

Faults and fractures in the subseafloor environment tell a different story than they do at the seafloor.

Nicholas W. Hayman¹ ¹University of Texas at Austin, Institute for Geophysics, Jackson School of Geosciences, 10100 Burnet Rd., Bldg. 196, Austin TX 78758, hayman@ig.utexas.edu.

Though other planetary bodies likely have quite different drivers of volcanic and hydrothermal processes, Earth's mid-ocean ridges (MORs) and surrounding ocean crust have many lessons for planetary studies to draw from. A particularly vexing problem, however, is that our understanding of MORs can partly depend on whether we are focusing on the seafloor or the subseafloor, the latter only accessible through sparse geophysical investigations, boreholes, or geologic studies of deeper crust. Geologic studies have been conducted via both on on-land exposures of oceanic crust and also via Remotely Operated, Human Occupied, and Autonomous Underwater Vehicles (ROV, HOV, AUV, respectively) of *in situ* crust exposed in submarine rift walls.

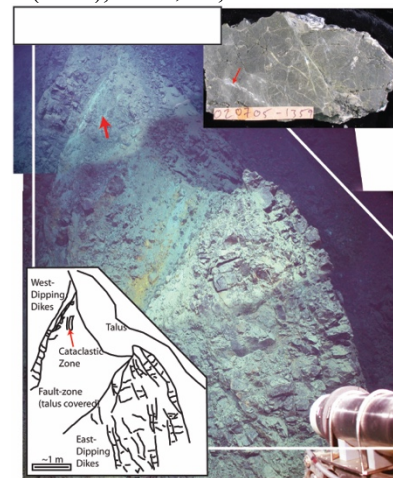
Fast (>100 mm/yr) spreading centers such as the East Pacific Rise are draped by basalt flows that radiate from the axial high. Along this axis, black-smoker vents form conical edifices atop what are thought to be pipe-like discharge zones for a cellular advective fluid flow regime. Because fast-spreading centers are considered to be predominantly magmatic systems, faults and fractures are thought to be relatively unimportant to tectonic extension and fluid flow. However, subsurface studies clearly show that faulting can be densely clustered across >100-m thick zones¹⁻³. Sampling from these fault zones provides microtextural and geochemical evidence for multiple phases of deformation and fluid flow that feed black smoker vents at the surface. The fault zones contain steep gradients in sulfides, silicates, and metals, with zones of lower-temperature hydrothermal minerals that formed in conditions conducive for subsurface microbiological activity. Isotopic studies also demonstrate that these zones fill with complex mixtures of downwelling seawater and upwelling "evolved" brines. In short, an environment thought to be relatively devoid of fault-related fluid flow based on surface observations is rich in quasi-planar zones of enhanced permeability and potentially microbe-supporting chemical exchanges and gradients in the subsurface.

Along slower (e.g., ~25-35 mm/yr) spreading centers there is a lower density of hydrothermal vents, but both black smoker systems on basaltic lava fields and lower-temperature vents along fault scarps are well known. Faults have long been considered to be important in such slow spreading centers, defining patterns of fluid-flow related seismicity and related venting at the surface. Here too the subsurface expres-

sion of faults and fractures has some surprising contrasts with the surface. Slow-spreading MOR faults in many cases have been exhumed from great depths, forming panels of highly impermeable deformed plutonic rock⁴. The contrasts in permeability cause large gradients in chemistry, potential driver and limitation to the subsurface biosphere. Vents at the surface have prominent ultramafic chemical signatures associated with serpentinization of mantle materials. Yet the subsurface suggests that many of these sites have deep crustal roots⁵. These crustal systems can be complexly fractured rather than cut by single, localized faults.

In summary, one draws different conclusions about the role of faulting and fracturing in Earth's seafloor spreading systems when comparing the seafloor and subseafloor observations. To translate this experience to planetary sciences, one might consider the range of possible flow regimes and compositional gradients possible, and design tests for fault/fracture controls using measures of bulk crustal anisotropy, spectral differences that are sensitive to fine-scale mafic vs. ultramafic heterogeneity, and targeted *in situ* observations that can find geologic exposures exhumed from the subsurface.

References: [1] Hayman, N.W., & Karson, J.A. (2007) *G3*, Q10002. [2] Hayman, N.W., & Karson, J.A. (2009) *G3*, Q02013. [3] Barker, A., et al., (2010) *Geol.*, 38, 379-382. [4] Hirose, T., and Hayman, N.W. (2008) *J.Struct.Geol.*, 30, 1060-1071. [5] Harding, J.L., et al. (2017), *Geol.*, 45, 839-842.



From (2), An image taken from the Jason-II ROV of a fault exposed in the Pito Deep, SE Pacific