The Abyss and Other Deep Ocean Habitats

Pelagic Zones

Beyond the continental shelf and beneath the well-illuminated epipelagic zone, a twilight region call the mesopelagic zone extends from about 200 to 1,000 meters in depth. The lower portion of this zone is dark and gradually extends to regions of total and perpetual darkness. The zone does not receive enough sunlight to support effective photosynthesis and is referred to as the disphotic or twilight zone. The limited light and subsequent lack of photosynthesis limits the food available to organisms. The environmental parameters are relatively constant in the mesopelagic zone. Water temperature remains about 10ºC with only slightly seasonal changes. Thermoclines, areas of the water column where temperature changes rapidly with changing depth, occur in this zone.

Within this part of the water column nearly 99% of the higher animals are bioluminescent. The bioluminescence allows the organisms to counter illuminate their bodies, find mates, attract prey and avoid predators. Some species of fish, shrimp, and squid hide in this dark zone during the day and migrate to the surface to acquire food at night. This migration pattern allows the organisms to avoid predators. Also, the migration patterns help the ecosystem by transporting energy from the ocean surface to deeper water. Many fishes of this zone have protruding structures on their bodies. They have extremely large cavernous mouths with recurved teeth, which aid in food acquisition. They are great hunters and have well developed musculatures. Many have tubular eyes, which point upward to view prey.

Beneath the mesopelagic zone down to the ocean floor are three layers of water that are homogenous for many of environmental parameters. The water is cold, salinity is constant and no light penetrates. Pressure is the only parameter that changes with continued increases of depth. Food is very scarce and the animals must rely on food sinking from the upper oceanic region. This limited food causes the organisms to be small in size. This region is stratified into the bathypelagic zone (1,000 to 4,000m), the abyssopelagic zone (4,000-6,000m), and the hadopelagic zone (>6,000m).

General Biological Characteristics of Deep Sea Organisms

Reproduction and Development:	
	Few eggs, yolk rich
	Slow gametogensis
	Late reproductive maturity
	Reduced gonadal volume
	Slow embryonic development
	High incidence of direct development
	Breed usually once
Physiology:	
	Low metabolic rate
	Low activity level
	Low enzyme concentration
	High water content
	Low protein content
	Small size
Ecology:	
	Slow, indeterminate growth
	High longevity
	Slow colonization rate
	Low population density
	Low mortality due to low predation pressure

Most of the deep-sea animals have low metabolic rates, an adaptation that suits an ecosystem with a limited food supply. Animals have physiological adaptations

THE ANATOMICAL DIFFERENCES IN MESOPELAGIC AND BATHYPELAGIC FISHES

FEATURE	*MESOPELAGIC SPECIES*	*BATHYPELAGIC SPECIES*
Color	**Many with silvery sides**	**Black**
Photophores	**Numerous and well developed in most species**	**Small or regressed in most; a single luminous lure on the female of most anglerfish**
Jaws	**Relatively short**	**Relatively long**
Eyes	**Fairly large to very large with sensitive pure rod retinas**	**Small or regressed, except in the males of some angler fish**
Olfactory organs	**Moderately developed in both sexes**	**Regressed in females but large in some males**
Central nervous system	**Well developed in all parts**	**Usually weakly developed**
Myotomes	**Well developed**	**Weakly developed**
Skeleton	**Well ossified; including scales**	**Weakly ossified; scales usually absent**
Swim bladder	**Usually present, highly developed**	**Absent or regressed**
Gill system	**Gill filaments numerous, bearing very many lamellae**	**Gill filaments relative few, with a reduced lamellae surface**
Kidneys	**Relatively large, with numerous tubules**	**Relatively small, with few tubules**
Heart	**Large**	**Small**

Source Nybakken, 1993

that prevent upward migration to the epipelagic and mesopelagic zones. They have reduced musculatures and skeletal systems which increase buoyancy but restrict them to deep zones. The fish of the zone exhibit a great reduction in activity when compared to surface water fishes.

Deep-Sea Hydrothermal Vents

Hydrothermal vents were predicted to exist in 1960's as researchers accepted the theory of tectonic plate movement. The plate tectonic theory suggested that hot springs would be located at spreading centers along ridges of the ocean. Geothermal vents have been known by geologist to exist as long as the ocean has existed. It was not until 1977 when John B. Corliss, working along the Mid-oceanic ridge near the Galapagos Islands in the submersible ALVIN, saw the first vent community. Corliss expected to find basalt rock desert. He discovered plumes of heated water emerging from chimney-like structures and a dense community of organisms thriving far from the sunlight (Figure 1). The community was an extensive oceanic "field" of worms, clams, fish, and clumps of floating and mats of bacteria growing on the ocean floor. With the discovery of these vents, a new research age began for oceanographers. Many marine

Figure 1. Black smoker (hydrothermal vent)

scientists became enthralled by these complex ecosystems. Scientists now know that these hydrothermal vents play significant roles in the temperature budget of the ocean, seawater chemistry, and circulation patterns. However, the most exciting aspect of the vent discovery for biologist was that of complex ecosystems based on chemosynthesis, not on photosynthesis. Since the initial discovery of hydrothermal vents in 1977, many vents have been studied and at least 80 are known to exist. The vents are found in areas where seafloor-spreading centers are located. These are regions where tectonic plates diverge (Figure 2).

