Interactions Between the Seafloor and the Oceans: From the Coastlines to Mid-Ocean Ridges

Rob. L. Evans
Department of Geology and Geophysics
Woods Hole Oceanographic Institution

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A common perception is that the seafloor is an isolated, static and unchanging desert—a place that has little bearing on our lives at the surface of the earth.

On the contrary, the more we learn about the seafloor, the more it is revealed as an ever-changing, dynamic environment that influences the largest ecosystem on earth, and can store and release huge quantities of energy. While many of the processes on the seafloor occur on timescales well beyond those of politics, there are occasional episodic events--some seen by the naked eye; others detected only by instruments--that represent large releases of energy and changes in the configuration of the seafloor and the coastline.

Interactions between the seafloor and the ocean are two-way. On Dec 26th 2004, a magnitude 9.0 earthquake caused seafloor uplift of several meters, generating a tsunami that devastated the shoreline over thousands of kilometers.

The town of Meulaboh, in the Aceh region of Sumatra was badly hit by the 2004 tsunami. I recently visited the town where obvious and dramatic changes in the shoreline resulted from the inundation. The photograph shows a destroyed fishing boat. The region in the background was once a river mouth bar on which rice paddies and a small village were located. *(Photograph: Rob. Evans, Woods Hole Oceanographic Institution)*

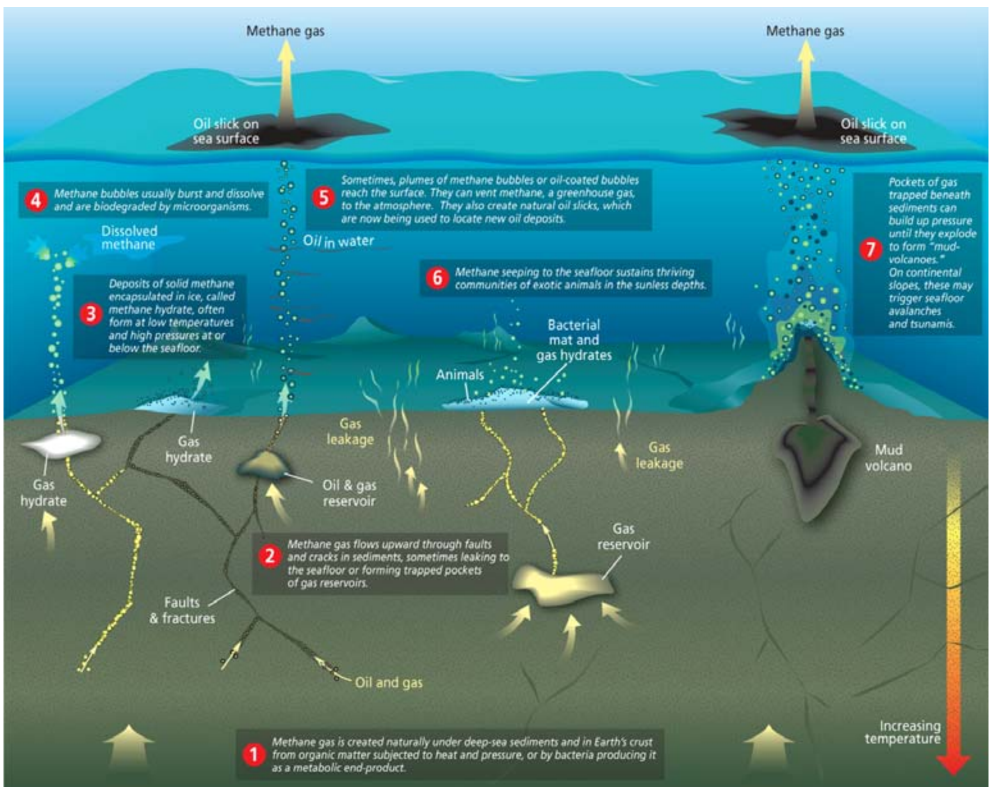
There are other exchanges between the seafloor and the ocean that are harder to observe and which, in fact, have been observable only over the last 10 years or so, thanks to advances in technology and techniques. Surprisingly, these exchanges are not limited to the deep ocean, but also include nearshore regions of seafloor.

