d8 Divergent plate boundaries < rifts, black smokers, MORB >

'Isn't the deep ocean supposed to be like a desert?' puzzles a geologist—the first to see vent-life from the submersible Alvin. —Robert (Bob) Duane Ballard, *The Eternal Darkness*.[1]

Cartographer **Marie Tharp** (1920-2006)[2] in 1953 drew oceanographer "a core a day!" Bruce C. "Doc" Heezen's (1930-1977) attention to what at the crest of the Mid-Atlantic Ridge she interpreted to be a rift valley.[3] This, Heezen initially dismissed as a spurious feature of the then available oceanic soundings of the broad rise-ridge system of mountains that, to either side of its crest at about 2 to 3 kilometers below sealevel, has rough flanks that symmetrically and gradually deepen away for a thousand kilometers and more to abyssal depths of 5 kilometers. His avid anti-drifter stance changed when Tharp discovered that epicenters of earthquakes line up along the rift valley.[4] Heezen and Maurice Ewing in 1956 announced that the most characteristic topographic feature of Mid-Atlantic Ridge is a Great Global Rift valley along its axes.[5] By the 1960s end, the rift valley (in places 40 kilometers wide and bounded by walls to 1500 meters high) was known to mark the boundary between diverging lithospheric plates. Asthenosphere isostatically rises to fill the space that, otherwise, would be created there by plate separation.[6] The oceanic rises are everywhere rough with extinct volcanic piles and ridge-parallel normal fault scarps that originate near the ridge either from plate-pull necking[7] or, where plate-push of fast spreading ridges forms a convex-up plate, from grabening as the plate flattens in its travel away from the ridge.[9]

For historical reasons (***Footnote d8.1***), continuations of Mid-Atlantic Ridge that snake and branch around the world are collectively part of a "mid-ocean ridge system" (total length, 65,000 kilometers), even though long stretches are not centrally located in other oceanic areas.[9] In the Pacific, for example, a long portion of the "mid-ocean ridge system" is the East Pacific Rise.

The volcanism that occurs at mid-oceanic ridges is the eruption of fissure basalts. In the *plate tectonics* model, these lavas originate from the partial melting of the asthenosphere that in maintenance of isostasy passively rises between diverging lithosphere plates. The melting occurs because rock is a poor conductor of heat and as it rises it mostly retains the temperature it had at depth. At lower pressure, this temperature comes to exceed the partial melting temperature of peridotite and complete melting of patches of eclogite and pyroxenite (that studies of xenoliths and peridotite massifs, elsewhere, have shown are mantle components). The magma which results from these meltings at depths of about 35 km has the composition of basalt. This magma that originates in the convectively rising asthenosphere, itself rises more rapidly (escapes upward) buoyantly to intrude the lithosphere as vertical dikes parallel the ridge and extrude volcanically as ridge associated fissure flows. These basalts accumulate on the diverging lithosphere plate edges and are moved away to either side of the ridge as oceanic crust. Basalts erupted at ridge axes, referred to as MORB (mid-ocean ridge basalt), usually accumulate there to a thickness of 3-7 km (***Figure d8.1***). However, the amount of basaltic lava erupted at the ridge is less constant than is the rate of seafloor spreading from the ridge with respect to which oceanic crust comes to be at a global rate of about 21 cubic kilometers per year. Volcanic activity waxes and wanes along the length of the ridge.[10] Where little lava erupts, as along a central 300 km length of the Arctic Gakkei ridge (slow full-spreading rate 6-13 mm/yr), the oceanic crust is serpentinite (a metasomatic rock derived from peridotite with the addition of water).[11] So too is the oceanic crust between the Nularbor Plain passive margin of Australia and the shield margin of East Antarctica. Outpourings of seamount basalts related to hotspots can thicken the ocean crust anywhere. In older regions of the oceanic crust, what is found is that the basalts are on average about 10 km thick.