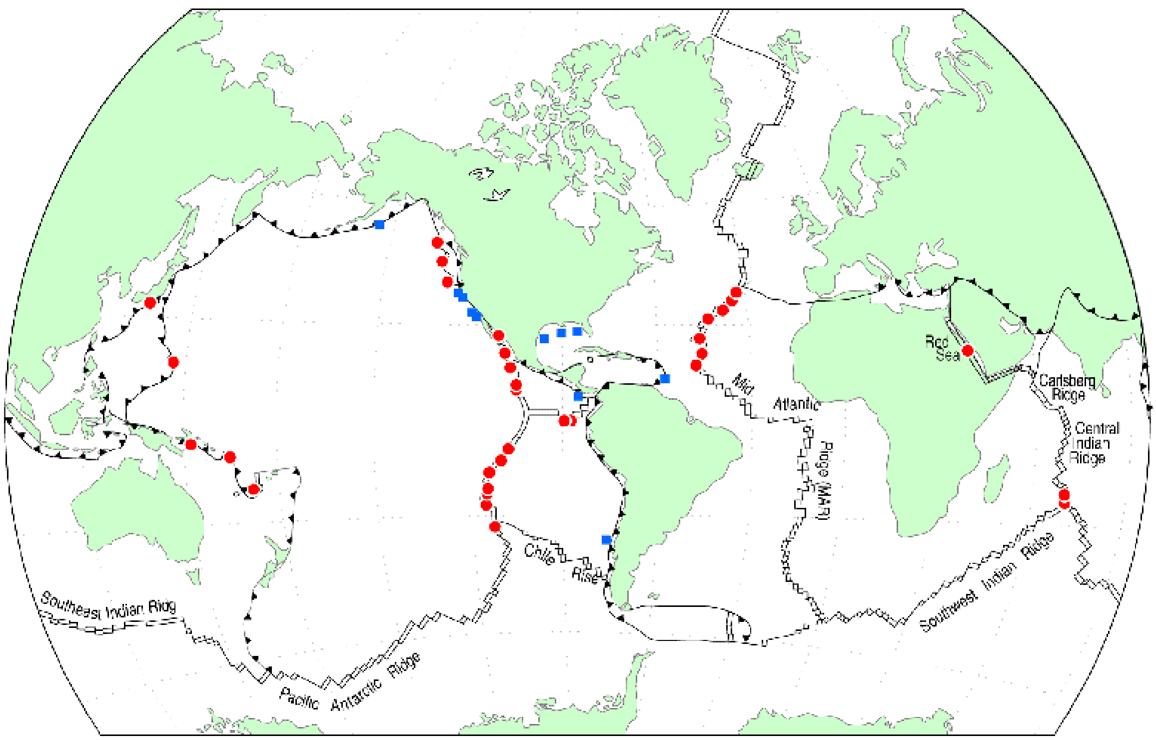


Figure 2. Sites along ocean ridge systems where hydrothermal vents exist.

In these areas cracks and fissures form on the ocean floor. Cold water is able to seeps below the ocean floor where hot magma bodies with temperature that exceed 1,200ºC super heats the seawater. This super heating of water to temperatures greater than 350ºC is possible because some magma bodies are only one kilometer from the sea floor.   Ambient temperature ranges from 60 -

110ºC.   It should be noted that the average depth of vents is about 2,100 meters. Water does not boil even though it is super heated because of the extreme pressure associated with depth. The super heated water dissolves the minerals of the ocean bedrock creating water saturated with inorganic chemicals. The water is rich in a variety of inorganic substances. Remember that as water temperature increases the solubility of water increases.   There are spots where the super saturated; super hot water emerges above the ocean floor surface. As the hot water encounters cooler adjacent water, the dissolved inorganic substances precipitate out of solution (Figure 3). As the solid precipitate settles out of solution, the typical smoke like plume is formed (Figure 1).   With the continuous discharge of super heated water and the mineral precipitation, solid material settles to form the chimney like structures called “smokers” (Figure 3). Some smokers are black, other are white in color. The color variation is dependent on the chemical composition of the vent water. Black smokers are rich in sulfide and iron, which form iron sulfides that are dark in color. The white smokers are rich in barium, silicon, and calcium. Black smokers are hotter than the white smokers. Some researchers have discovered that some chimneys may develop 30 feet in height in only 18 months. One of the tallest vents was approximately 180 feet before it fell and reformed a new vent.

The hydrothermal vent environment is an environment of extremes. Extreme pressure, extreme temperatures, no sunlight, low pH (H_2SO_4) and a variety of toxic substances (H_2S) establish the harsh conditions.   It is important to note that temperatures approaching 100ºC normally would denature proteins and nucleic acids which would kill organisms and cause membranes to be more fluid. Note that most organisms that live in water prefer ph ranges of 6.5 – 8.5. Most seawater has a pH of about 8.2. Vent water is acidic, pH 3-5. The vent water is rich in hydrogen sulfide that is as toxic as cyanide for most organisms.   Even

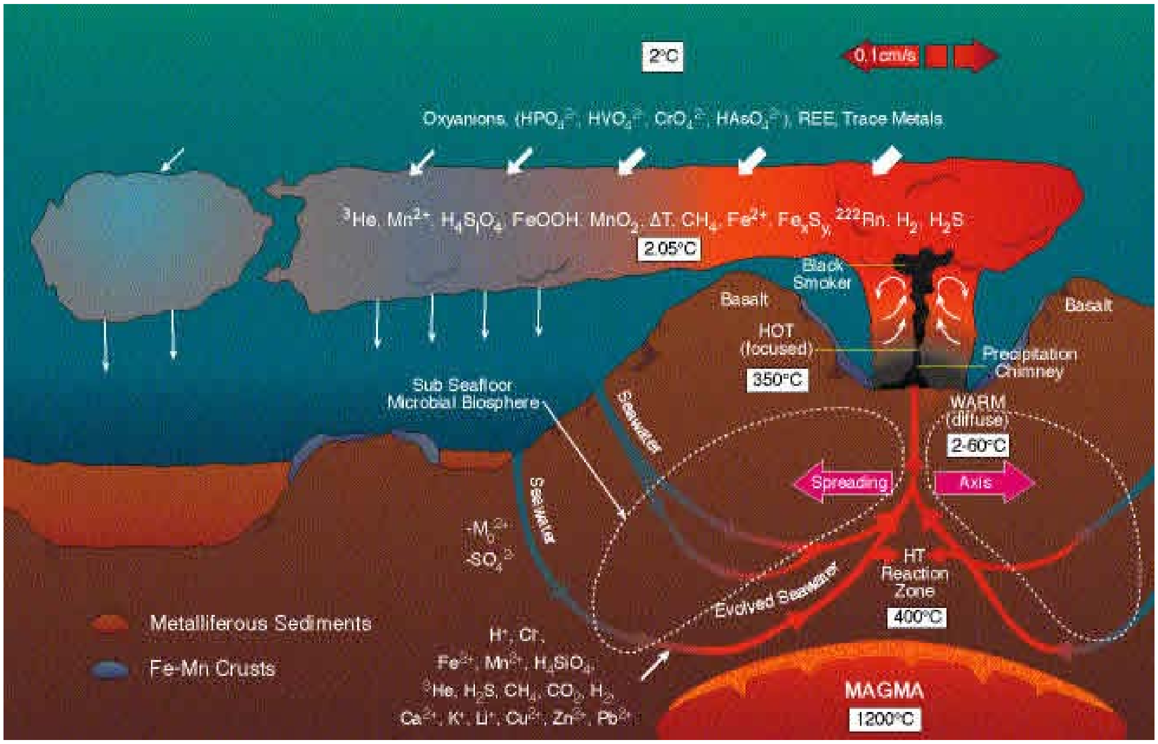


Figure 3. The hydrothermal vent activity.

with these extreme conditions, organisms have adapted and flourish in these areas. They flourish because some of the inorganic chemicals allow certain species of bacteria (prokaryotes) to chemosynthesize. The chemoautotrophic bacteria use inorganic substances to make organic molecules. Therefore, vent communities represent communities of organisms that rely on the production of food by chemoautotrophs, not photoautotrophs. Chemoautotrophs synthesize food, as do plants. The difference is that chemoautotrophs use chemical energy from inorganic compounds to cause the synthesis of organics molecules. It is this production of food that causes the vents to have high biomass that is in stark contrast to the very sparse distribution of animals outside the vent areas.