We can roughly divide coastal regions into two types: *mainland beaches*, where the continent directly contacts the ocean, such as along the west coast of the U.S.; and *barrier settings*, where an offshore stretch of sand protects the mainland. Barrier beaches stretch down the east coast of the US and into the Gulf of Mexico. Left to their own devices they are constantly shifting, responding to changes in sea level, sediment supply (mainly from rivers), ocean currents and waves, and of course to storms and tsunami. Sediment is lost from the beaches during storms and high-energy events, and returns to rebuild the beach during calmer periods. Our ability to monitor and understand sediment transport has only recently been viable through improvements in mapping capabilities, global positioning systems, and coastal observatories that provide continuous, realtime measurements of processes affecting coastal evolution.

Two aerial photographs of Chatham, Massachusetts taken before (left) and after (right) a large storm in 1987. The barrier beach which lies offshore from the mainland was breached during the storm forming a new inlet which remains to this day. ***(Photographs: Duncan FitzGerald, Boston University)***

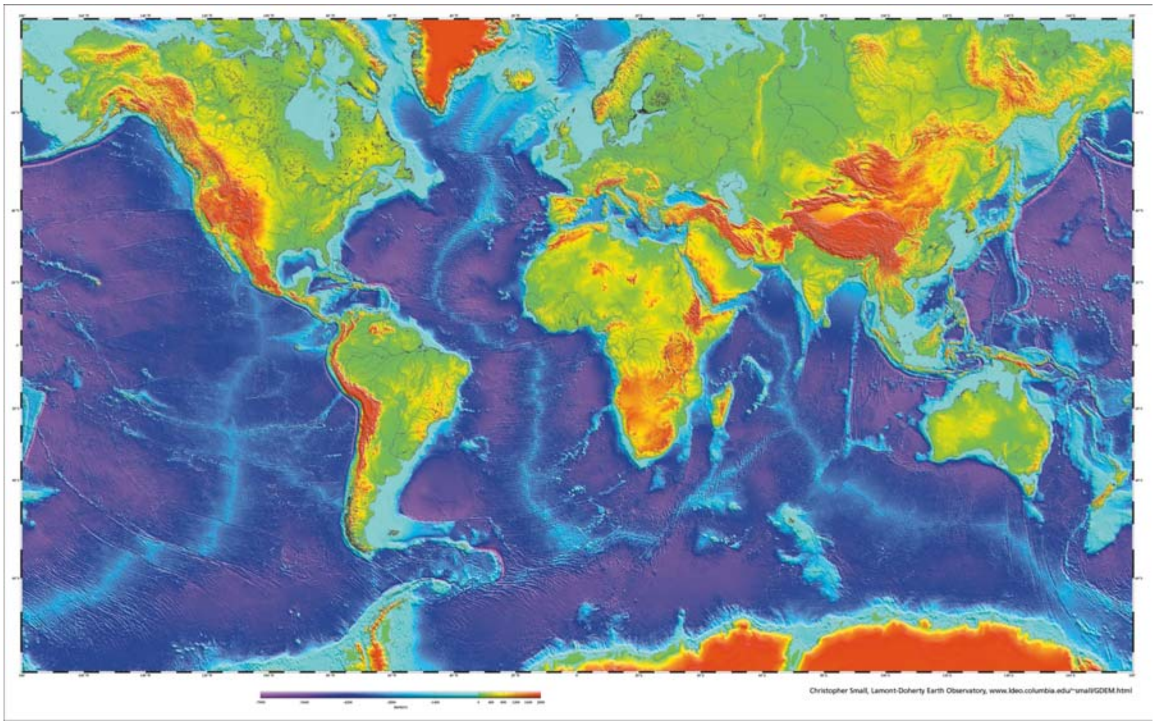
The fate of the shoreline matters because most of us live in coastal counties. More than 155 million people (53%) of the US population now reside in coastal counties, and this number is expected to grow to 168 million over the next decade. More than 3 trillion dollars are currently invested in dwellings, resorts, infrastructure, and other real estate along the Atlantic and Gulf Coasts of the United States. The acceleration in sea-level rise that has been projected for the next century puts much of this coastal property in jeopardy. The Heinz Center (*Evaluation of erosion hazards*, Washington: The H. John Heinz III Center for Science, Economics, and the Environment, pp. 111-182, 2000) has predicted that in 60 years one house in four within 500 feet of the shoreline will be destroyed as a result of coastal erosion.