MORB is basalt crystallized from lava erupted after some crystal settling in a cooling magma that originated by the decompression melting of rising mantle peridotite. Geochemical studies of MORB and its volume indicate extraction at high temperature and ranging from 10 to 35 percent of the volume of the original peridotite.[12] The peridotite mantle from which MORB is derived is thereby left much depleted in sodium (Na), titanium (Ti), strontium (Sr), and light rare-earth elements (LREE) such as neodynmium (Nd) that preferentially partition into basalt melts. The altered peridotite will have no way again to remelt unless first metasomatised by penetrating seawater and then contact reheated by later intrusions of magmas from below. Mathieu Benoit in 1999 suggested this can account for found small volumes of andesites in seafloor crust.[13] At 11°N, the Vema transform fault offsets the central Mid-Atlantic Ridge by 310 km. Along a 20 million year length of its 4 km high mantle-exposing scarp, Enrico Bonatti in 2003 found, 3-4 million year long cyclical variations in crustal compositions and thickness.[14]

Deepocean submersibles have directly observed processes of oceanic ridge volcanism. As expected from theory, lavas well out of fissures in the rift zone. Also, a basaltic volcano eruption on the ocean floor, at a depth of 1,525 meters, has been recorded by a Volcanic System Monitor (VSM or rumbleometer).[15] The VSM tiltmeter recorded that the "inflation and drainout" cycle of the underlying magma chamber was completed in two hours. As described by Christopher Fox in 2001 the eruption event involved a brief burst at a high effusion rate, followed by a longer period of waning rates, and then subsidence during lava withdrawal. When the frigid (2°C) ocean water met the lava, a solid crust formed while the molten (1200°C) interior continued flowing. Although the rumbleometer footing became trapped in the flow, the temperature of the water it measured above the crust peaked at only 9.5°C. The basaltic lava spread thinly over the ocean floor to create a lava plain more than 350 meters wide.[16]

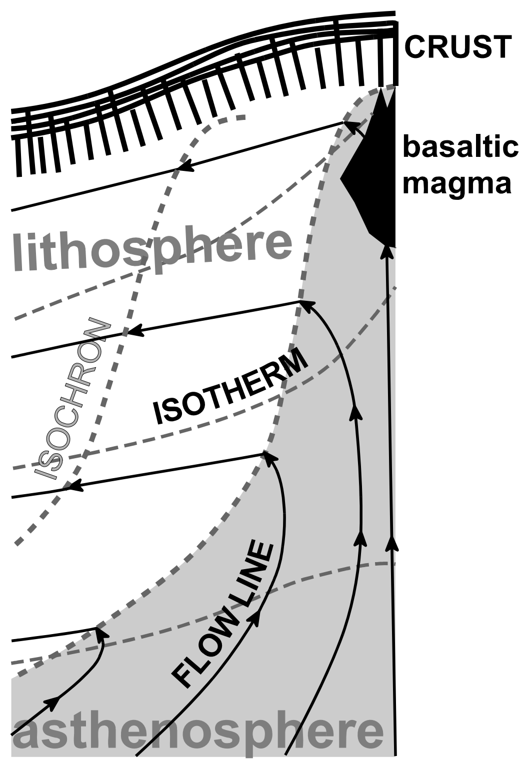
Away from the oceanic-ridge rift, impermeable sediments (that cover most ridge rises beyond where the lithosphere is 1 million years old) should prevent circulation of seawater through the underlying plate. But this sedimentary seal is compromised by seamounts that penetrate and allow for inflow and outflow of seawater. The temperature and heat flow through seafloor to 65 million year old distance is less than plate tectonic theory originally predicted and this, Andrew T. Fisher in 2003 found is due to hydrothermal circulation through oceanic basement rock that effectively removes 30 % of the lithospheric heat energy to emerge along mid-oceanic ridges as mineral-rich, highly acidic, water to as hot as 400°C.[17] These hydrothermal vents (first discovered in 1979 under more than 2,400 meters of water about 400 kilometers northeast of the Galápagos Islands) are called "black smokers" for the iron, sulfur, and other materials that precipitate to form dark (when illuminated) clouds in the ocean depths. A great surprise was the proliferation of life about the vents. In the cooled vent-water, unlit by sunlight, chemosynthetic bacteria that oxidize hydrogen-sulfide (H_2S) to sulfate for their metabolism energy are the base of the food chain for filter feeders (that for their metabolism require environmental O_2 and so chlorophyll-driven photosynthesis elsewhere in the world).[18] The most noticeable near-vent organisms are 2-m tall, red- (hemoglobin) flesh tipped tubeworms, sans mouth, eyes or gut (present at an early stage), and a body filled by bacteria that oxidize the H_2S and convert CO_2 into nourishment for the worm (solid sulfur remains embedded in the organism as waste). Crawling free are blind (as to eyes in their heads but with heat-sensing organs on their backs) shrimp. Lava eruptions are ongoing and an often-revisited vent site nicknamed the Rose Garden for its tubeworms was buried by lava outpourings between 1990 and 2002 visits.

