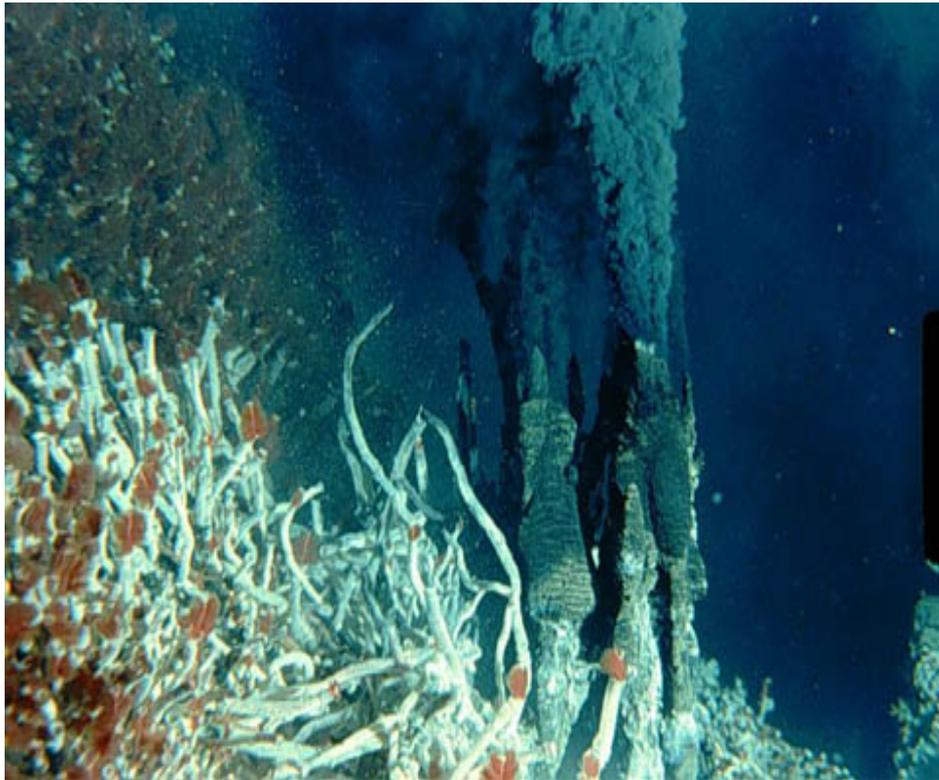


# The strange ecosystem of hydrothermal vents

Nation Taiwan Ocean University

Department of Marine Biology



Professor: Jiang-Shou Hwang, Ph. D

Submitted by: Isani Chan

## **Deep sea and shallow Hydrothermal Vents**

In 1977, the citing discovery of hydrothermal vents was made by the scientists diving in *Alvin* to the Galapagos spreading center in the eastern Pacific off Equator, who were greeted at a depth of about 2.5 km by a spectacular sight of clouds of what looked like black smoke gushing out from tall chimneys on deep ocean floor ('black smoker'). More exciting however, was the totally unexpected discovery of a lush community of exotic and unusual sea life – giant tube worms, huge clams, mussels etc thriving around the hot springs, which changed our understanding of planet Earth and life on it. The waters around the deep ocean hydrothermal vents as hot as 3800C are home to a unique ecosystem. The organisms that are common to vents include various forms of microbes – bacteria and archaea, and macrofauna – mussels, crabs, shrimps, worms, anemones, fish, octopus, snails, limpets and so on. H<sub>2</sub>S-oxidising bacteria, which live symbiotically with larger fauna, form the base of the ecosystem's food chain. The energy source that sustains this deep ocean ecosystem is not sunlight, but energy from chemical reactions (chemosynthesis). Hydrothermal fluids coming out from vents contain H<sub>2</sub>S – an element lethal to most organisms. But vent microbes not only survive it, but depend on it for the survival of the entire ecosystem. The vent microbes get energy by breaking down H<sub>2</sub>S and they use this energy and oxygen to convert CO<sub>2</sub> to sugars.

Vent fauna live at extreme conditions of no sunlight, tremendous pressure (300 atm), very high temperature (highest measured vent temperature is 4030C) and very acidic vent waters (pH as low as 2.8). Discovery of vent ecosystem altered our assumption that all ecosystems are dependent on sunlight and photosynthesis. The fact that life can exist without sunlight means possibility of finding life on other planets. Biomass as well as diversity of species in vent ecosystem is as high as that of a rain forest and life forms are both bizarre and ancient. Most vent fauna are new to science, and many of them are found nowhere else, and cannot exist outside vent conditions.

