Chapter 1

Introduction

Subduction zones are complex plate boundaries in which variable geometry and structure can be seismically observed. The along-strike transition from flat to normal subduction is one such geometric variation that is identified by changes in Wadati-Benioff zone seismicity. This transition may be accommodated by either a tear in the slab or a smooth contortion of the plate. Examination of the fine-scale seismic structure along this change in geometry can elucidate the nature of the transition and identify other features of the subducted plate. In this thesis, I investigate the seismic structure along transitions from flat to normal subduction located in central Mexico, southern Peru, and southwest Japan (Figure 1.1). A common feature of all three regions is a thin ultra-slow velocity layer (USL) atop the flat slab that is interpreted to consist of hydrous minerals and/or free water (*Song et al.*, 2009; *Kim et al.*, 2010). The presence of this layer is identified by the occurrence of complex P waveforms recorded by regional seismic arrays. The lateral extent of the USL is used as one constraint on the nature of the flat-to-normal transitions in central Mexico (Chapters 2 and 3) and southern Peru (Chapter 4). In southwest Japan, I explore the spatial coincidence of the USL with locations of slow slip events (SSEs) and the possible causal relationship between the two (Chapter 5).

In Chapter 2, I study the fine-scale seismic structure of the central Mexico subduction zone along the western transition from flat to normal subduction. Fragmentation of the subducting Cocos plate has been proposed to be actively occurring along the projected continuation of the Orozco Fracture Zone (OFZ), which overlies this transition, based on recent tectonic observations.

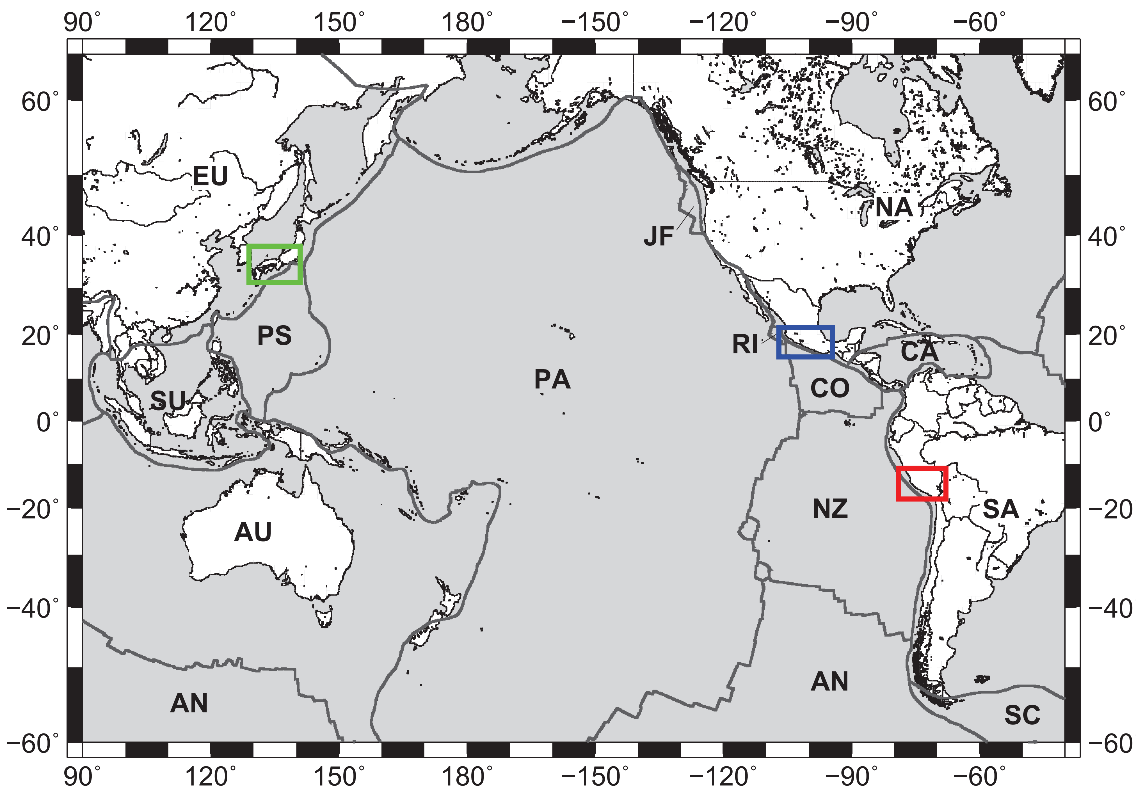

Figure 1.1: Map showing study locations in central Mexico (blue box), southern Peru (red box), and southwest Japan (green box). Major plate boundaries from *Bird* (2003) are shown in dark grey lines. The Rivera (RI), Cocos (CO), North American (NA), Nazca (NZ), South American (SA), Pacific (PA), Philippine Sea (PS), and Eurasian (EU) plates are indicated. Other plates labeled are the Australian (AU), Sunda (SU), Antarctic (AN), Scotia (SC), Caribbean (CA), and Juan de Fuca (JF).