Chemosynthesis and the Bacteria

As most of you are aware, most of life on Earth is dependent upon the chemical process of photosynthesis. Photosynthesis is the process by which the energy of the sun is trapped in the chemical bonds of organic molecules. The organic molecules serve as the energy resource for the consumers of ecosystems. Nonvascular and vascular plants, some protistans (microalgae), macroalgae, cyanobacteria (blue-green algae) and some species of eubacteria carry out photosynthesis. (Refer to Dr. Cynthia Moncreiff's presentation for the phyla of marine producers.) It is easy to understand why there is great density and diversity of marine organisms in neritic zones and the epipelagic areas of the ocean where photosynthetic organisms exist and support significant communities of consumers. The bottom of the ocean does not provide sunlight for producers. This is why the benthic and deep mesopelagic to hadopelagic communities are sparse. In the hydrothermal vent locations, the chemosynthetic bacteria use inorganic compounds to produce the food that supports dense populations of animals. Chemosynthesis is a process similar to photosynthesis in that CO_2 and H_2O are used to produce glucose and other types of organic molecules. The difference is that light drives photosynthesis and chemical energy released through the oxidation of inorganic molecules drives the chemosynthesis.

SYNTHESIS OF ORGANIC MATTER

$$6CO_2 + 6H_20 + \text{energy} \rightarrow C_6H_{12}O_6 + 6O_2$$

carbon dioxide | water | light or chemical | glucose | oxygen

CHEMOSYNTHETIC ENERGY RELEASE FROM INORGANIC COMPOUNDS

$$\mathbf{H_2S + 2O_2 \rightarrow H_2SO_4 + energy}$$

hydrogen sulfide + oxygen → sulfuric acid + chemical energy

or

metal + oxygen → oxidized metal + chemical energy

NOTE: It is solar energy that is significant for photosynthesis and energy from chemical bonds that is significant for chemosynthesis.

Both prokaryotic and eukaryotic species are known to photosynthesize. Only certain species for procaryotes (bacteria) are known to chemosynthesize. Some achaebacteria and eubacteria are capable of chemosynthesis. Archaea play a significant role in vent communities as both producers and consumers. The Archaea are different from the other procaryotes due to the following:

1.) possess unusual rRNA structure,
2.) use different RNA polymerases,
3.) have a different lipid composition of the plasma membrane,
4.) different mechanism of protein synthesis, and
5.) have an absence of peptidoglycan in cell walls.

The cells may be cocci (round), bacilli (rod shaped) or spiral shaped (Figure 4). They can be Gram negative or Gram positive and vary in size from 0.1 to > 15 μm. They are aerobes, facultative anaerobes, and anaerobes. Some are heterotrophs while others are autotrophs. As a group they are known as the organisms of extreme habitats. They live in hot springs, hydrothermal vents, rumens and intestines of animals, anaerobic sediments and salt lakes. Many species are extreme thermophiles and extreme halophiles.

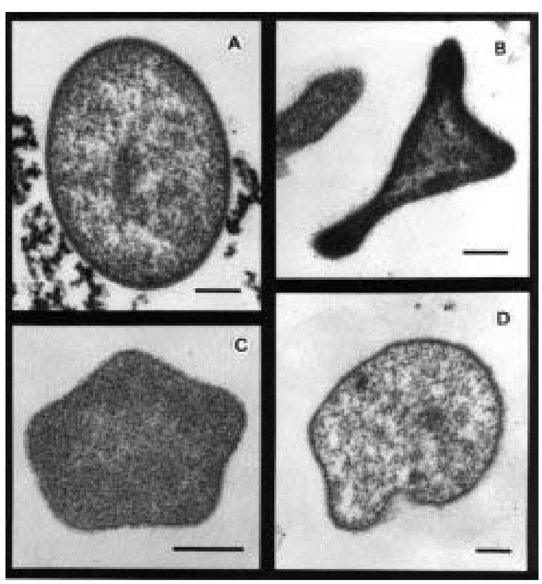


Figure 4. Morphological types of Archaea.

The Archaea have different chemical structure in their cell walls and membranes than do other prokaryotes and eukaryotes. The cell walls do not contain muramic acid or D-amino acids as seen for other prokaryotes. Their membranes are unique by lacking fatty acids. The fatty acids are replaced by branched chain hydrocarbon isoprene. The membrane molecules do have polar and nonpolar regions that allow for a lipid bilayer structure found in membranes. Scientists have suggested that the membrane lipids of the Archaea are probably associated with the survival of these organisms in extreme environments. The branched chains of the hydrocarbons may contribute to greater mechanical strength and chemical resistance of the membranes.

The sulfate reducer *Archaeolobus* is an isolate of hydrothermal vents and is considered unique among the Archaea because it uses sulfate as an electron acceptor for respiration. Two genera of extreme thermophilic archaea are *Thermococcus and Pyrococcus.* These organisms are obligate anaerobes and grow near hydrothermal vents. They are chemoautotrophs and grow by utilizing proteins, starches and other forms of organic matter. *Thermoplasma acidophilum* and *T. volcanium* are wall-less Archaea found in deep-vents area. They are also chemoorganotrophs.

Archaea Groups

GROUP	*GENERA*	*MAJOR CHARACTERISTICS*
Extreme Thermophiles	*Desulfurolobus* *Pyrococcus* *Pyodictium* *Sulfolobus* *Thermococcus* *Thermproteus*	Sulfur metabolizers (most) Obligate thermophiles Acidiphilic or neutrophilic Chemoautotrophic or chemoheterotrophic growth
Cell wall-less	*Thermoplasma*	Obligate thermophiles Obligate acidophiles Facultative anaerobes Chemoorganotrophic growth
Extreme Halophiles	*Halobacterium* *Halococcus* *Haloferax* *Natronobacterium* *Natronococcus*	Aerobic (Some can grow anaerobically in the presence of nitrate.) Chemoheterotrophic growth Need NaCl for growth (at least1.5M) Some alkalophilic (pH>8.5)
Sulfur reducers	*Archaeoglobus*	Strictly anaerobic Autotrophic growth with thiosulfate and H_2 Chemolithotrophic or chemoorganotrophic growth Produce methanopterin and coenzyme F_{420}*
Methanogens	*Methanobacterium* *Methanobrevibacter* *Methanococcus* *Methanolobus* *Methanomicrobium* *Methanosarcina* *Methanospirillum* *Methanothermus*	Strictly anaerobic Chemoautotrophic or chemoheterotrophic growth Methane always the product of metabolism Produce methanopterin and coenzyme F_{420}*

- Methanopterin and coenzyme F_{420} are two chemically found in some Archaea and are found in the species that can generate methane.

Hydrothermal Vent Community

More than 300 species of organisms have been studied from the vent communities. The microbes are the basis for the dramatic biological colonization of the vents. They serve as the producers for these complex ecosystems. Some of the bacteria form thick mats and are fed on by a variety of fish and invertebrate grazers. Others are found in the water column (subsurface bacteria) of the vent plumes and adjacent water and serve the same ecological niche of phytoplankton. Perhaps the most interesting role that the microbes have is as symbionts living in the bodies of worms, clams and other organisms. The host organisms provide the bacteria with the nutrients they need for chemosynthesis (carbon dioxide, water, inorganic chemicals) and the bacteria produce organic molecules needed by the host. Two of the most studied symbiotic relationships are those of the giant clams of the genus *Calyptogena* and the tubeworms of the genus *Riftia* (Figure 4 and Figure 5).   In the tissue of the tubeworm up to 385 billion bacteria per square inch has been observed.