Giant tube worms are one of the most amazing animals that live in vent ecosystem. They grow up to 3 m long and 10 cm in diameter and more than 33 inches per year, making them the fastest growing marine invertebrate. They have a head, collar, trunk, and anchor, but no mouth, eyes or gut. Tubeworms contain a unique form of haemoglobin that transports both H<sub>2</sub>S (absorbed by

the worm's plumes from vent fluid) and O<sub>2</sub> (absorbed from cold water) to endosymbiont bacteria. Billions of bacteria living inside the tubeworm produce sugars from CO<sub>2</sub>, H<sub>2</sub>S and O<sub>2</sub>.

Pompeii worm (*Alvinella pompejana*) – an organism that has only been found in hydrothermal vents, living close to the vent than any other species, ranks as the most heat-tolerant among higher order life forms. The worm resides in tubes. When in tube, the worm's tail end basks in water as hot as 800C, while its head rests in water that is much cooler, about 200C. The grey fleece or 'hairs' on the worm's back are actually bacteria, which act as protective thermal blanket for the worm and also detoxify the lethal toxic chemicals.

The first creatures to appear at a vent are bacteria that come up with the hydrothermal fluids, sometimes so densely that the vent looks like a 'snow blower'. The 1991 discovery of snow blower vents blasting white bacterial matter into the ocean opened up another previously unimagined possibility – the existence of a sub-sea floor microbial biosphere, which may be as large as the biosphere on earth surface. By studying microbes in hydrothermal vents, scientists learn how life may develop and survive in extreme environments on earth and other planets. Many scientists believe that hydrothermal vents are the cradle, where life originated 3.5-3.8 Ma ago.

Vent organisms have wide industrial and medical applications. They may be useful to combat industrial pollution (H<sub>2</sub>S) and cleanup sites contaminated with Cu, Cd, Hg etc. They may help in development and manufacture of new heat resistant industrial chemicals and new drugs to combat germs now resistant to now plant and soil based drugs. Methanogenic (methane-producing) archaea could provide a renewable source of natural gas. Giant tube worms may help us understand and combat deadly human iron deficiencies. Extremozymes – enzymes produced by heat loving extremophiles like vent microbes have great potential in biotechnology. Proteins and enzymes of ultrathermophilic archaea in hot vent waters have unusually high thermal stabilities and hence, such enzymes are expected to have longer shelf life, produce less waste, and have lower risk of contamination. They will also permit reactions to run hotter, faster and purer, and will be biodegradable. Extremozymes may thus help (i) make dry oil wells productive by thinning oil now too thick for extraction (ii) convert corn starch to sugar (iii) allow anaerobic bioremediation (iv) production of a biocomputer chip and (v) a host of other industrial processes by speeding up biological and chemical reactions.

Vent bacteria possess special proteins - eurythermal enzymes that function effectively in a wide range of temperatures. They find applications in pharmaceutical, textile, paper and detergent industries. They act as catalysts to break down fats, wood etc, as well as DNA and operate in organic solvents. The most commonly used DNA polymerase in PCR (Polymerase Chain Reaction – a technique used to amplify and clone DNA) is Taq DNA polymerase, isolated from *Thermus aquaticus*, a bacteria from hot springs of Yellow Stone National Park. But, for a few PCR applications, the lack of proof reading by Taq DNA polymerase is a problem. DNA polymerase isolated from *Thermococcus littoralis*, a microbe from deep-sea hydrothermal vents have proof reading activity. This DNA polymerase, marketed as ‘Vent DNA polymerase’ has now 30% market share in DNA polymerase sales. The discovery of life in deep sea hydrothermal vents revolutionized ideas about where and how life could exist. But it also raised questions that never entered our minds before: How can so much life thrive at the sunless sea floor? What special features do the organisms have to live at deep sea vents? What else might be living at the sea floor or below it, or in environments in other planets that once we thought were too extreme to support life?