Farther offshore lies the *continental shelf*. This shelf is where the water deepens to typically a few hundred meters, but it varies in width depending on tectonic setting. Here, there are important chemical exchanges with the ocean through the seeping of fresh groundwater and also from the seeping of methane gas and petroleum. In nearshore regions, groundwater discharge can be a significant supplier of nutrients to the seafloor. Methane seeps can provide habitats for chemosynthetic communities that form the basis for complex ecosystems. They are also a potential source of energy as the methane freezes, forming solid gas hydrate in mounds on the seafloor. Off South Carolina, the Blake Ridge, is estimated to contain --in an area about the size of Massachusetts--1,000 trillion standard cubic feet of methane in the form of hydrates. This is a huge energy resource, about six times the total proven U.S. reserves of conventional gas. (*American Scientist,* May-June 2001, p 246.)

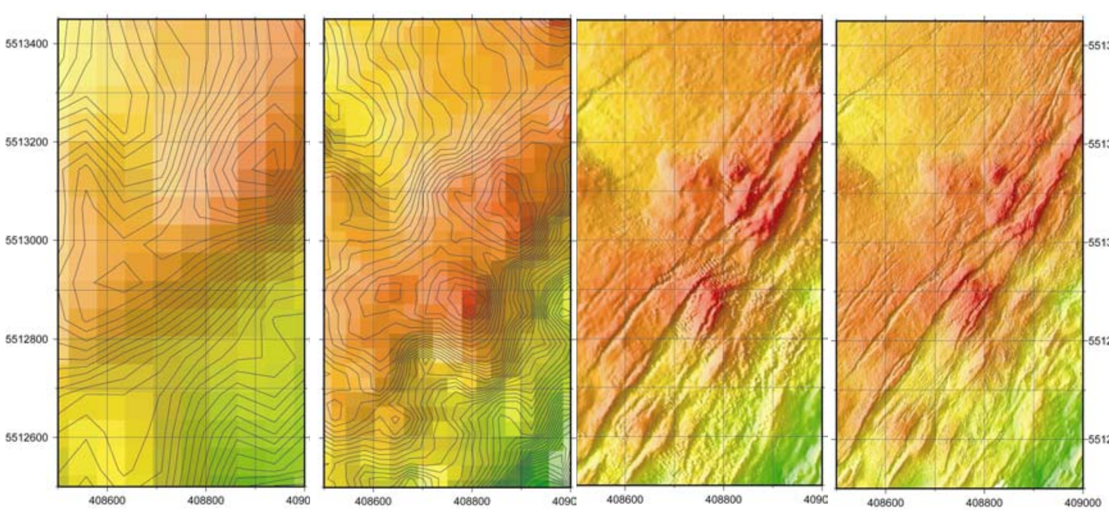


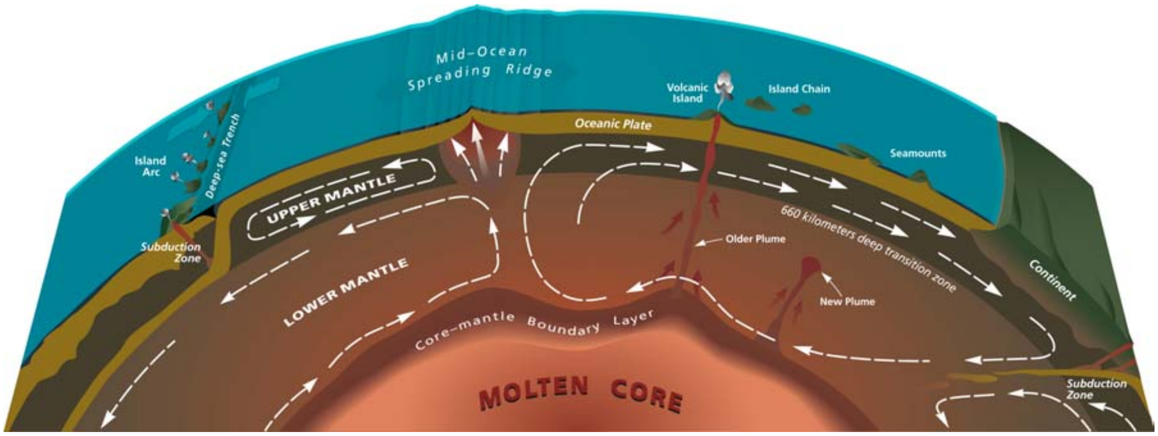
A cartoon showing the key processes occurring at methane seeps on the continental shelf. ***(Illustration from Oceanus Magazine, Woods Hole Oceanographic Institution)***