Figure 4. Vent calms are common and are heavily prey upon by other organisms such as these spider crabs.

(below).

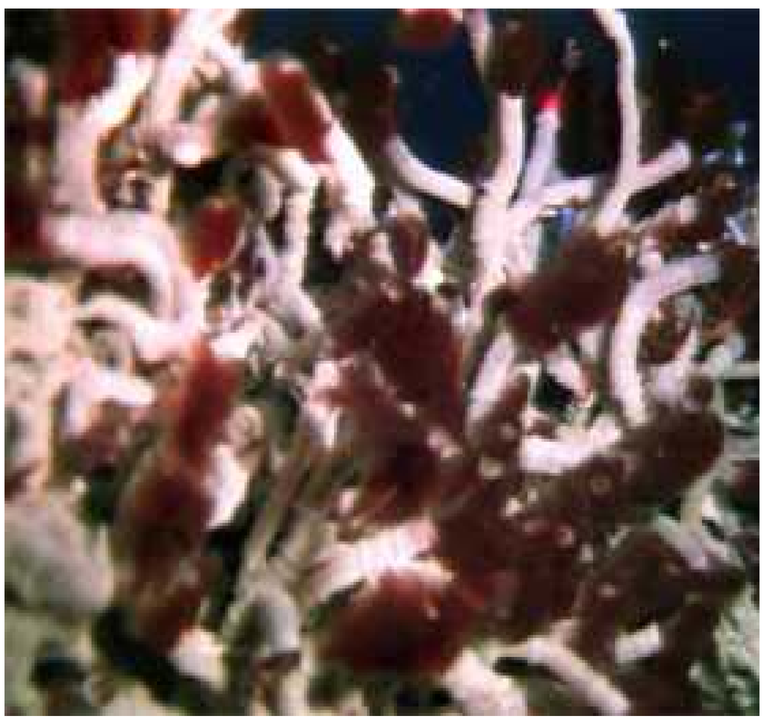


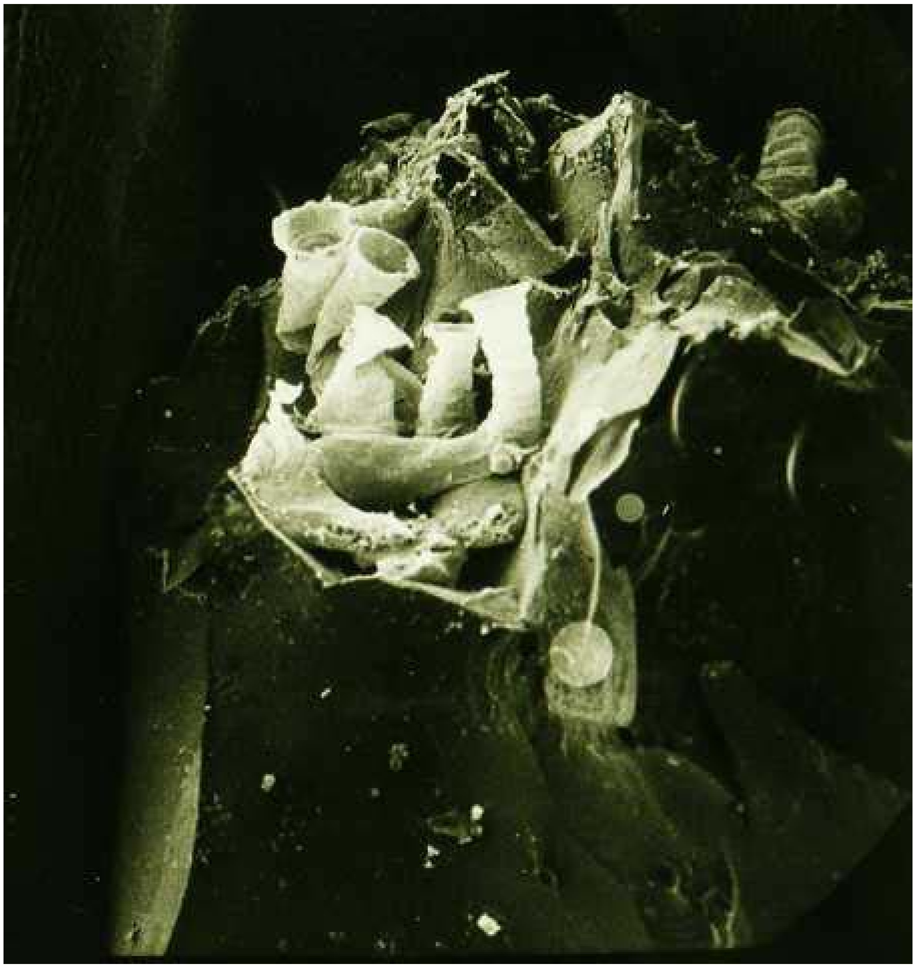
Figure 5. *Calyptogena pacifica* (Bivalvia) depends on the bacteria in their gills for food (above). *Ridgeia piscesae* (Vestimentifera) is extremely abundant. As a vestimentiferan it forms the structural base for the hot vent community. These worms do not possess guts. They rely on the chemosynthetic bacteria for food (below).

The large Galapagos tubeworm, *Riftia,* is the most conspicuous symbiont species of the vent community. It can be as long as one meter in length. It is covered in a white tube of chitin. The worms have large tentacles that form a plume structure that is about 30 cm long. The plumes are bright red because of the vascular tissue rich with oxygenated hemoglobin. The hemoglobin provides oxygen to both the worm and the bacteria. The blood has a second protein that binds to the hydrogen sulfide that the symbiotic bacteria need for chemosynthesis.

Photograph of Vent Animals From NOAA's Gallery

www.pmel.noaa.gov/vents/nemo/explorer/bio_gallery/biogallery1.html

Ciliata

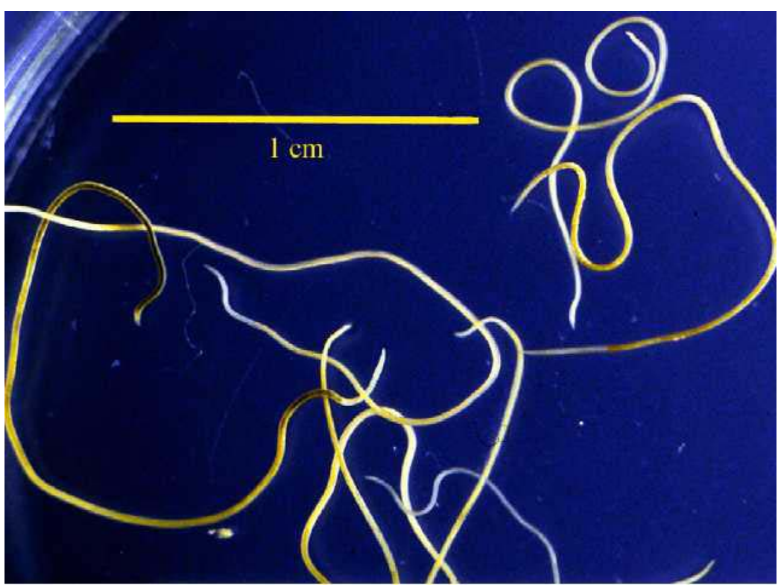


The ciliate forms extensive mats that are blue in color. They are believed to exist with symbionts.

