Hydrothermal Vents

<https://www.nationalgeographic.org/encyclopedia/ocean-vent/>

An ocean vent sits over a deep fissure in the ocean floor. Ocean vents eject hot, often toxic, fluids and gases into the surrounding seawater. They often mark sites of tectonic activity, and create some of the most hostile habitats on Earth.

Ocean vents are a type of hydrothermal vent. Other types of hydrothermal vents include hot springs, geysers, and fumaroles. As their name indicates, all hydrothermal vents are characterized by water (*hydro*-) and extremely high temperatures *(thermal).*

Tectonic Activity

Ocean vents are the product of tectonic activity beneath the ocean floor. Tectonic activity describes the way tectonic plates, giant slabs of Earth’s lithosphere, interact with each other.

Ocean vents are found in all ocean basins, although they are most abundant around the Pacific Ocean’s “Ring of Fire,” which also includes active earthquake zones, volcanoes, and ocean trenches.

Ocean vents are primarily found around mid-ocean ridges and volcanic arcs. At both mid-ocean ridges and back-arc basins, the molten magmaof Earth's asthenosphere wells up close to the surface.

Mid-ocean ridges form at divergent plate boundaries, where tectonic plates are moving apart from each other. New oceanic crust is formed at mid-ocean ridges. The Mid-Atlantic Ridge, for instance, runs through the entire Atlantic Ocean, separating the North American and Eurasian plates in the north and the South American and African plates in the south. Ocean vents dot the entire underwater mountain range.

Volcanic arcs form at convergent plate boundaries, where a densetectonic plate is falling beneath a less-dense plate in a process called subduction. Oceanic crust is being destroyed in the subduction zones around volcanic arcs. Volcanic arcs may include volcanoes that rise above sea level, such as Japan’s Ryuku Islands, while some volcanic arcs are seamounts, or underwater mountains.

Ocean vents found around volcanic arcs are located on the overriding (less-dense) tectonic plate. This area is called a “back-arc basin.” Back-arc basins are formed as the ocean trench created by subduction migrates “backward” toward the subducting plate in a process called trench rollback. Trench rollback causes the overriding plate to be stretched thin, creating conditions that allow for the formation of ocean vents.

Going with the Flow

The process that creates ocean vents takes place in three zones: the recharge zone, the reaction zone, and the upflow zone.

*Recharge Zone*

Vent fluid in the recharge zone is formed by seawater seeping into cracks in the seafloor. As the seawater is warmed by its proximity to magma, it is stripped of its magnesium.

At this point, seawater changes to an acidic vent fluid. As an acid, the vent fluid leeches more metals from surrounding rocks of the oceanic crust.

*Reaction Zone*

The acidic vent fluid continues to heat up as it flows and seeps toward the vent’s source of heat. The closer magma wells to the fluid, the warmer the fluid becomes and the quicker its chemical reaction time will be.

Chemistry and vent outflow are also influenced by the vent fluid’s residence time, or the time it spends in the region close to the heat source.

*Upflow Zone*

The vent fluid becomes more buoyant in the reaction zone and races back toward the surface. Incoming flows of vent fluid may also push the superheated fluid upward toward the seafloor. Vent fluid has the least amount of time in this upflow zone.

The vent fluid’s temperature drops slightly as it races away from the vent’s heat source. Vent fluid can lose heat in three major ways. First, heat can dissipate into the surrounding rocks. Second, it can mix with cold seawater seeping in from above. Both of these methods involve a transfer of heat (from the vent fluid to either rocks or seawater). This process is called conductive cooling.

The third way a vent fluid can lose heat is through decompression. Unlike the interaction of vent fluid with rocks or seawater, decompression does not involve a transfer of heat. The fluid cools through a loss of pressure. (Pressure is higher in the reaction zone, which lies deeper in the Earth.) This process is called adiabatic cooling.

*Ejection Sites*

Hydrothermal vents are where the hot, toxic vent fluids from the upflow zone are spewed from oceanic crust into the surrounding seawater. Hydrothermal vents are narrow and well-sealed, and vent fluids exit at high velocity.