Hot springs on the ocean floor are called hydrothermal vents. The most numerous and spectacular hydrothermal vents are found along world’s mid-ocean ridges. The heat source for these springs is the magma (molten rock) beneath the volcanic ridge system. Geothermal activity beneath 2000 to 5000 meters of seawater is markedly different than on land because of the high pressure at the bottom of the ocean. As seawater descends into the region of partly molten rock beneath the mid-ocean ridge, it heats up to 300-400°C and becomes extremely corrosive. This hot fluid is capable of dissolving the surrounding basaltic rock and leaching out metals and other elements. This 300-400°C fluid is also very buoyant and begins rising rapidly back to the surface, and eventually reenters the ocean at hydrothermal vents.

The most spectacular kind of hydrothermal vent is called "black smokers", where a steady stream of "smoke" gushes from chimney-like structures. The "smoke" consists of tiny metallic sulfide particles that precipitate out of the hot vent fluid as it mixes with the cold seawater. Plumes from such vents can be traced in the ocean for hundreds of meters upwards and hundreds of kilometers horizontally. The chimneys are made out of sulfide minerals that precipitate out of the vent fluid and can grow 10's of meters high. Many large ore deposits now found on land were formed at

hydrothermal vents millions or even billions of years ago. Black smokers are an example of focused vents, in which almost all the vent fluid comes out of one small pipe.

Sometimes the hot fluids rising from depth are mixed with cold seawater and spread out before they emerge back onto the seafloor. These are called diffuse vents and are usually only a few tens of degrees above the near freezing deep ocean water. Diffuse vent areas have warm water exiting the seafloor over a large area and consequently do not build sulfide chimneys. However, they still contain high levels of hydrogen sulfide and other compounds that specialized microbes can use for energy. This is the basis for an ecosystem that is largely independent of the sun and gives rise to the specialized vent animals such as large tubeworms and clams. The relatively low temperature allows the animals to remain immersed in the nutrient rich water and allows the diffuse vent sites to develop into complex ecosystems. Often chimneys with focused, high-temperature venting are surrounded by areas of diffuse, low-temperature venting.

#### Hydrothermal vents

Deep-sea hydrothermal vents form as a result of volcanic activity on the ocean floor. Water seeps through cracks in the Earth's crust, dissolving metals and minerals as it becomes super-heated from nearby magma. This water - which can reach temperatures of 400°C - eventually rises back through the ocean floor, erupting as a geyser from a hydrothermal vent. The dissolved minerals and metals precipitate on contact with the cold sea water, forming a chimney around the vent.

#### **Oases of Life**

When scientists first discovered these vents in the 1970s, they were amazed to find thriving communities of shrimp, crabs, giant tubeworms, clams, slugs, anemones, and fish. These rare geological features turned out to be oases on the otherwise sparsely inhabited ocean floor, with a biomass equivalent to that of a rainforest. At first glance, the animals inhabiting deep-sea hydrothermal vents may not seem so dissimilar to other deep-sea creatures. But in fact, they are unlike any other life on Earth.

Instead of sunlight, vent life relies on hydrogen sulfide - more commonly known as rotten egg gas and toxic to most land-based life. In a process called chemosynthesis, specialized bacteria

create energy from the hydrogen sulfide present in the mineral-rich water pouring out of the vents. These bacteria form the bottom level of the food chain in these ecosystems, upon which all other vent animals are dependent. The reliance on chemosynthesis instead of photosynthesis is not the only unique feature of vent life. Vent microorganisms can survive temperatures of up to 113°C, the highest temperature recorded at which an organism can live. Even complex animals such as tube worms can live at 80°C, much higher than any other animal. Apart from hydrogen sulfide, vent water also contains poisonous heavy metals and is more acidic than vinegar. Biologists still don't know exactly how vent animals survive in these conditions.

### **Unique Biodiversity**

More than 300 species have so far been identified in deep-sea hydrothermal vent ecosystems, of which over 95% are new to science. Many are restricted to a particular vent field, making each ecosystem unique. On average, a new vent species has been discovered every 10 days since vent ecosystems were first discovered in 1977. Amazingly, vent life has changed little over time. A whole new domain of life was discovered in vent ecosystems - Archaea, an ancient form of life most closely related to the first life on Earth. Other vent life also appears to be more closely related to ancient animals than to animals living closer to the ocean's surface. Indeed, vent animals on opposite sites of the globe are more closely related to each other than to those living outside the vent ecosystem, just a few metres away. Some researchers have speculated that life began in extreme environments similar to hydrothermal vents. Others have even suggested that if these environments exist on other planets, then life might very well exist there too.

