SEISMIC STUDIES OF DEEP SLAB MORPHOLOGY BENEATH CENTRAL PERU

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Resume

A large-amplitude secondary P-wave recorded on the broad-band seismograph at Cusco, Peru, is interpreted to be an underside wide-angle reflection from the upper surface of the steeply dipping Nazca plate. Possible reflection points are in the depth range 150 to 400 km, where the slab is wholly aseismic, indicating that the descending Nazca plate exists in and is probably continous through that zone.

Key Words: Andes, aseismic slab, subduction zones, secondary seismic arrivals

Introduction

Two prominent features characterize subduction of the Nazca plate beneath western South American: (1) alternating regions of "normal" and "flat" subduction; and (2) the absence of earthquakes everywhere between depths of 300 and 500 km. Central Peru is characterized by both flat subduction and an abnormally large aseismic gap (150-525 km). An important question is whether or not the slab is continuous through the aseismic gap. Despite the fact that high frequency seismic waves from nearby deep focus earthquakes are propagated through at least some aseismic regions of the Andes, this alone is not sufficient to *require* slab continuity, and the issue remains unresolved (see James and Snoke, 1990, for discussion).

Wortel (1984) proposed for central Peru that the transition from older subducting lithosphere (age > 70 Ma) to younger and relatively hotter lithosphere gives rise to a force system in which the deeper, more dense, slab detaches from the anomalously buoyant young slab. The buoyant younger slab forms a "flat" subduction limb, while the more dense lower portion sinks into the deeper mantle. On the other hand, Schneider and Sacks (1989) concluded that the descending Nazca plate is continuous through the aseismic zone and that the absence of earthquakes can be explained as due to a brittle-to-ductile transition at depth.

Here we present direct seismic evidence for the existence and, inferentially, the continuity of the Nazca plate through the aseismic zone beneath eastern Peru. This result is based on the analysis of an anomalous large-amplitude P-wave arrival in the P codas of Peru-Brazil deep focus earthquakes recorded on the Carnegie broad-band station at Cuzco, Peru (CUS) (see Figure 1). We shall show that the anomalous arrival, which occurs approximately 1.5 seconds after direct P and is the largest arrival in the P-wavetrain, is best explained as an underside wide-angle reflection from the upper surface of the slab somewhere in the depth range 150 to 400 km, a region in which the slab is wholly aseismic.

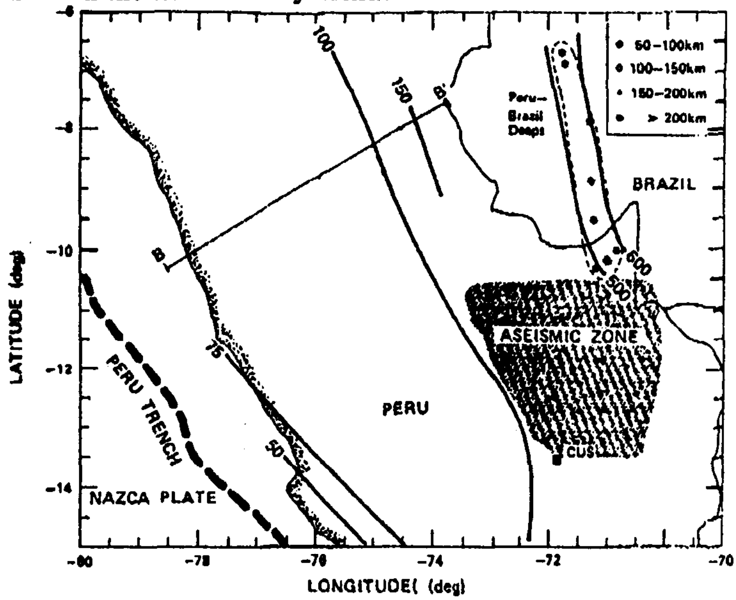

Fig. 1. Map of central Peru showing Benioff zone contours where defined by seismicity (shallow contours not complete), Peru-Brazil deep focus earthquakes, and aseismic zone within which slab reflections are shown to occur.

Data

The primary data for this study are broad-band recordings at Cusco, Peru, of four deep focus Peru-Brazil earthquakes with epicentral distances of $< 4.0°$ from the station. An example of velocity-corrected seismograms and particle motion from one of the Peru-Brazil deeps is shown in Figure 2. The anomalous arrival which we analyze in this paper (P_r) occurs approximately 1.5 sec after the direct P arrival (P_d). P_r has a number of important characteristics, some of which can be seen clearly in Figure 2:

1. It is the largest amplitude arrival in the P-wavetrain, with amplitude substantially greater that that of P_d (note radial component).
2. It is a clearly defined phase with sharp onset and rectilinear particle motion.
3. It is a P-wave.
4. It is opposite in polarity to P_d.

5. It differs substantially in backazimuth and emergence angle from P_d and hence has a significantly different propagation path.