Cnidaria

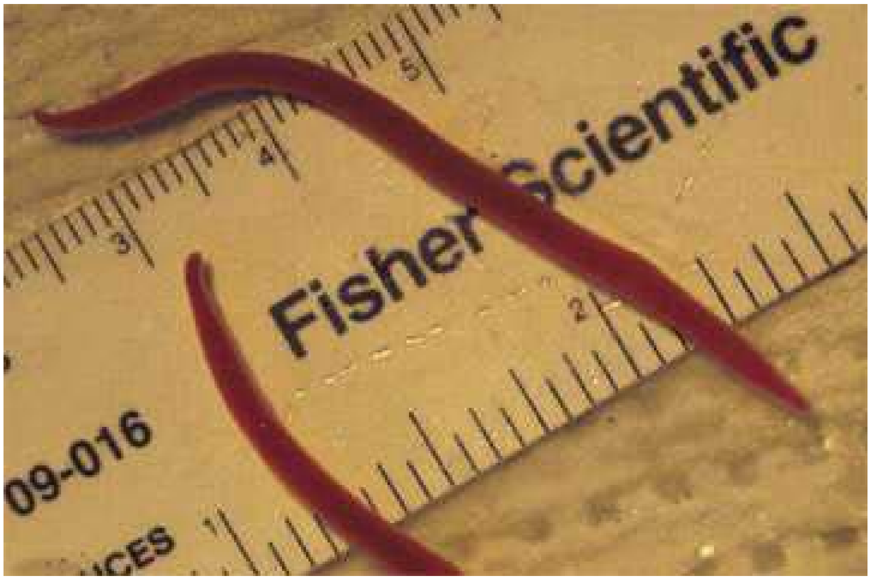
This is an unknown sea anemone that is abundant in the Ashes vent field where it is found on the periphery of the vents. This anemone represents a new taxon of perhaps two species.

Nematoda



This is an unknown species of nematode that is abundant in vents regions. There are a variety of nematode species in vent areas but little taxonomic or ecological information is available.

Nemertea



Nemerteans are commonly called ribbon worms. The species *Thermonemertes valens* appears shortly after eruptions and colonizes new vents.

Annelida
(Polychaeta)

Amphisamytha galapagensis is a species recorded throughout the Pacific vents.

Nicomache venticola is a tube dweller and is found at the base of smokers in the cool parts of the habitat.

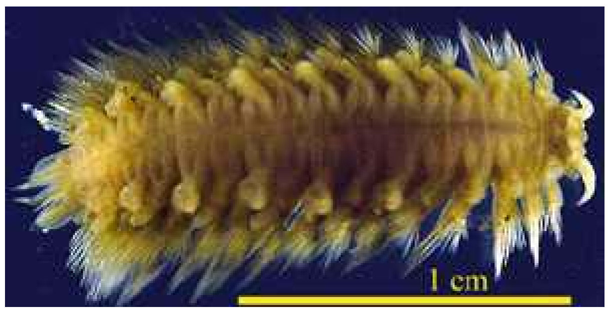
Hesiospina vestimentifera is common along the Ridge and has been found in vents off Mexico.

Nereis piscesae is a large worm with the jaws of a nasty predator. It is not common.

The two pictures above are of *Paralvinella palmiformis*, the palm worm. It is very abundant. The family is new to science and specializes at the habitat. There are four species described for the Juan de Fuca Ridge. The large palm-like branches are used for gas exchange. The oral tentacles ingest bacteria from surfaces and the water column.

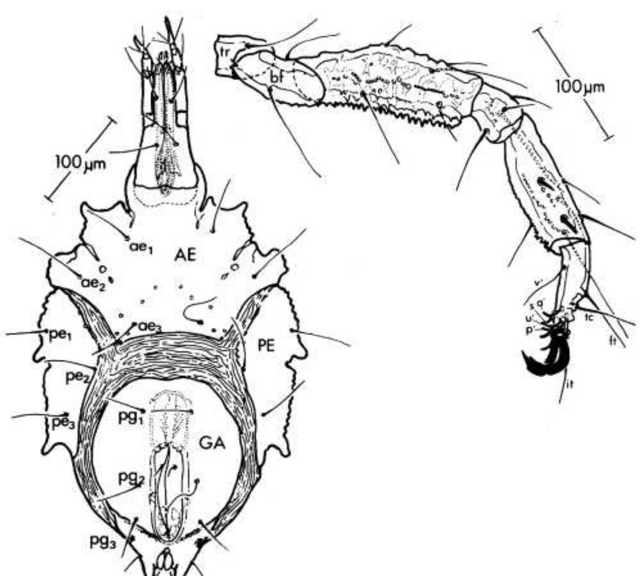
Lepidonotopodium pisceae is an adundant scale worm associated with worm tubes and chimneys of the vents. It appears to nibble on the tubeworms of *Ridgeia.*

Branchinotogluma grasslei is a scale worm common to vents. It has small gills under the scales.