### **Cold seeps**

Chemicals don't only spew out of scalding-hot hydrothermal vents: they also seep from the Earth's crusts at some locations, at the same temperature as the surrounding seawater. Since the discovery of vent ecosystems dependent on hydrogen sulfide, scientists have found similar communities living around these so-called 'cold seeps'. Others have also been found that rely on methane instead of hydrogen sulfide. Some of these are around bizarre deep-sea lakes called 'brine pools': depressions in the sea floor filled with water that has a much higher concentration of salt than the surrounding water. And recently a tube worm community was found living on

solid methane hydrate on the ocean floor. Apart from temperature and the chemical used for energy, a major difference between vent and cold seep ecosystems is the rate of growth. Vent creatures generally grow fast - giant vent tube worms are one of the fastest-growing animals on Earth. They need to be: hydrothermal vents generally only exist for a few decades. However, their cold seep cousins grow much more slowly. Seep tube worms, for example, are thought to live for up to 250 years. The deepest cold seep ecosystem discovered so far is located in the Sea of Japan at a depth of 5,000 to 6,500m. Other cold seeps and 'chemosynthetic biological communities' have been found in the Gulf of Mexico, the Monterey Canyon off the coast of California, US, and off the coast of Alaska, US.

Hydrothermal vents are found on tectonic plate boundaries, most commonly mid-ocean ridges. Mid-ocean ridges are areas where two tectonic plates are moving away from each other and new crust is being formed. Magma is exposed to the sea water and is cooled which created the new crust. They can also be found in Subduction zones and hot spots. A subduction zone occurs when two tectonic plates collide together and one plate falls beneath the other. The plate that subdues is heated up by the magma beneath it and creates volcanic activity. A hot spot is an area of the ocean that has volcanic activity but is not at a plate boundary. At a hot spot, a tectonic plate glides over an area that is extremely hot and creates a volcano. As the plate continues to pass over the hot spot it creates more volcanoes. The Hawaiian Islands is an example of a hot spot. Hydrothermal vents are present at depth of between 7,000-8,000 feet.

As the tectonic plate activities occurs water seeps into little cracks and crevices in the crust. As the water passes through the crust and is exposed to the magma it collects many different minerals and metals. The water is then heated by the magma that is present at the areas. Since warm water is less dense than cold water, the heated water, with its minerals and metals, is shot up out of an opening and into the sea water. The water leaving the vents can reach temperatures of up to 750 degrees F. Though this water does not boil due to the extreme pressure present at this depth. Since the water leaving the vents are much warmer than the ocean water, just above freezing, the water cools very quickly and the metals present in the water settle down around the opening of the vent. As time goes on these metals build up on top of each other and grow. There have been reports of hydrothermal vents being as large as a fifteen story building. If the vents crumple or collapse, they just start back up and rebuild.

There are two different types of hydrothermal vents; Black Smokers, and White Smokers. The black smoker is the hottest of all the hydrothermal vents. It spews out mainly sulfides and iron. When the warm water hits the cool water the minerals precipitate and it creates the black smoke effect. The white smoker typically has cooler water than that of the black smoker and is generally smaller in size as well. The minerals in the white do not contain metals which prevent it from having the black smoke effect. The structure in which the hot fluid flows out of is called a chimney. These chimneys can reach up to tens of meters tall. They are made of dissolved minerals and metals that are present in the water leaving the vents such as sulfur, copper, zinc, and iron. These structures will continue to grow as long as water containing the minerals flow out of it. Scientists have observed some chimneys that grow at around thirty centimeters a day. The chimney is very fragile and can collapse if it grows too high.

The ecosystem in which hydrothermal vents are present has such extreme conditions that it is a wonder there is life there at all. At depths of between 7,000-8,000 feet below the surface of the water pressure can reach 300 atmospheres. The temperature of the water in these areas can range from 403 degrees Celsius where water leaves the vents to 2 degrees Celsius away from the vents. The water has extremely high levels of hydrogen sulfide which are toxic to most living organisms. The water leaving the vents is also very acidic. The pH in hydrothermal vent communities can be as low as 2.8 which are unhealthy for most living organisms. The majority of living organisms need sunlight to live. Through photosynthesis plants transform sunlight into energy and use it as food. But at such great depths there is no sunlight available to the organisms in a vent community. They use a process called chemosynthesis. Chemosynthesis is the process of converting inorganic material into food using chemical energy. Bacteria that are present in a vent community go through chemosynthesis to create the base of the food web in the hydrothermal community.