Upon contact with the cold, dense ocean, the vent fluid “precipitates” minerals such as sulfates, sulfides, and quartz. These minerals often give ocean vents their characteristic color.

Not all vent fluids are violently ejected into seawater from hydrothermal vents, however. Diffuse flows form in areas where vent fluids mix with cold seawater before exiting the seafloor.

Diffuse flows usually cover a larger portion of a vent field than narrow hydrothermal vents. Vent fluids exiting through diffuse flows are usually cooler, less toxic (from mixing with seawater), and exit into the ocean more slowly over a larger area. Diffuse flows also lack the telltale “smoke” of gushing hydrothermal vents.

*Plumes*

As vent fluid is ejected into the ocean, it forms a hydrothermal plume. This plume is more buoyant than seawater, and continues to rise.

As it rises and expands, the plume constantly mixes with seawater and its chemistry is diluted. Eventually, the plume reaches neutral buoyancy (the point where the pressure inside the plume equals the pressure of the surrounding seawater, and the plume no longer rises or sinks). At neutral buoyancy, the plume and its chemistry are entirely dispersed by ocean currents.

Vent Chemistry

The chemistry of ocean vents has an enormous impact on the chemistry of the ocean. At mid-ocean ridges, ocean vents help cool new oceanic crust. At volcanic arcs, they contribute to the geology of the seafloor and even underwater mountains.

Temperatures at vent fields range from below 50° Celsius (122° Fahrenheit) to more than 400° Celsius (752° Fahrenheit). Some ocean vents are rich in oxygen and oxygen compounds (such as sulfates), while others are anoxic. Some are highly acidic, with a pH as low as 2. Others have a pH as high as 8.

The temperature and chemistry of vent fields varies across the ocean, and these factors are influenced by such features as the frequency of volcanic eruptions in the area, the presence and quantity of sediments, the permeability of the seafloor, the composition of rocks in the oceanic crust, the depth of the heat source, the residence time of vent fluids in the reaction zone, and the water-to-rock ratio at the reaction zone.

*Temperature*

Ocean vents help cool the Earth’s interior. In fact, oceanographers and geologists estimate that ocean vents account for a whopping 10% of total heat loss from Earth’s mantle and core.

The temperature of vent fluid is always warmer than the surrounding seawater. Seawater at the deepest ocean vents is just above freezing at 2° Celsius (35° Fahrenheit). Energy from the Earth’s superheated mantle and core can heat vent fluid to temperatures of more than to 400° Celsius (752° Fahrenheit). Around diffuse flows, the temperature of vent fluids is usually below 50° Celsius (122° Fahrenheit).

The temperature of a vent fluid, and the temperature difference between the vent fluid and surrounding seawater, can determine the chemistry of a vent.

For instance, most hydrothermal vents eject vent fluids that would boilat ambient temperatures at sea level. However, at great depths and great temperatures, phase separation (the separation of a liquid into two distinct liquids) prevents vent fluids from boiling. Instead, the chemical reaction between seawater and vent fluid forms a high-salinity brine. This chemical reaction is called brine condensation.

*Chemicals*

The most characteristic feature of ocean vents is probably the dense particle plumes that inject chemicals into seawater. Vent fluids most often include sulfides and sulfates. Sulfides are negatively charged ions of the mineral sulfur, while sulfates are negatively charged ions of sulfur-oxygen molecules.

Sulfides and sulfates exist in a dazzling array at ocean vents: calcium sulfate, strontium sulfate, zinc sulfide, iron sulfide, copper sulfide, iron sulfide, manganese sulfide. These compounds interact with other elements, including hydrogen, helium, potassium, gold, silver, and cadmium. Perhaps most crucially, vent fluids interact with sodium and chloride, forming salt.

As ocean vents eject mineral-rich fluids into the ocean, many of these minerals precipitate, or solidify. Tall, thin vent chimneys are made of these precipitated minerals, including copper, iron, zinc, cadmium, silver, and even gold.