Different from black smokers and away from a mid-oceanic ridge is hydrothermal activity in seamounts of raised mantle rock. In these hydrothermal systems (the first was found in December 2000 atop a seamount called *Atlantis*, 15 km west of the Mid-Atlantic Ridge at 30°N), circulating water is heated, not by molten rock but by exothermic reaction of seawater with olivine (that produces serpentinite at temperatures less than 600-700°C). Vented is 40-75°C highly alkaline water, methane, hydrogen, and dissolved minerals (mostly calcite) that precipitate to build massive vent mounds (on the 1.5 million year old Atlantis seamount ocean crust, the "Lost City" vent chimney described July 2001 by Deborah S. Kelly was18 stories tall and growing).[19] ❑

Footnote d8.1 The first topographic profile of the Atlantic seafloor (to explore the practicality of laying a transatlantic telegraph cable) was prepared in 1853 (when John Brooke's sounding device that released its sinker upon striking bottom was available for "blue-water" hydrography)[20] by Matthew Fontaine Maury, U.S. naval officer, pioneer hydrographer and a founder of oceanography. (In 1855 he published the first modern—but offering totally incompetent physics!—oceanographic text *The Physical Geography of the Sea*).[21] He does not mention a mid-ocean ridge. In fact, the "profile" is of an essentially flat deep seafloor.[22] And that falsity was furthered by Huxley's widely read essay *On a Piece of Chalk*: "The Admiralty consequently ordered Captain Dayman, an old friend and shipmate of mine, to ascertain the depth over the whole line of the cable, and ... in the months of June and July, 1857, my friend performed the task assigned to him with great expedition and precision, without, so far as I know, having met with any [monetary] reward of that kind. ... The result of all these operations is, that we know the contours and the nature of the surface-soil covered by the North Atlantic for a distance of 1,700 miles from east to west, as well as we know that of any part of the dry land. It is a prodigious plain—one of the widest and most even plains in the world."[23]

HMS Challenger, Expedition led by John Murray, December 7, 1872 to May 26, 1876, with the cooperation of the British Admiralty and the Royal Society, discovered the existence of the Mid-Atlantic Ridge and, in the western Pacific, a more than five mile deep "chasm" (deepsea trench) in the course of its world survey of ocean basins during which 492 deep soundings were taken. The procedure was to tie to the end of a hemp rope a weight of over a 100 pounds. This was lowered over ship-side and allowed to drop. The rope would then play out from a vast coil on board until the weight hit the seafloor miles below. The length of rope played out gave a fair measure, after allowing for boat drift, of the depth to the seafloor. The rope often broke when attempting to haul the weight back up again. The inventory for hemp rope listed 144 miles of it.[24]

Figure d8.1 [25] Schematic cross section of the upper mantle and crust to one side of an oceanic ridge crest where rising hot asthenosphere cools to become lithosphere.



The transition temperature of the asthenosphere to lithosphere also depends on the pressure. At any moment the transition boundary between the asthenosphere and the lithosphere along the flow lines is an isochron (same time), and not the isotherm (same temperature). The movement of these isochrons away from the transition boundary is a measure of the rate of "sea-floor spreading."

In the "sea-floor spreading" model proposed by Hess in 1962, melting does not occur and the seafloor (oceanic) crust is serpentinized peridotite. However, deepsea drilling has since shown that much of the oceanic crust is basalt. In 1972, geologists at the Penrose Conference agreed to modified model: Near the top of the rising asthenosphere, the decrease of pressure can cause a partial melting of the mantle peridotite. Basaltic magma is discharged and it rises buoyantly to accumulate as oceanic crust with an upper part of extrusive pillow lavas and feeder dikes, and a lower intrusive part which is a vertically sheeted dike complex. The newly solidified crust, in the course of the ongoing divergence, becomes split into same age strips. These move away to either side of where they form, as the upper part of the oceanic lithosphere.

About three-quarters of the area of the oceanic crust has a basaltic "layer cake" structure and it accords to the "Penrose" model.[26]

"Hess" amagmatic seafloor (oceanic) crust (*see* Topic *g2*) occurs at the inside corners of ridge-transform intersections of slow-spreading ridges.[27]