Methane seeps can also destabilize the edge of the continental shelf, and there are some researchers who postulate that a large slump of sediments off the US continental shelf could cause an east coast tsunami (Driscoll N. et al., *Potential for large-scale submarine slope failure and tsunami generation along the U.S. Mid-Atlantic coast*, *Geology*, 28, 407, 2000).



Probably the best map we have of the deep ocean comes, paradoxically, from space – being derived mainly from satellite gravity measurements *(Map: Chris Small, using data from Smith & Sandwell, Global Seafloor Topography from satellite altimetry and ship depth soundings, Science, 1997)*. This map has limited resolution, but gives a good overview of the regional scale features on the seafloor. The sequence of maps below show the level of increasing detail that is available from more sophisticated devices *(Figures: Maurice Tivey, Woods Hole Oceanographic Institution)*. Each panel shows the same ~900m by 500m area imaged with a different acoustic device. The resolution of the panels improves from about 50m on the left to about 1m on the far right. For reference, same area plotted from the satellite data would contain a single color value.

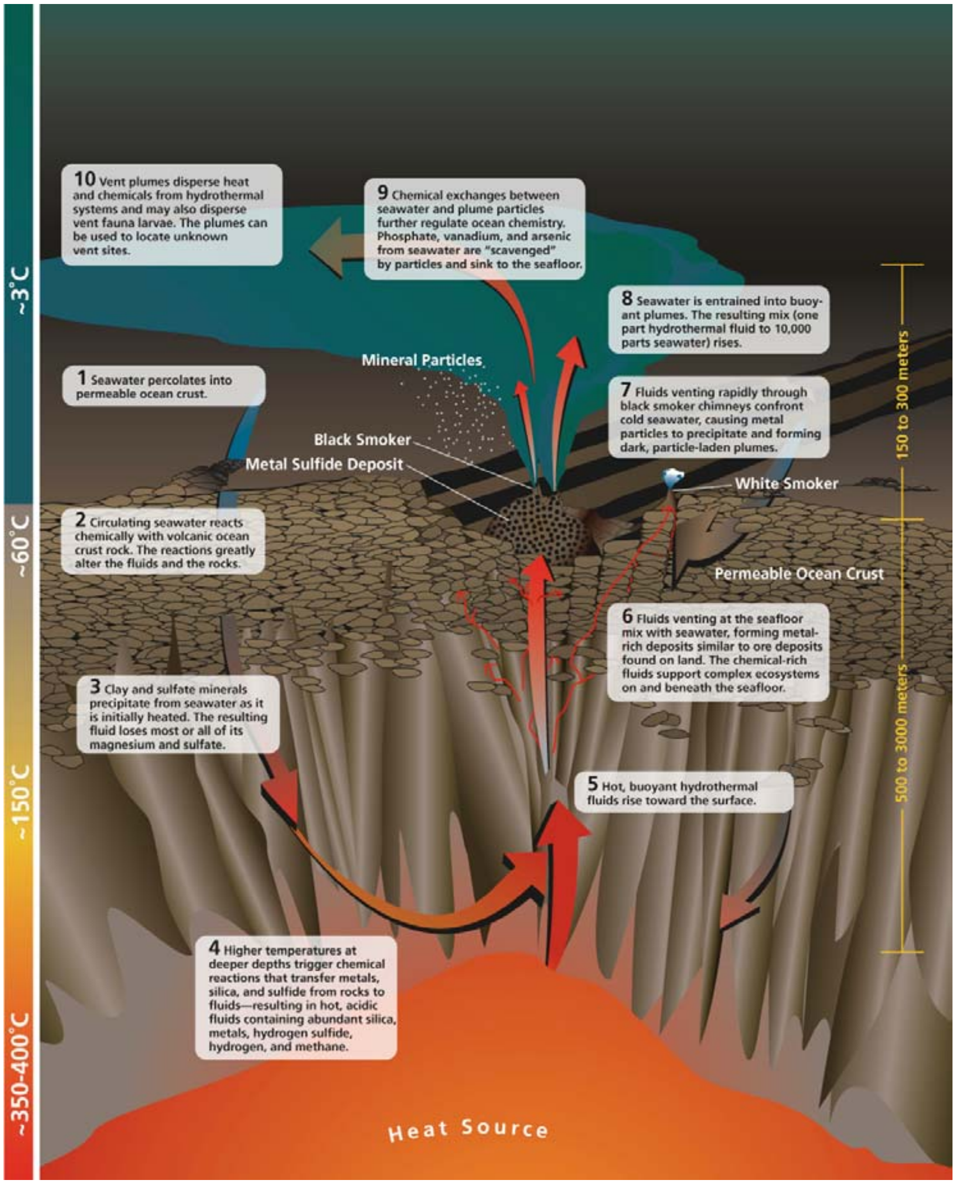




A cartoon showing the basic processes of plate tectonics and the flow patterns in the underlying mantle of the Earth. ***(Illustration from Oceanus Magazine, Woods Hole Oceanographic Institution)***

The most dynamic and well-known seafloor system is the 60,000km-long, global network of mid-ocean ridges. They comprise the largest mountain range on Earth, forming where the oceanic plates are created and then separate. These ridges account for about 80% of Earth's volcanism. They produce enough magma (or molten lava) to completely resurface the planet in less than 100 million years (I warned that some of the processes sound long term, but really that is much less than a week in geological terms). Rates of spreading at the ridges vary, but are comparable to the rate of growth of human hair. However, unlike hair growth, the spreading is not uniform, and takes place through episodic eruptions. The key exchanges between the seafloor and the ocean in these settings involve the transfer of heat and chemicals. Nearly 75% of the earth's internal heat is lost through the seafloor, and about 10% of that is lost at ridges by hydrothermal venting—either at high temperature "black-smokers" or through lower temperature diffuse flow through cracks in the seafloor. The energy for this venting comes from the magma that erupts at the seafloor and is itself transported from deep within the earth. One of the reasons Iceland is the largest producer of geothermal energy is that it straddles the mid-Atlantic ridge, where magma lies near the Earth's surface.