As long as they continue to eject fluid, the chimneys continue to grow. Some chimneys can grow 30 centimeters (almost 12 inches) a day and reach 20 meters (65 feet) tall. Tall chimneys don’t last long, though. The mineral structure is fragile. Powerful undersea currents and pressure often lead to their collapse.

Types of Ocean Vents

Ocean vents can be classified as black smokers, white smokers, or snowblowers. All these ocean vents form in the same way. Their differences are marked by color, temperature, and chemistry.

Black smokers are the largest type of ocean vent, and eject the hottest fluids. Vent fluids spew out of tall chimneys at rates of up to 5 meters per second (16 feet per second). The “smoke” blown from black smokers is a dense cloud of particles, mostly metals such as iron and copper. The metals in the fluid mix with the oxygen in the seawater to form a black cloud.

White smokers generally develop over cooler vents. White smoker fluid is generally more acidic, and chimneys have much higher ratios of minerals such as zinc, cadmium, silver, and gold.

Snowblower vents develop around low-temperature diffuse flows, often around lava from underwater volcanoes. Snowblowers earn their nickname by ejecting columns of white, fluffy particles.

Unlike the particle plumes of black and white smokers, snowblower particles are not minerals. The ejecta from snowblower vents are made up of billions of tiny, organic microbes. The heat and minerals present in lava interact with seafloor communities of bacteria and archaea, producing flocculent microbial blooms.

Ocean Vent Communities

Many unique organisms are adapted to life in the harsh environmentof an ocean vent. In fact, ocean vents set the current highest temperature possible for life to exist—a fiery 121° Celsius (250° Fahrenheit), found on the Endeavor hydrothermal vents on the Juan de Fuca ridge off the coast of Vancouver, British Columbia, Canada.

The producers in ocean vent food webs are extremophiles. Extremophiles thrive in chemically extreme conditions that usually discourage life on Earth. Most food webs on Earth, for instance, rely on the sun. Producers near Earth’s sunlit surface (such as green plants and phytoplankton) use sunlight, water, and carbon dioxide to manufacture simple sugars and oxygen in a process called photosynthesis.

Organisms near an ocean vent do not always have access to sunlight. These organisms depend on a process called chemosynthesis. In chemosynthesis, microbes convert vent fluids such as hydrogen sulfide into energy (simple sugars), water, and sulfur. Sulfur is naturally a yellow, and many bacterial mats have a characteristic golden color as a result.

These specialized microbes (mostly bacteria and archaea, single-celled organisms similar to bacteria) live everywhere in the vent community. They live on the vent floor. They live inside chimneys. They even live inside animals like tube worms and mussels. These microbes are the basis of food webs in the ocean vent ecosystem. Tube worms, mussels, and clams use the microbes to produce nutrients. Plankton and shrimp eat the microbes. In turn, predators like crabs, fish, jellies, and octopuses prey on these animals.

The deep ocean is often so dark that many creatures do not have functioning eyes. Their bodies are often gelatinous and lightweight, to offset the crushing pressure of the deep.

Ocean vents provide an “oasis” of biological activity on the ocean floor, which is often dominated by abyssal plains. For this reason, ocean vents have one of the highest rates of biomass of any habitat on Earth. Busy, clustered communities of organisms thrive around the vents, while hardy bacterial mats stretch out meters wider.

Exploring Ocean Vents

In 1977, oceanographers, led by National Geographic Explorer-in-Residence Robert Ballard, were exploring the Galápagos Rift along the mid-ocean ridge in the eastern Pacific.

The scientists noticed a series of temperature spikes in their data. They wondered how deep-ocean temperatures could change so drastically over such a short distance—from near-freezing to 400°C (750 °F). Ballard and his crew quickly sent cameras to the seafloor to investigatethe anomaly.

What they discovered, of course, were ocean vents. Fascinated by these undersea features, oceanographers used a submersible to study the vents themselves. They were even more fascinated to discover a diverse, thriving community of living organisms. Until this point, all life on Earth was considered to be dependent on sunlight.

