Tracing the Evolution of Slab Fluids during Progressive Subduction: Insights from Serpentinite Mud Volcanoes in the Mariana Forearc

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Geological processes in subduction zones strongly influence seismicity, igneous activity, and geochemical cycling between the oceans, crust, and mantle. The down-going plate experiences metamorphism, and the associated dehydration and fluid flow alters the physical properties of the plate interface and overlying mantle wedge. Direct study of active slab evolution is inhibited by the great depths at which these processes occur and there is a dearth of physical samples to assess the state of water-rock-sediment reactions, thermal and pressure conditions, and physical properties of materials within the subduction channel.

The drilling of serpentinite mud volcanoes in the Mariana forearc provides a telescope into these deep processes and allows us to sample fluids and xenoliths from the subducting slab and forearc mantle. Fluid-laden serpentinite is transported along active extensional faults in the upper plate and seeps out at mud volcano edifices. There is widespread evidence for episodic voluminous serpentine eruptions, likely related to seismic events. Mud volcanoes are found across the forearc and sample the slab interface from 13 to 19 km depth. Samples obtained over three Scientific ocean drilling legs (ODP Legs 125 and 195; IODP Leg 366) and additional ROV expeditions elucidate the evolution of fluid production, reaction and exchange, during the progressive subduction of the down-going plate.

Fluid analyses show clear trends in pore water chemical and isotopic composition with progressive subduction. These parameters can be used to assess the thermal state of the subduction channel at different depths, identify the reactions controlling fluid releases, and to estimate fluid fluxes. Pore waters from the shallowest depths-to-slab (13-16 km) are Ca and Sr-enriched compared to seawater, but otherwise solute poor, low alkalinity fluids of pH ~11. In contrast, more deeply derived fluids (>18 km) have higher pH (12.5), reduced concentrations of Ca and Sr and elevated DIC, Na and Cl, as well as B and K compared to seawater – these changes are associated with the breakdown of slab sheet silicate phases. These waters also have higher δD and δ11B values than
shallower waters (δD values up to +16 ‰; δ¹¹B ~ 14-15 ‰ cf. δD < 0‰; δ¹¹B ~ 12-13 ‰). PHREEQC modelling indicates pore water chemical evolution reflects mineralogical characteristics of a predominately basaltic source from the downgoing Pacific Plate; however, a component from sediment sources is a likely contributor, especially for those mud volcanoes near the trench.

Our new data indicate that the lawsonite-epidote mineral transformation boundary (~250 °C, >18 km depth) is an important source of devolatilization waters and may also drive slab carbonate breakdown, despite its apparent thermodynamic stability at such temperatures and pressures. At shallower depths, the main reactions controlling fluid liberation are sediment compaction (<13 km) followed by clay diagenesis and desorbed water release (>13 km depth). This study thus provides direct evidence for the progressive mineralogical and chemical evolution of a subducting oceanic plate.