I use intraslab earthquakes recorded by the regional Mapping the Rivera Subduction Zone (MARS) seismic array to test this hypothesis and further explore the subduction zone structure. Observed waveform complexities are used to map the western lateral extent of the USL that was imaged atop the flat Cocos slab by the Meso America Subduction Experiment (MASE) array (*Pérez-Campos et al.*, 2008; *Song et al.*, 2009; *Kim et al.*, 2010) to test if it ends along a lineament related to the landward projection of the OFZ. The edge of the USL is found to be approximately coincident with the western margin of the projected OFZ region, implying a structural boundary which I interpret as a tear in the Cocos plate. Forward modeling of the 2D structure of the subduction zone using a finite-difference algorithm provides constraints on the velocity and geometry of the slab's seismic structure and confirms the location of the USL edge. An analysis of seismicity and slab dip across the USL edge reveals a sharp transition in slab dip within the projected OFZ region and a significant decrease in seismicity west of the edge. On the basis of these results and tectonic observations, I propose a slab tear model, wherein the Cocos slab is currently fragmenting into a North Cocos plate and a South Cocos plate along the projection of the OFZ by a pivoting subduction process similar to that which occurred when the Rivera plate separated from the proto-Cocos plate.

Chapter 3 is a similar study to that presented in Chapter 2, now applied to the flat-to-normal transition that occurs in eastern central Mexico. Here, observations of a sharp transition in slab dip coupled with the abrupt end of the Trans Mexican Volcanic Belt (TMVB) suggest a second possible tear located within the subducted South Cocos plate. I use intraslab earthquakes recorded by the MASE, Veracruz-Oaxaca (VEOX), Servicio Sismológico Nacional (SSN), and Oaxaca Network (OXNET) seismic arrays to study the fine-scale structure of the subduction zone along this transition and elucidate the nature of the slab morphology (i.e., tear or contortion). Mapping the eastern lateral extent of the USL reveals an end to this layer which is coincident with the western boundary of a zone of decreased seismicity and the end of the TMVB near the sharp transition in slab dip. The coincidence of these features implies a change in structure which I interpret as evidence of a possible tear. Waveform modeling of the 2D structure in this region confirms the location of the USL. Analysis of intraslab seismicity patterns reveals clustering, sudden increase in depth, variable focal mechanism orientations and faulting types, and alignment of source mechanisms along the sharp transition in slab dip, further supporting the possibility of a slab tear. I propose the subduction of parallel ridges of seamounts and/or stress due to the abrupt change in geometry as potential causes of the possible slab tear in the South Cocos plate. This potential tear, together with the tear along the projection of the OFZ to the northwest, indicates a slab rollback mechanism in which separate slab segments move independently, allowing for mantle flow between the segments.

In Chapter 4, I investigate the slab morphology along the transition from flat to normal subduction in southern Peru. Previous studies of this transition region have suggested both tearing and continuous curvature of the subducted Nazca plate, with a recent receiver function study indicating a continuous slab with no clear breaks (*Phillips and Clayton*, 2014). In order to test this conclusion and expand on investigations of this region, I use regional intraslab earthquakes recorded by the Peru Subduction Experiment (PeruSE) and Central Andes Uplift and Geodynamics of High Topography (CAUGHT) seismic arrays to study the fine-scale structure of the southern Peru subduction zone along the flat-to-normal transition. I also analyze seismicity patterns and focal mechanism orientations for any indications of fragmentation or contortion of the subducted plate. Examination of the lateral variation in slab dip across the transition reveals a gradual increase with no sharp transitions, suggesting a smooth contortion of the Nazca plate. A lack of any gaps or vertical offsets in the intraslab seismicity, coupled with concentrations of focal mechanisms at orientations which are indicative of slab bending, further support this conclusion. The presence of a thin USL like that observed in central Mexico is also identified and located atop the horizontal Nazca slab. The lateral extent of this USL is coincident with the margin of the projected linear continuation of the subducting Nazca Ridge, implying a causal relationship. Unlike in central Mexico, the lateral extent of the USL in southern Peru does not suggest a tear in the slab due to its location and the lack of coincident tear indicators. Waveform modeling of the 2D structure in southern Peru provides constraints on the velocity and geometry of the slab's seismic structure and confirms the absence of any tears in the slab. In summary, the seismic and structural evidence suggests smooth contortion of the Nazca plate along the flat-to-normal transition. I also estimate the along-strike strain experienced by the continuous Nazca and torn Cocos slabs across their respective transitions, finding values of 10% for the Nazca slab and 15% for the Cocos slab in both western and eastern central Mexico.

Chapter 5 explores the fine-scale seismic structure of the transition from flat to normal subduction in southwest Japan in a manner different than that of the previous three chapters. Here, rather than focusing on the nature of the transition, I focus on the USL and its possible causal relationship with SSEs. *Song et al.* (2009)'s study on subduction beneath central Mexico indicated that there is a relationship between the location of SSEs and the location of intraslab earthquakes that generate complex P-waves. Simple P waveforms indicate normal slab conditions with no occurrences of SSEs, whereas complex P waveforms imply the presence of the USL atop the slab and the occurrence of SSEs. I further test this hypothesis in a region of southwest Japan that experiences SSEs and has a similar geometry to that studied in central Mexico. I use intraslab earthquakes recorded by the Hi-net array to estimate the location of a possible USL along the Philippine Sea slab surface and find this region of low velocity to be coincident with locations of SSEs. The fluid-rich composition of the USL would be expected to greatly reduce the effective normal stress on the plate interface, decreasing the coupling, and promoting SSEs. I interpret the source of the possible USL in this region as fluids dehydrated from the subducting plate, forming a high pore-fluid pressure layer.

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