Geophysical Research Abstracts
Vol. 12, EGU2010-13243, 2010
EGU General Assembly 2010

The impact of splay faults on the geochemistry and fluid budget of a subduction zone

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Fluid samples obtained from convergent margins indicate that pore fluids are geochemically distinct from seawater, and characterized by reaction products derived from deeper within the subduction zone. The geochemical anomalies indicate a hydraulic connection from the site of these reactions to the seafloor, although it is unclear how the observed geochemical signature is related to the underlying permeability architecture, and overall fluid budget. In erosive margins like Costa Rica, the majority of sediments on the incoming oceanic plate are subducted, and therefore represent significant fluid sources derived through processes of compaction and mineral dehydration. In regions characterized by thin sediment cover and low heat flow (eg. Costa Rica) temperatures sufficient to drive mineral dehydration are not reached prior to subduction. In these settings, the geochemical anomalies observed at seafloor seeps most likely represent fluids flowing from deep within the subduction zone to the seafloor via the décollement or major subsidiary faults that connect the plate boundary to the seafloor. Observations of geochemical anomalies and seeps far upslope highlight the role of the latter features in both chemical transport and overall fluid budgets. Although previous modeling studies designed to estimate pore pressures, flow rates, and fluid budgets for convergent margins have successfully predicted pore water geochemical signatures and flow rates at seafloor seeps, they have not investigated the role of major splay faults. Here, we address this problem using a 2-D numerical model of coupled fluid flow and transport in order to quantitatively evaluate the physical and chemical hydrogeology of the forearc using the well studied Costa Rica margin as an example. Costa Rica provides an ideal setting for the proposed modeling study, as it has been well constrained through ocean drilling and borehole observatories that continuously monitor pressure, temperature, and geochemistry along a transect perpendicular to the trench. Specifically, we investigate the effect of realistic permeability architecture on the fluid budget, distribution of fluid pressures, and the spatial pattern of geochemical signals in the fluids expelled at the seafloor.

Our model consists of a cross section perpendicular to the Middle American trench, extending from 10 km seaward of the deformation front to 50 km landward. In our models, we assign fluid sources within the subducted sediment section to represent both compaction and clay dehydration in order to evaluate the distribution and fate of freshened (dehydration derived) water from deep in the subduction zone to the seafloor. We assign sediment porosity following an exponential decrease with depth, and define permeability using a relation to porosity derived from laboratory data. Because it is not composed of accreted sediment, we assign a uniform permeability to the overriding margin wedge. We evaluate the effect of clay dehydration by first establishing a baseline model with wedge and décollement permeabilities of 10^{-19} m^2 and 10^{-15} m^{2}respectively, without including faults. In subsequent model runs, we vary the splay fault and décollement permeability from 10^{-17} m^2 to 10^{-13} m^2 in order to examine the effect of these changes on the distribution of fluid pressures, the fluid budget, and distribution of fresh pore water through comparison with the baseline model. Comparison of modeling results with direct measurements from seafloor seeps and borehole observatories will clarify the link between geochemical data and the underlying physical processes that determine fluid pressures and the distribution of fluids in the forearc. Preliminary results show that flow rates at the seafloor are consistent with those estimated from gravity coring (0.3-1.5 cm/yr) and the distribution of fluids (ie. fluid budget) is sensitive to changes in the permeability of the faults and décollement, especially in cases where fault permeability is greater than décollement permeability.