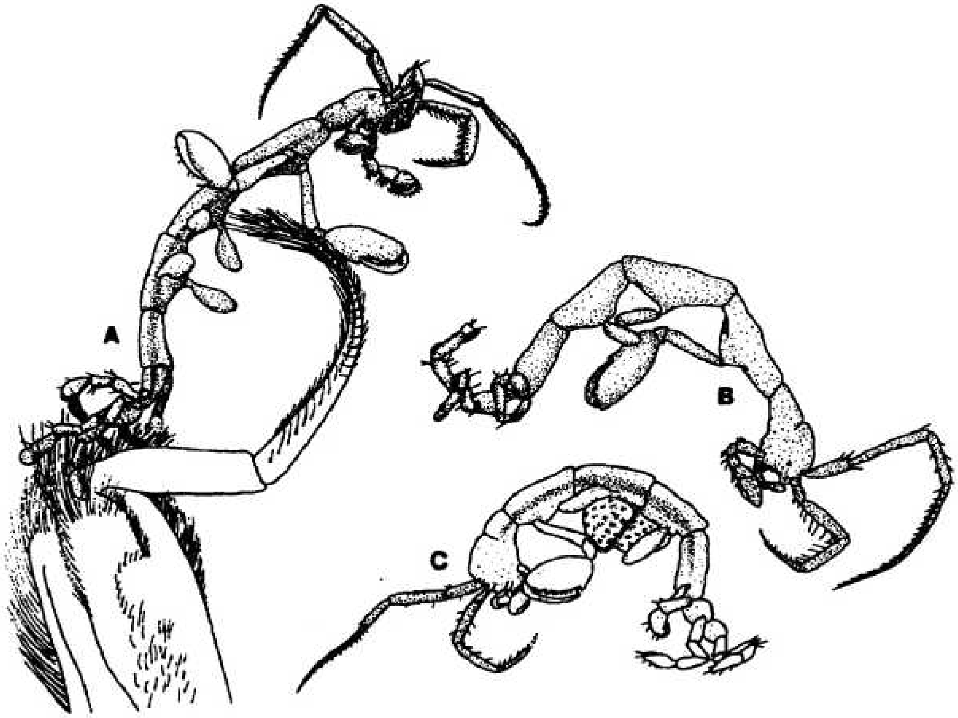


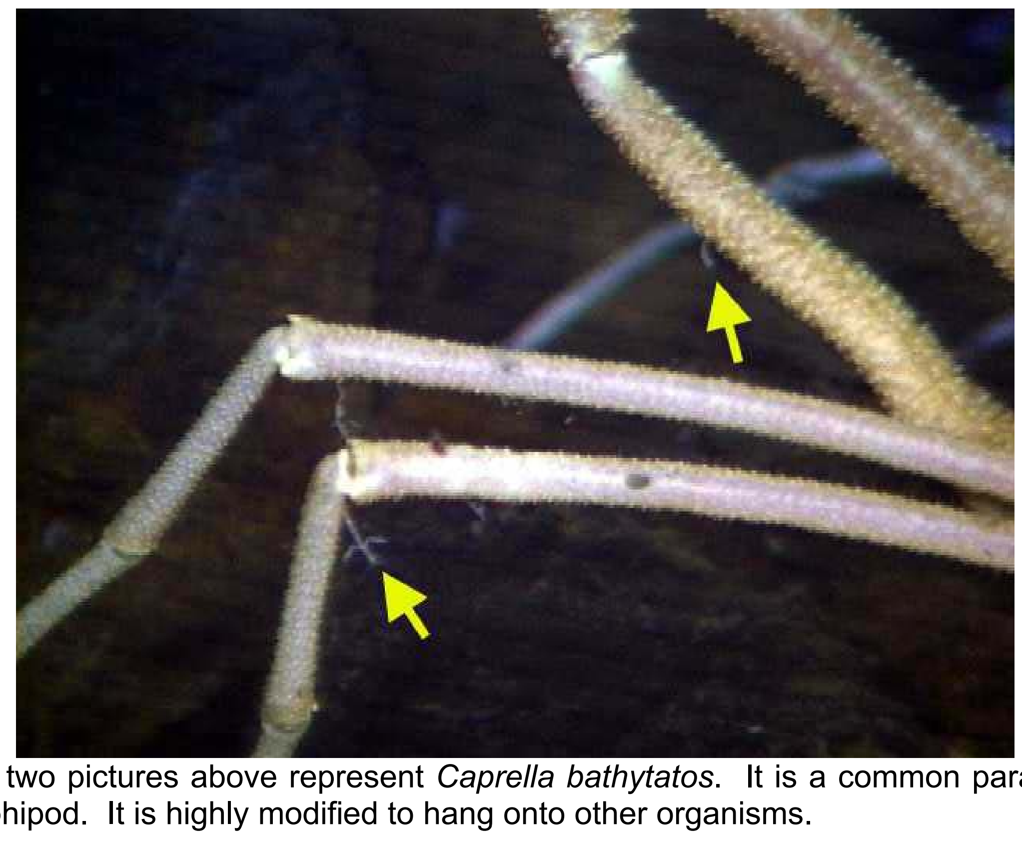
Opisthotrochopodus tunnicliffeae is not common. As with other scale worms, the gills are located under the scales. This species has two wheel organs at the posterior.

Arthropoda



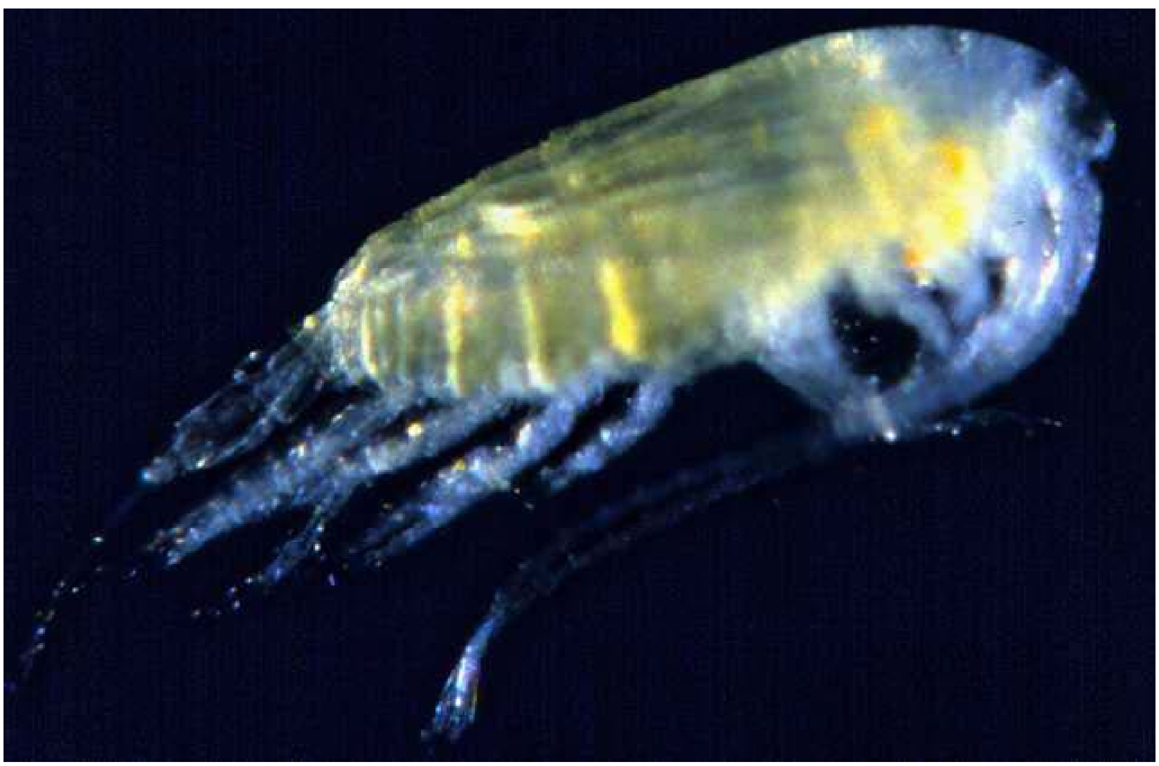
Copidognathus papillatus is a mite uncommon to the vent region. It is believed to be a parasite and was first described from the Galapagos Rift vents.



