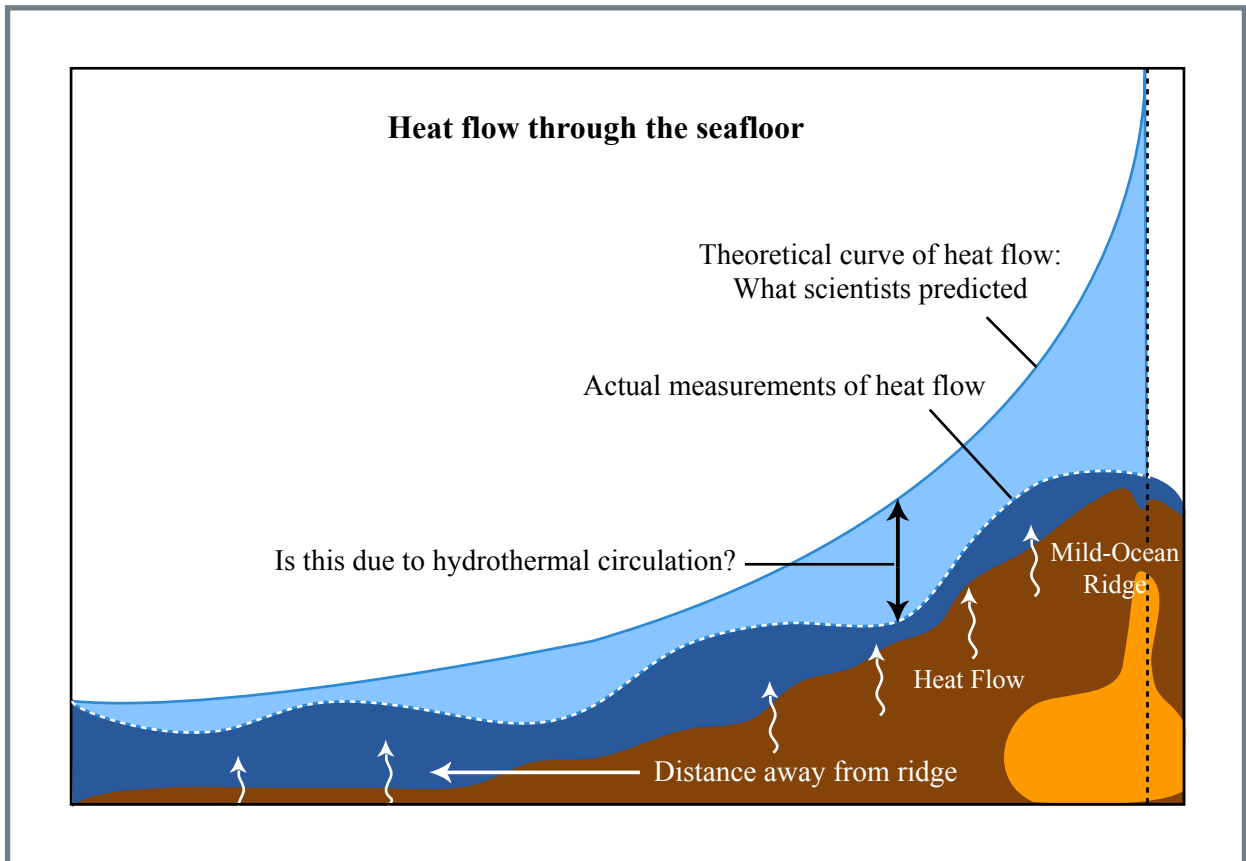


Another wrinkle on observations of the Abyssal Ocean: Geothermal Heating & Hydrothermal Vents



Models of Magma injection at Ridge Spreading Centers lead Geophysicists to expect a heat flux out of the ocean bottom that exceeded observations of diffusive heat flux made with probes placed in sediments. This “missing heat flux” (of order $0.1-1 \text{ w m}^{-2}$) lead some to speculate that it might be hydrothermal: involving oceanic water circulating within the earth’s crust and being injected into the ocean like hot springs.

Indeed, these hot springs were discovered by the Alvin submersible (see figure at right) in the Pacific Ocean with black fluid, filled with dark mineral particles, emerging from vents at temperatures of 350°C . The chemical signature of these vents can be traced over 2 thousand km. across the Pacific as was first demonstrated by in paper by Lupton and Craig (Science, 1981) using an isotopes of helium (^3He , ^4He) which are emitted from the earth at vent sites.

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Because the emitted fluid is so hot, it is buoyant and quickly rises from the bottom. These buoyant plumes can rise up to a few hundred meters above the sea floor, where their buoyancy is finally lost due to entrainment of surrounding fluids. From laboratory & atmospheric studies of these (spurred on no doubt by a need to know how high to make smoke stacks in cities) the rise height can be related to environmental variables such as the background stratification and the initial buoyancy (e.g. heat) flux from the plume. During the plume rise, entrainment will draw surrounding fluid into the plume and rotation effects will be seen (as in a hurricane). Similarly, at the level where the plume rise stops, fluid will spread away from the center again feeling rotation (Speer & Rona, JGR, 1989). This produces a cyclonic lower level flow and an anti-cyclonic flow at plume height (both of which have been observed: Joyce *et al.*, GRL, 1998). A series of these plumes located along a Ridge Crest or in an Axial Valley, may be largely responsible for the existence of anticyclonic mean currents which flow along oceanic ridges (Helfrich *et al.*, GRL, 1998).

On a larger scale, these plumes often influence temperature, salinity, and tracers far from their source. The best studied cases (East Pacific Rise, Juan de Fuca Ridge) have anomalies extending westward over a thousand km. The WOCE one-time hydrographic survey included tracers such as deep helium, which have been used (Lupton, JGR, 1998) to map out these helium plumes from Ridge venting sites. A north/south section across the Pacific Ocean (line P17, see figure at right) really consisted of multiple legs, which have been “joined” together to look at a large-scale view of these plumes. The sources for the observed plumes (see color figure below) are from the East Pacific Rise (EPR) with local maxima at 12S and 8N, and Juan de Fuca (JdF) Ridge, located just to the west of the NW US coast, with a maximum at 42N. The helium anomalies are

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still detectable far (in the case of the EPR) from their sources. These must have been advected by mean flows in the abyssal Pacific Ocean. Lupton makes the case that mean flows at the depths of the plumes are consistent with what is known about the deep circulation of the Pacific as deduced by Reid (Progress in Oceanog., 1997).

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Stommel (Earth & Plan. Sci. Lett., 1982) explained the westward motion of plumes in terms of the β -effect which causes temperature anomalies to move westward from their source. These β -plumes are important features in understanding how regions of deep water mass formation influence their local surroundings. While their motion is influenced by the β -effect & Rossby wave propagation, which we will study shortly, the spread of tracers such as helium is mainly due to deep currents. Since mean flows in the deep interior of the ocean can be very small, indirect (tracer) measurements may be the best way to learn something about them. The vertical spreading of plumes may also be related to vertical velocities/mixing in the abyssal ocean as well. Below the sea surface, ^3He is not a conservative tracer. Its concentration will increase because of the radioactive decay of tritium in seawater. At the surface, it outgases into the atmosphere. These effects need to be considered in any serious circulation budgets involving this tracer.