Today, oceanographers use an array of instruments to study ocean vents. Bathymetric maps of the seafloor and interactive maps of ocean currents help them identify hydrothermal plumes rising through the ocean. Plumes may be identified through their temperature, chemical structure, and even their color.

One of the innovative ways to identify and study ocean vents is the “tow-yo.” A tow-yo is attached to a research vessel and a collection of sophisticated instruments (called a conductivity-temperature-depth package). The tow-yo raises and lowers the instruments—just like a yo-yo—within a few hundred meters of the water column. This allows oceanographers to determine the shape of the plume and help pinpoint the vent field from which it came.

Once a vent field is located, oceanographers use both ROVs and manned vehicles to study ocean vents up-close and personal. In fact *Alvin*, the sub originally used by Ballard and his team in the 1970s, is still one of the most effective ways scientists investigate the geological, chemical, and biological characteristics of ocean vents. Most vents are far too deep—under far too much pressure, with far too many toxic fluids penetrating the water—to allow study by divers.

These manned and unmanned vehicles collect samples—of the seafloor itself, chimneys, bacteria, and even fish.

Benefits of Ocean Vents

Ocean vents are one of the primary determinants of ocean chemistry. (Other major contributors include runoff from rivers and atmospheric changes in the air.)

The ocean’s salinity, for example, was not fully understood until ocean vents were discovered in the 1970s. Prior to the discovery, most oceanographers suspected the ocean was salty due to sediments deposited by rivers and streams. Today, we know the ocean is salty because ocean vents eject chemicals directly in the water column.

While ocean vents help explain how chemicals such as salt are added to seawater, they can also help explain how chemicals are taken out. For decades, for example, oceanographers could not explain how the concentration of magnesium in the ocean remained constant. Magnesium was being added to seawater from terrestrial sources, but the chemistry of the ocean remained the same. The discovery of ocean vents solved the mystery: Volcanic rocks in the recharge and reaction zones extract magnesium from seawater. The water coming out of the vents has virtually no magnesium in it.

While ocean vents contribute to the ocean’s chemistry, their profound heat only slightly influences ocean temperatures. The reason is that while vent fluids are super-hot, they are super-cooled by the tons of cold water surrounding them. In fact, beyond a meter (3 feet) of a vent, the water is back to a near-freezing 1.7° Celsius (35° Fahrenheit).

*Industrial Applications*

The unusual properties of ocean vents may influence concepts developed by chemical and industrial engineers in a process called biomimicry. Biomimicry is the process of using the natural world as a guide to develop new technologies.

Chemosynthetic bacteria, for instance, may influence the way pharmaceutical companies develop antibiotics and enzymes that combat diseases or injuries.

Chemosynthetic bacteria, which convert toxic chemicals to harmless substances, may also provide resources to help clean up hazardous waste or toxic spills in the ocean.

Finally, biomimicry may guide engineers to develop ways for machinery to better withstand heat, toxicity, or intense pressure.

*Mining*

Ocean vents are surrounded by seafloor massive sulfide (SMS) deposits. SMS deposits are minerals that harden as vent fluid interacts with seawater.

SMS deposits can be material left over from collapsed chimneys or even chimneys themselves. They contain metals such as copper, iron, zinc, lead, silver, and gold. These metals are valuable for human industry and can be sold for high prices.

Mining companies have studied ways to extract SMS deposits from the deep ocean. Seafloor mining is a complicated and expensiveprocedure. The environmental impact is enormous. Microbes and animals are destroyed or displaced as the seafloor is disrupted.

The waters surrounding Papua New Guinea in the South Pacific are rich in SMS deposits. The world’s first major SMS mining operation is expected to begin extraction in this area by 2017.



Ocean vents bubble with carbon dioxide, the same gas that carbonates soda—in addition to some nastier stuff, such as hydrogen sulfide.

Photograph courtesy Pacific Ring of Fire 2004 Expedition. NOAA Office of Ocean Exploration; Dr. Bob Embley, NOAA PMEL, Chief Scientist. (CC BY 2.0)