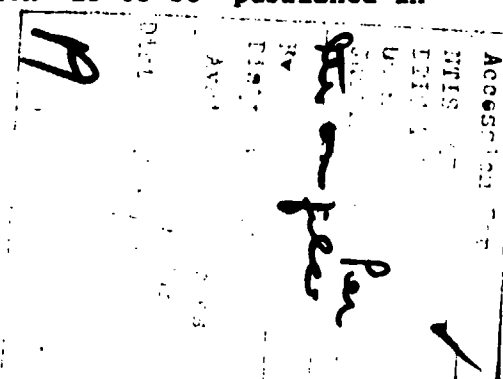
Sn is not observed at distances beyond about  $15.5^\circ$  along paths

in the eastern part of the relatively young (Eocene) oceanic Nazca plate. This observation does not appear to be related to any specific tectonic or structural feature along the propagation paths. In contrast, Sn is observed at distances beyond about  $25^\circ$  in the older (Jurassic-Cretaceous) parts of the western Pacific and western Atlantic oceanic plates and to distances of over  $40^\circ$  in continental shield regions. One interpretation of these and other data is that the maximum distance over which Sn is observed increases with the thickness of the lithosphere. The disappearance of Sn in the Nazca plate is quite sharp, occurring between  $15^\circ$  and  $16^\circ$ . Such a phenomenon cannot be explained by simple attenuation mechanisms.

Lateral variations in Sn propagation occur beneath the Altiplano, a high plateau in the central Andes. Two types of seismograms imply inefficient Sn propagation: one shows no Sn, implying an average low-Q along the path; the other has a complex ringing character suggesting a large amount of scattering along the path. Sn is also observed to propagate efficiently across some parts of the Altiplano, which would usually imply high-Q material in the mantle wedge that separates the South American plate from the descending Nazca plate. However, because of the relatively shallow dip ( $\approx 30^\circ$ ) of the descending Nazca plate beneath the Altiplano, it is possible that these Sn waves are actually refracted along the descending plate instead of traveling mainly through the mantle wedge.

Sn has a velocity of about 4.5 km/sec along western South America. Sn traveling in the oceanic Nazca plate converts efficiently into Lg traveling in the continental crust where the crust thickens beneath the Andes. No reverse Lg to Sn conversion is observed. Lateral variations in Lg propagation appear to be related to the orientation of the path relative to the structural trend of the Andes rather than to anomalous regions in the continental crust. It appears that Lg propagates efficiently only when the direction of propagation is approximately parallel to the strike of the Andes.

Our study on the excitation of high-frequency seismic waves within a continental-oceanic region is completed. The relative amplitudes of Sn and Lg were observed from New Guinea earthquakes recorded at Australian stations. The relative excitation with source depth of these two phases supports the interpretation that Sn and Lg are normal mode surface waves. A preprint of the paper, which is to be published in Annali di Geofisica, is also enclosed.



ABSTRACT of the paper, "Relative Excitation of the Seismic Shear Waves Sn and Lg as a Function of Source Depth and Their Propagation from Melanesia and Banda Arcs to Australia", by Muawia Barazangi, Jack Oliver, and Bryan Isacks, Annali di Geofisica, 1978, in press

Seismic activity associated with the collision of the continental part of the Australian plate with the oceanic Melanesian arcs along Papua New Guinea, and the Banda arc provides an unusual opportunity to study the relative excitation of the seismic shear waves Sn and Lg. These waves are produced by earthquakes located along the arcs in the upper 200 km of the earth and are recorded by the Australian WWSSN stations at Charters Towers (CTA) and Alice Springs (ASP). The paths to these stations are predominantly continental. The data clearly show that for events located at crustal depths, Lg is the predominant phase on the records and Sn is either absent or very weak. For events deeper than about 50-70 km, Sn becomes the predominant phase on the records. These observations are in qualitative agreement with the explanations of Sn and Lg as higher modes of surface waves, for the particle displacement amplitudes are maximum within the crust for Lg and maximum within the lid of the lithospheric mantle for Sn. The data suggest that either the crustal wave guide for Lg is more efficient than that for Sn, or that Lg is more easily excited than Sn. No clear Lg is observed from shallow earthquakes when the length of the segment of the path crossing oceanic structure is greater than about 100 km. Also, widespread Quaternary volcanism within the "stable" area of central Papua New Guinea to the south of the mobile belt does not seem to affect the efficient transmission of high-frequency (1 Hz) shear energy.

The paths from events located along the New Hebrides, Solomon, and New Britain arcs to Australia traverse oceanic structure, and no Lg is observed from these paths. The inefficient propagation of Sn along these paths from both shallow and intermediate-depth events can be explained as follows: (1) For the New Hebrides case, the inefficiency of Sn propagation for paths exceeding about 20° distance is related to the relatively young age (Lower to Middle Eocene) of the suboceanic lithosphere of the Coral Sea. As proposed by Chinn, Isacks, and Barazangi (1978), such relatively thin lithosphere is probably not an efficient wave guide for shear energy of about 1 Hz. (2) The inefficiency of Sn propagation from events located along the northern Solomon and the New Britain arcs is probably due to anomalous attenuation in the uppermost mantle beneath the Woodlark basin and beneath southeastern Papua New Guinea. (3) The inefficiency of Sn propagation from events deeper than about 150 km located in the westernmost part of the northerly-dipping Benioff zone of the New Britain arc could be due either to structural isolation of the nearly vertical descending segment of the plate in which the events occur, or could be due to structural complexity of the plates in the region which interrupts the wave guide for Sn to the Australian stations. This structural feature could be the result of the collision of the Australian plate and the New Britain arc.