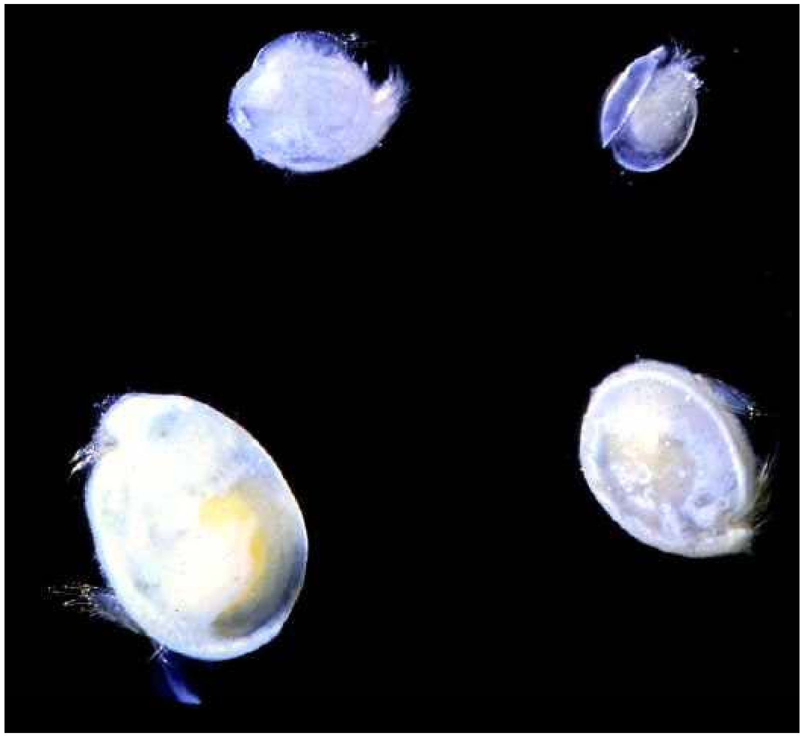


The two pictures above represent *Caprella bathytatos*. It is a common parasitic amphipod. It is highly modified to hang onto other organisms.

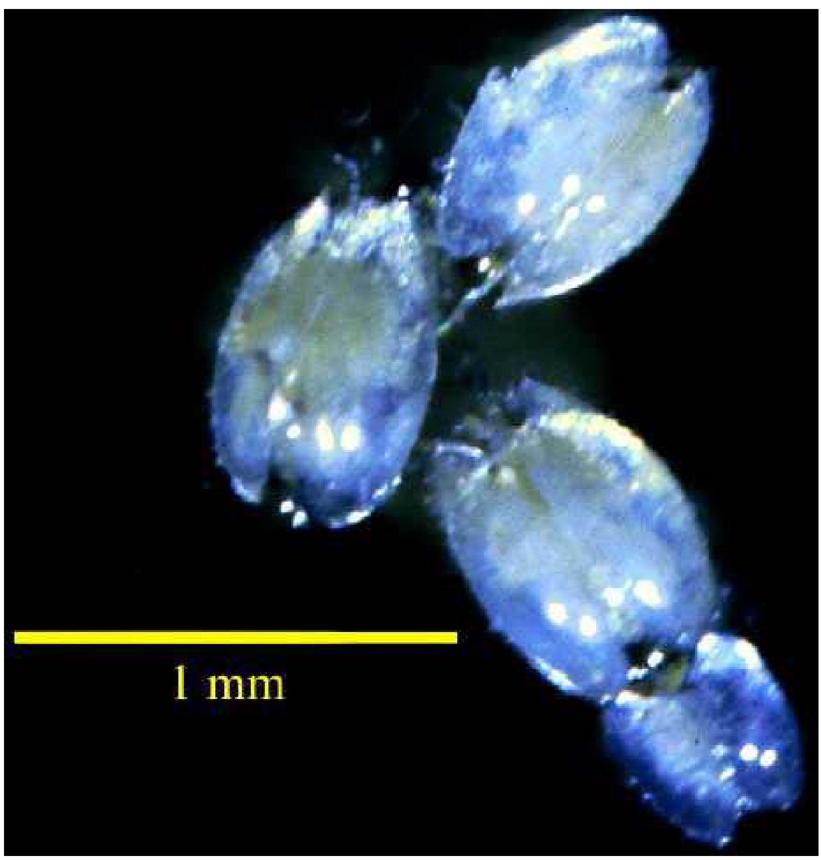
Benthoxynus spiculfer is a common copepod found along ridge crests. It is common to the Juan de Fuca vents. This is a female bearing eggs. The copepod is red in color in real life.



This is an unknown; uncommon species of calanoid copepod form the Juan de Fuca vent. Calanoid copepods are observed on few occasions and may represent contaminants.



Ostracod



This is an unknown species of a podocopid ostracoda.

Macroregonia macrochira is a spider crab with a leg span of 80 cm. This female is brooding eggs. The males range more widely than females and are aggressive towards each other. They were first described from the Emperor Seamounts and are common to the fringes of the Explorer and Juan de Fuca Ridges.

These spider crabs are major predators.

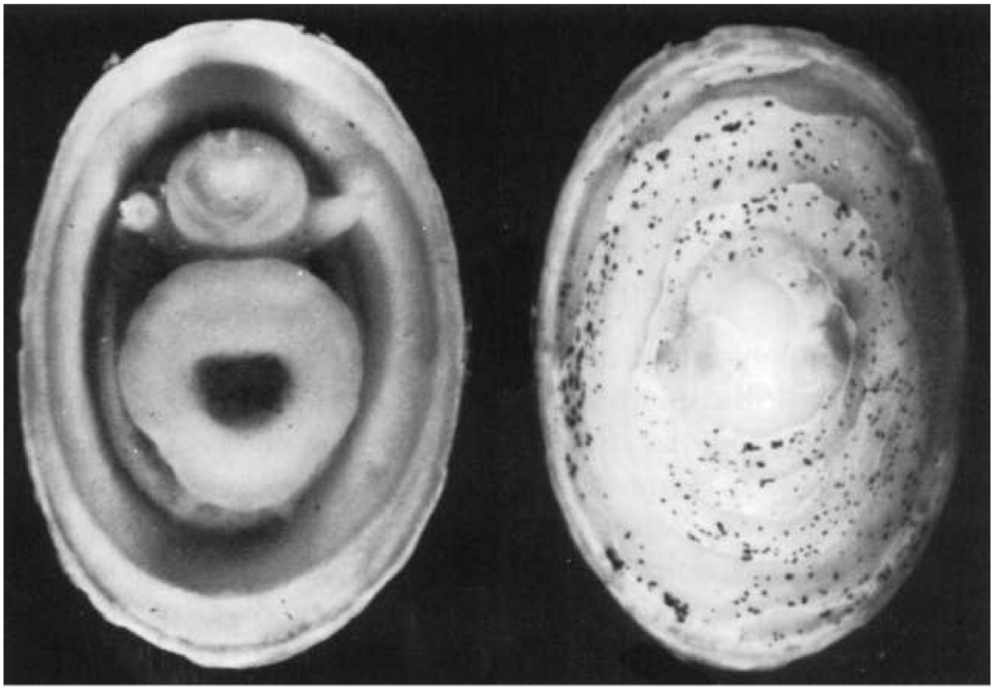
Minidisks alvica is a galatheid arthropod called the squat lobster. It is rare and is a scavenger.

