Mapping plate boundary fluids at a Subduction Zone Observatory using electromagnetic soundings

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At convergent margins, the subduction of oceanic lithosphere is the primary process by which fluids are transported to the interior of the Earth. From their impact on seismicity to their capacity to promote mantle melting that feeds arc volcanism, fluids are inextricably linked to the expression of tectonic phenomena at subduction zones. Quantifying the storage, transport, and release of subducted fluids is critical to understanding the factors that govern a variety of tectonic processes, including tsunamigeneric earthquakes and volcanic eruptions, and the hazards associated with them. By lowering the effective normal stress along the plate boundary, fluids likely play a role in regulating slow-slip events, low frequency earthquakes and episodic tremor and slip.

Electrical conductivity is an intrinsic material property that can be used to elucidate the geological and hydrological structure of the Earth’s interior, particularly at subduction zones. The conductivity of the crust is largely dependent on its porosity and the pore fluid temperature. In the oceanic plate, zones of active serpentinization likely have enhanced conductivity resulting from higher degrees of fracturing [Evans et al., 2010] and within the upper mantle, conductivity is greatly influenced by the presence of melt and to a lesser degree by temperature and hydration state [Yoshino & Katsura, 2013].

Electromagnetic (EM) data offer the unique means to image crustal fluid reservoirs and migration pathways, and to quantify porosity, fluid budgets, and the hydration state of the mantle. Both passive and active source EM methods are used to map the conductivity structure in oceanic and continental environments. Onshore and offshore data acquisitions with large 2D or 3D receiver arrays are now routinely performed for both commercial and academic applications [Key, 2012]. The passive magnetotelluric (MT) technique has been used for marine and continental exploration for decades. With recent industry interest and support, the controlled-source EM (CSEM) method has become a standard tool for hydrocarbon exploration on the continental shelves [Constable, 2010].

CSEM data collected at the Middle America subduction zone offshore Nicaragua has demonstrated its utility for imaging hydrogeologic systems and quantifying porosity [Naif et al. 2015; submitted]. In Figure 1 we show results from this first, and to-date only, subduction zone CSEM survey. These results show that the entire section of water-rich incoming seafloor sediments are carried down with the subducting oceanic lithosphere, where the décollement appears as a conductive channel. Porosity and water budget estimated from the conductivity are in good agreement with compaction studies of subducted sediments, showing rapid decay from 65% porosity and 400 m of water at the trench axis to 10% porosity and 75 m of water at 25 km into the margin where the plate interface lies 6 km below seafloor. Both porosity and water budgets show significant lateral variations that we attribute to changes in the subducted sediment thickness caused by bending faults at the trench-outer rise. Between 18-23 km from the trench axis the
Conductive channel broadens greatly with a peak thickness of 1.5-2 km. The anomalous feature is likely caused by concentrated blind faults or sediment underplating, and its presence suggests a sudden change in the hydrogeologic structure that results in the loss of fluids from the plate interface. This fluid loss could lead to significantly greater plate coupling farther down dip.

We propose that active-source CSEM imaging and deeper sensing passive magnetotelluric imaging should be components of the future subduction zone observatory. The acquisition of several offshore CSEM and amphibious MT trench-perpendicular profiles will provide key constraints on both the lateral and down-dip variability in conductivity structure, allowing us to image the fore-arc, arc, and back-arc plumbing systems, and to constrain the role of fluids in seismogenic and volcanic processes. Offshore, each profile may consist of 20 to 40 ocean-bottom EM receiver deployments, which record MT and CSEM data simultaneously, with 5-10 km nominal site spacing. A single 150 to 200 km long CSEM-MT profile like the image shown in Figure 1 can be collected with only about 10-12 days of ship-time on station, so during a single 30-40 day cruise multiple profiles could be collected. Figure 2 shows several such profiles as an example for the Central American margin.

Figure 1: The electrical structure of the Middle America Trench from nonlinear inversion of deep-towed CSEM data. The vertical cross-section shows the electrical resistivity structure and the stitched upper panel shows seafloor bathymetry. The dark blue cubes show the location of EM receivers. The blue cylinders show the location of active seafloor seeps. The incoming Cocos plate develops several steeply dipping bending faults that correlate with sub-vertical conductive channels, which significantly hydrate the oceanic crust [Naif et al., 2015]. The channel of low resistivity within the forearc margin is caused by subducted sediments. The 1992 tsunami earthquake ruptured this section of the megathrust. From Naif et al. [submitted].
Figure 2: A hypothetical array of amphibious trench-crossing EM profiles traversing the Central American margin with 50 km spacing between transects.

References:


