Controlled source seismic imaging of subduction zones; what can we learn from the down-going plate

Subduction zones in the world are monitored in real time, mostly by spatial arrays of geodetic sensors and seismometers. Co-seismic slip distributions now reach unprecedented resolution for the most instrumented regions (e.g., the Tohoku rupture area in Japan). While the main slip patches and asperities of recent giant earthquakes are well defined, as well as the kinematics of their rupture, there is still a lot to understand about what structures and/or processes limit the extent of the rupture zones (1) and contribute to the locked or aseismic nature of the plate interface (2).

We here focus on what can be learned from marine studies involving controlled source seismic imaging of the interplate interface and of the down-going oceanic plate. We discuss two marine geophysics cruises that have been recently conducted by LDEO and Dalhousie University using R/V Marcus G. Langseth and its modern seismic acquisition system (6600 cu. in. tuned gun array and 8 km long streamers). These are the 2011 ALEUT Project that targeted the Alaska subduction zone and the 2012 Ridge2Trench Project that targeted the Juan de Fuca (JdF) plate and Cascadia subduction zone.

Central point of the JdF Ridge2Trench cruise is the important question of the origin of fluids in the subduction system. The Cascadia subduction zone shows evidence for hydration of the JdF oceanic plate, with intra-slab earthquakes detected under/above the oceanic Moho and active arc-volcanism, both generally related to de-watering of the slab. The Cascadia subduction is also well known for Episodic Tremor and Slip (ETS), for which the mechanics of aseismic slip can be explained by fluid overpressure. However, the incoming JdF slab is very young (9 Ma) and theoretically too warm to incorporate large amount of water through serpentinization of the mantle. The proximity of the JdF spreading-ridge offers a unique opportunity to study, through reflection and refraction seismics, the hydratation of the oceanic crust and upper mantle from the ridge to the trench, and its variation along the trench. Intraplate faults are the likely fluid paths used to hydrate the plate. Therefore, the along-strike variations in hydration may be related to N-S variations in the stress regime within the JdF plate as it enters the Cascadia subduction zone, but also to both the orientation of the ridge-generated fault fabric relative to the trench and along-trench variations in the thermal state of the JdF plate.

The ALEUT cruise in 2011 focused on a section of the Alaska-Aleutian subduction zone from the Shumagin Gap in the SW, across the Semidi Segment in the middle, and to the SW Kodiak Island in the NE. The highly coupled Kodiak Asperity has ruptured in 9.2 magnitude 1964 earthquake. The variably coupled Semidi Segment has last ruptured in 1938 and is thought to have a recurrence rate of 50-75 years. The poorly coupled Shumagin Gap is thought to behave aseismically. The Alaska subduction zone is particularly interesting to investigate because the entire seismogenic zone and the downdip transition to aseismic slip are accessible by sea. Based on previous observations showing different megathrust reflector properties as a function of the aseismic (ductile) or locked (brittle) nature of the rupture plane, one of the main goals of this cruise is to verify the possibility of mapping these different behaviors through reflection seismics. Initial processing of the acquired data shows varying plate interface reflections to depth greater than 30 km, and along-strike variations in the reflection expression of splay faults.

Advances in our understanding of the subduction systems using controlled source seismic data are not only dependent on collecting new data using advanced systems but also on our ability to apply advanced imaging technology to such data to extract additional information. We present perspectives in seismic imaging using full-waveform inversion of the seismic wave-field that has the potential to greatly impact future research. For shallow targets (using long streamer MCS profiles) or deep targets (using high density OBS profiles), waveform tomography inversions bring velocity field imaging to the resolution of the fault making it a powerful tool for detecting fluids or velocity inversions in general. The full waveform approach may open a new era in the observation of structures and processes impacting the subduction systems.