MASSIVE HYDROTHERMAL FLOWS OF FLUIDS AND HEAT: EARTH CONSTRAINTS AND OCEAN WORLD CONSIDERATIONS. A. T. Fisher[1], [1]Earth and Planetary Sciences Department and Center for Dark Energy Biosphere Investigations, University of California, Santa Cruz (EPS Department, UCSC, 1156 High Street, Santa Cruz, CA 95064, afisher@ucsc.edu).

Earth's Ocean Crustal Aquifer: Earth's ocean crust is a ~6-8 km shell of basaltic composition, comprising intrusive gabbro and dikes overlain by extrusive flows, pillows, and breccias. The extrusive section forms a vast aquifer, containing up to 1-2% of the ocean's volume in free water (about the same as the global cryosphere), and forms an extensive habitat capable of supporting microbial life across a range of thermal and geochemical conditions. Global assessments of Earth's geothermal heat flux indicate output of 40-44 TW, but the conductive heat flux determined from seafloor measurements is low by 20-25% of conductive predictions. This global "heat flux anomaly" is often attributed to hydrothermal advection, much of which occurs on ridge flanks, areas far from the magmatic and tectonic influence of seafloor spreading, where fluid temperatures are ≤70°C. The global flow rate of low-temperature, ridge-flank hydrothermal circulation is orders of magnitude greater than that occurring at high temperatures in volcanically active areas, and rivals the flow of all of Earth's rivers and streams into the ocean.

Crustal Properties and Topography: There have been relatively few *in-situ* measurements of ocean crustal permeability, which determines the ease of fluid flow in the presence of a driving force. Permeability is a tensor property, and is both scale dependent and dynamic. Most direct measurements made in boreholes are based on pumping and pressure perturbation data or borehole temperature measurements using heat as a tracer of fluid flow. Other estimates have been made using data proxies or computer models of related processes.

Seafloor relief plays a critical role in guiding ridge-flank hydrothermal circulation. In contrast to conditions on land, where potential for fluid flow tends to mimic topography, seafloor bathymetry serves mainly to warp isotherms, thus providing lateral variations in temperatures and thus fluid density at depth in the crust. In addition, much of the seafloor is covered by low permeability sediments, although there are some areas, especially at spreading centers and on young ridge flanks, where the sediments are thin and patchy. Crustal relief creates permeable outcrops where fluids can bypass surrounding sediments. Basement relief below sediments can also result in large differences in seafloor heat flow, a strong indication of local to regional advective redistribution of heat. These observations are important for testing coupled (fluid-heat) models of hydrothermal circulation in the ocean crust.

Modeling Low-Temperature Hydrothermal-Flows: Recent efforts in modeling subseafloor hydrothermal processes include three-dimensional, transient simulations of ridge-flank circulation between volcanic rock outcrops and along dipping faults. One well-studied field site is on the eastern flank of the Juan de Fuca Ridge, where there is outcrop-to-outcrop hydrothermal circulation, a "hydrothermal siphon." Seawater recharges into one seamount, flows laterally >50 km under sediments, then discharges through another (smaller) seamount. This system moves relatively little fluid, with a siphon flow rate of only ~5-20 kg/s, and reaction temperatures in the volcanic crust of ~60-65°C. Computer simulations show that this outcrop-to-outcrop hydrothermal siphon can be sustained at a low flow rate only when upper crustal permeability is modest (10^{-13} to 10^{-12} m^2) and there is a large difference in outcrop transmittance, the product of permeability and outcrop area. At another field site, in the eastern Equatorial Pacific Ocean, a large region of suppressed seafloor heat flow provides evidence for much greater advective heat loss. Simulations of this area show that basement permeability must be 10-100x higher than at the first area, with siphon flows ≥1000 kg/s. Simulations of both sites indicate that smaller outcrops are favored for discharge.

Simulations of hydrothermal circulation along high- to low-angle faults in the upper ocean crust demonstrate the trade-off between buoyancy (stronger influence in higher fault angles) and the mining of crustal heat from a large area (favored by lower fault angles). Also, simulations suggest that deep faults, which have been inferred from seismic reflection data near subduction zones on Earth, should be associated with large seafloor heat flux anomalies if these faults are hydrogeologically active. The lack of observed anomalies suggests that there are undiscovered vent sites near subduction zones where excess heat is extracted, or that plate flexural faults may be relatively unimportant for crust/mantle hydration reactions (e.g., serpentinization).

Implications for Ocean Worlds: These results raise questions for understanding the influence of hydrothermal processes on ocean worlds, including: the fraction of planetary heat advected from solid lithospheric into an overlying ocean, the nature of bathymetric relief at the bottom of a planetary ocean, the presence/absence of sediment, and the depth extent of faults and joints that could enhance permeability and permeability anisotropy.