The plumes of hot water that rise from vents can act as a conveyor belt for larval dispersal, allowing animals to migrate from one hot-spot to another. In addition to heat, the vent fluids also carry chemicals with them, some of which provide food for microbes and others which precipitate on the seafloor as large sulfide mounds bearing gold and other economic minerals.



At mid-ocean ridges, the presence of hot magma at shallow depths results in the heating of seawater which penetrates the seafloor. Often this can result in spectacular high temperature vents, or "black smokers" which release fluids at temperatures in excess of 300°C into the ocean. ***(Illustration from Oceanus Magazine, Woods Hole Oceanographic Institution)***

Seamounts and ocean islands are ubiquitous and are also the result of volcanism. There are two types: those that are formed by a "mantle plume'' a hot plug of magma that rises from deep within the Earth, and those that form by shallower production of melt through processes that are less well understood. Examples of plume-formed islands are Hawaii, and they can typically form a chain as the plume remains relatively stationary as the oceanic plate drifts above.

Of course, as the plates move apart, they must at some point be consumed and this takes place through the process known as subduction. The recycling of oceanic crust is a complex process: the interaction of the subducting plate with the surrounding material itself produces volcanism and, in some settings, new seafloor. It also frequently triggers earthquakes: the region of Sumatra is in a subduction setting.

To summarize, the interaction between the ocean and the seafloor involves a wide range of processes, from chemical interactions that produce economic minerals and methane gas, to physical interactions that can affect shoreline evolution, to the release of nutrient rich fluids that support unique ocean ecosystems.

I have only touched the surface in describing the seafloor, but I hope I have convinced you that, rather than a sterile desert, it is in fact a rich and dynamic frontier –one that remains largely unexplored, yet one to which all our futures are intimately tied.