Ammothea verenae is a pycnogonid commonly called a sea spider. It is common along the ridge areas confined to vents. Sea spiders commonly eat hydroids but hydroids are not found on vents. At the vent locations they appear to scavenge or eat microbes.

The sea spiders of this species, *Ammothes verenae*, form mating clusters of hundreds of individuals. The males collect eggs from several females, fertilize and incubate them in sacs of the abdomen.

Mollusca

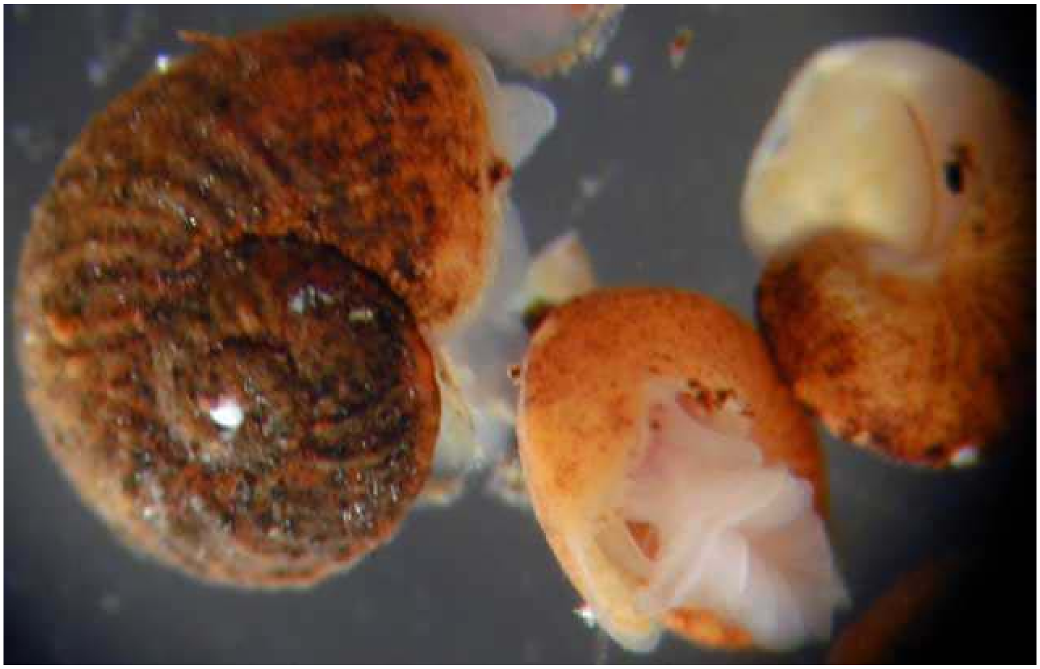
Helicoradomenia juani is a slug-like aplacophoran mollusk. It is covered by spicules that give it a furry appearance.



Pyropelta musaica, the cap snail, is common on Axial Seamount. It has been seen on whale carcasses, but appears to be rare at other vents.

Cornisepta verenae

Lepetodrilus fucensis limpets are represented in the two photos above. They are probably the most abundant animals on the Juan de Fuca Ridge. They form huge masses that coat the sides of chimneys and drape the tubeworms. They are found in nearly every vent habitat. They can graze, suspension feed and farm for food.

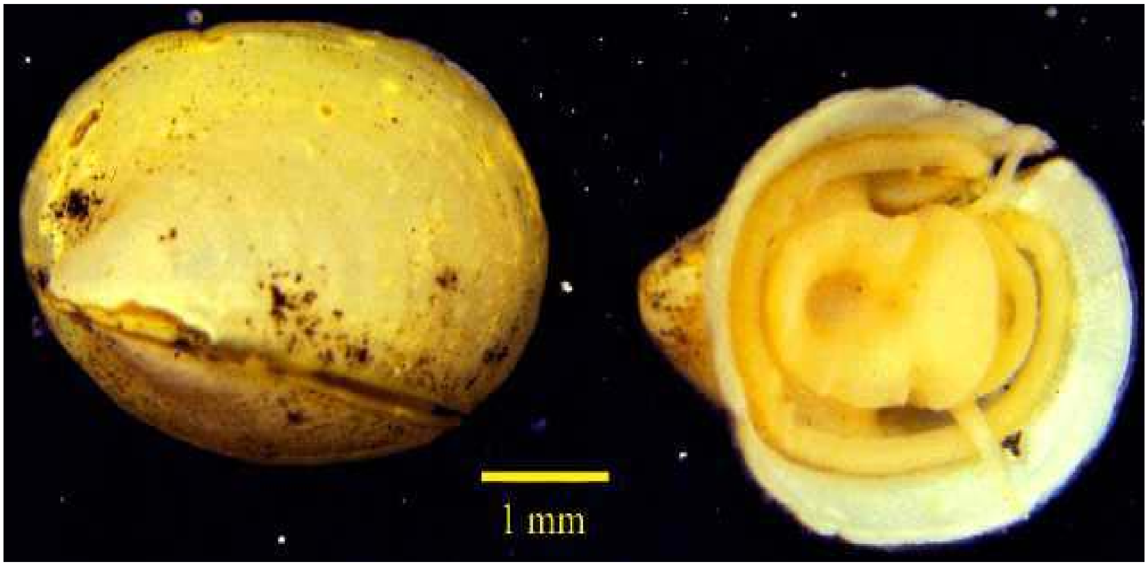


Melanodrymia brightae is an uncommon snail of the vent region. It was found at the Endeavor and Middle Valley ridges.

Hyalogyrina sp. was recently discovered at two sites on the Juan de Fuca vents and is rare.

Provanna laevis is known as the mia snail.

Temnocinclis euripes, the split limpet represents an antiquated group that was typical of Paleozoic fossils.



Clypeosectus curvus is a type of split limpet that is uncommon. This family of snails is indigenous only to vents and seeps.

Diazole Washingtonian is found on whale carcasses and is believed to be a "visitor" to the vent community.

Graneldone sp. Is an octopus cephalopod. A couple of species of the octopus are known form vent areas. They prey on other mollusks of the vent.

Chordata

Pachycara gymnium is a zoarcid fish commonly observed around vents.

Coryphaenoides acrolepis is a rattail fish common to vents of the North Pacific. It has been observed in plume areas and on the bottom regions feeding on tubeworms.

Psychrolues phrictus is a fathead sculpin. It is a giant and can reach a length of one meter with almost the same width.