P_r is clearly observed on all records of deep focus events from the Peru-Brazil region [redacted]

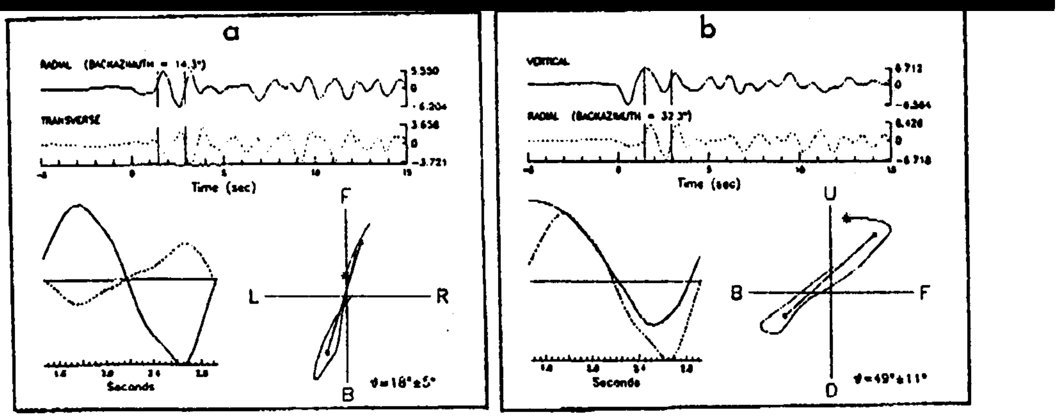

Figure 2. Particle motion for secondary phase, P_r. (a): Radial to transverse components. (b): Radial to vertical components. Vertical lines on seismic traces define time window over which particle motion is determined. Directional conventions F, B, L, R, U, and D stand for front, back, left, right, up, and down, respectively, for an observer facing toward the station from the epicenter.

Analysis

We analyze the nature of the anomalous arrival, P_r, chiefly by examining particle motion. Measured particle motions for P_d (direct arrival) confirm that the first arrival propagates along the direct path as predicted by a radially symmetric earth model. On the other hand, particle motion analysis of P_r shows that the angle of arrival at CUS is very much out of the plane of direct propagating phases. In particular, the backazimuth of P_r is about 18° greater than that of the direct arrival (Fig. 2)and the vertical-radial particle motion shown in Fig. 2 yields an apparent angle of emergence of $\sim 49°$. When the effect of interference between P_d and P_r is removed by subtracting the first arrival from the vertical and radial components (see James and Snoke, 1990, for details), the apparent angle of emergence for P_r is found to be $\sim 34° \pm 8°$.

The results of the particle motion analysis and forward modelling show that the anomalous P_r arrival cannot be due to effects either of the crust beneath CUS or source or near-source complexity. The most plausible explanation for the phase is that it has propagated along a relatively high Q path and has been reflected at a major velocity discontinuity with a *negative* velocity contrast that produced a polarity reversal.

Conclusions

We conclude that P_r is a wide-angle reflection from the boundary between the descending plate and the overlying mantle wedge. Thus, P_r is a P-wave that leaves the source travelling upward *in the slab* and is subsequently reflected at wide-angle from the underside of the upper slab boundary. For a specified *depth* of the reflection point, forward modelling gives the latitude and longitude of the refection and the attitude (strike and dip) of the reflector at that point. Modelling results show that the reflection point must be at a depth between 150 km and 400 km and that the slab must be very steeply dipping at the point of reflection. Inferred depths to the subducting slab are shown contoured in Fig. 3a, and families of calculated reflection points that fit the data for a variety of slab velocity models are shown in Figure 3b. The large amplitude of P_r seems to require a large velocity contrast between slab and overlying mantle of at least 5 to 10%.

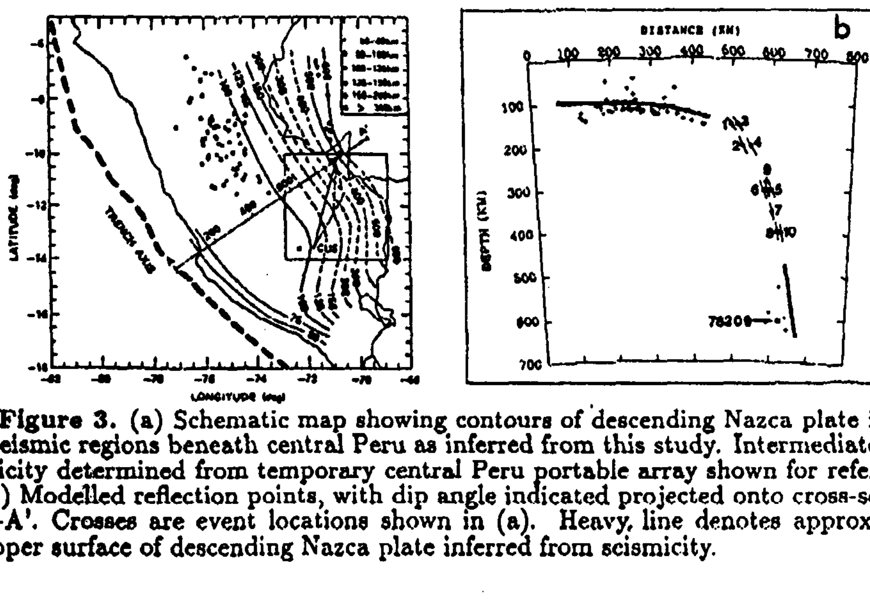

Figure 3. (a) Schematic map showing contours of descending Nazca plate in the aseismic regions beneath central Peru as inferred from this study. Intermediate seismicity determined from temporary central Peru portable array shown for reference. (b) Modelled reflection points, with dip angle indicated projected onto cross-section A-A'. Crosses are event locations shown in (a). Heavy line denotes approximate upper surface of descending Nazca plate inferred from seismicity.

References

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