With such extreme conditions it is a wonder as to how any life form can exist around hydrothermal vents. Hydrothermal vent community makes way for organisms that seem almost alien and cannot be seen anywhere else. Creatures such as crab, fish, tube worms, shrimp, and chemosynthetic bacteria have a way of surviving the extreme conditions. These creatures will feed off of the chemosynthetic bacteria or feed off of the creatures that eat the bacteria. Some of the creatures in the community such as the tube worm do not have a mouth or a digestive track or

an anus. The bacteria will give the creature the necessary nutrients through its skin. Because of this, a food web is produced. At the base of the web there are the primary producers including chemoautotrophic sulfur bacteria. Then there are the secondary producers which feed off of the bacteria including, tube worms, clams, mussels, and shrimp. Finally in the web are the predators. These include fish and crabs and they feed off of the creatures that eat the bacteria. So either directly or indirectly each creature in a hydrothermal vent community depends on the bacteria. Some believe that life on the planet started in such a way as it does in a vent community. Conditions on Earth were much different and much harsher than what they are today. So it has been some special bacteria that started life and more and more creature began to evolve.

Processes within a vent community are strange. Some things like the chimneys and tube worms can grow at a very rapid pace. Chimneys can grow centimeters every day and tube worms have been known to grow several meters each year. But, while these may grow at a fast rate when the organisms die, decomposition work slower. On one expedition scientists observed several dead tube worms on the community floor. A year later when the scientists returned to the same site the dead tube worms were relatively unchanged. Scientists are not really sure why this is but they believe it is due to the extreme pressure and the lack of the typical decomposing organisms that are usually present on land and other areas of the sea. A hydrothermal vent community life is unpredictable. It may live for a few years or it may continue to live a long life. Volcanic activity, earthquakes, or the collapsing or a chimney may end the life of a vent community. If one of these events take places it can block the flow of the vent fluid and end the rare relationship between the surrounding and its inhabitants.

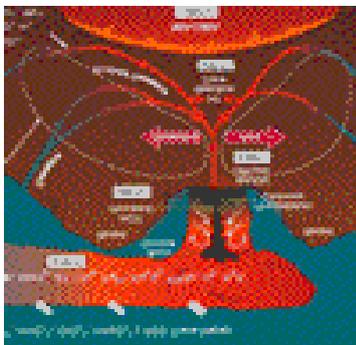
If it were not for the extreme depth of the locations of the hydrothermal vents mining these areas would be very profitable. Copper, magnesium, and even gold can sometimes be found in a vent community. But because it is so hard to reach it would cost more money to mine it than you would make if you did. This does not mean that these vent community cannot serve a purpose to use today. Some of the bacteria extracted from the vents are being used to help break down dangerous hydrogen sulfide waste create by some industries.

There is no doubt that hydrothermal vents are unique and important structures on this planet. In an area where no life should be present a vibrant community exists with creatures that cannot be seen anywhere else on Earth. These communities are so unique and so hard to explore that it was

discovered until 1977. This brings up the question of what else is out there. Some people may say that space is the final frontier and we need to explore it more, but I say why not explore our own planet more. With 71% of the Earth surface underwater there has to be much more that we do not even know about yet. The fact of the matter is hydrothermal vents are a huge step towards the exploration of the deep blue sea.

**Research that could be conducted at a hydrothermal vent site:**

**Chemistry Program:** Plume studies have been conducted on the Juan de Fuca Ridge each year since the inception of the VENTS program.



**Study Areas** – Plume studies have been conducted on the Juan de Fuca Ridge each year since the inception of the VENTS program.

- Plume Chemistry
- Helium
- Vent Fluids
- Hydrothermal Particles
- Geochemistry Studying the effects of hydrothermal venting on the oceans. At the broadest scale, we are studying the circulation of the deep and intermediate waters of the Pacific Ocean.

**Vent Fluid Chemistry** Hydrothermal vents are the interface between the hot, anoxic up flow zone and cold

**Hydrothermal Particle Chemistry** Assess the effects of submarine hydrothermal venting from Juan de Fuca and East Pacific Rise ridge crest systems on the ocean chemistry of the Pacific Ocean.

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