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**IN TERMS OF ECOSYSTEM COMPONENTS AND FUNCTIONING, DESCRIBE AND DISCUSS
A NAMED ECOSYSTEM FOR WHICH SUNLIGHT IS NOT THE PRIME SOURCE OF ENERGY**

ABSTRACT –

Hydrothermal vents occur due to tectonic activity whereby fractures in the sea floor allow water to seep down, leach minerals and be erupted in a violent explosion. This hot water cools rapidly causing minerals to precipitate a black or white smoke, which eventually may form a chimney structure. Chemosynthesis occurs in this allochthonous system with chemoautotrophic bacteria using the expelled chemicals to create energy, consequently forming the base of a hydrothermal vent food chain.

INTRODUCTION –

Mankind has always craved for adventure, to discover the unknown and see the unseen. In 1969 Neil Armstrong became the first person to walk on the moon immediately sparking a world interest in the possibility of life in outer space, eight years later marine researchers in a submarine named 'Alvin' discovered the first hydrothermal vent near the Galapagos Islands, destroying the misconception that life could not exist without sunlight.

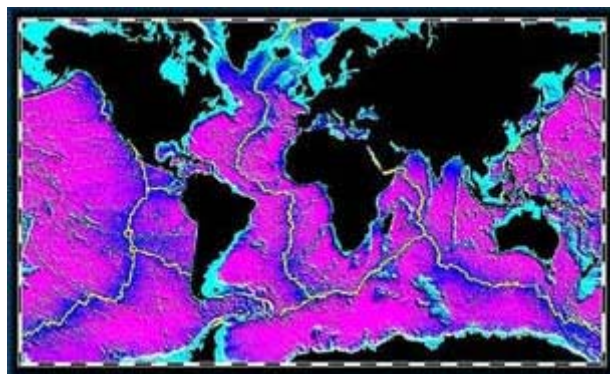
Ecologists are particularly interested in hydrothermal vents as these allochthonous ecosystems provide a unique opportunity to study organisms in their natural habitat, whereby trophic structures and biotic diversity and not primarily derived from sunlight.

VENT GEOLOGY –

Sitting on top of a central core of molten magma the earth's crust, composed of tectonic plates is a very dynamic region, giving rise to continental drift, erupting volcanoes, earthquakes and hydrothermal vents. Most activity occurs at edges of these giant plates along mid ocean ridges¹ (*figure 1*²).

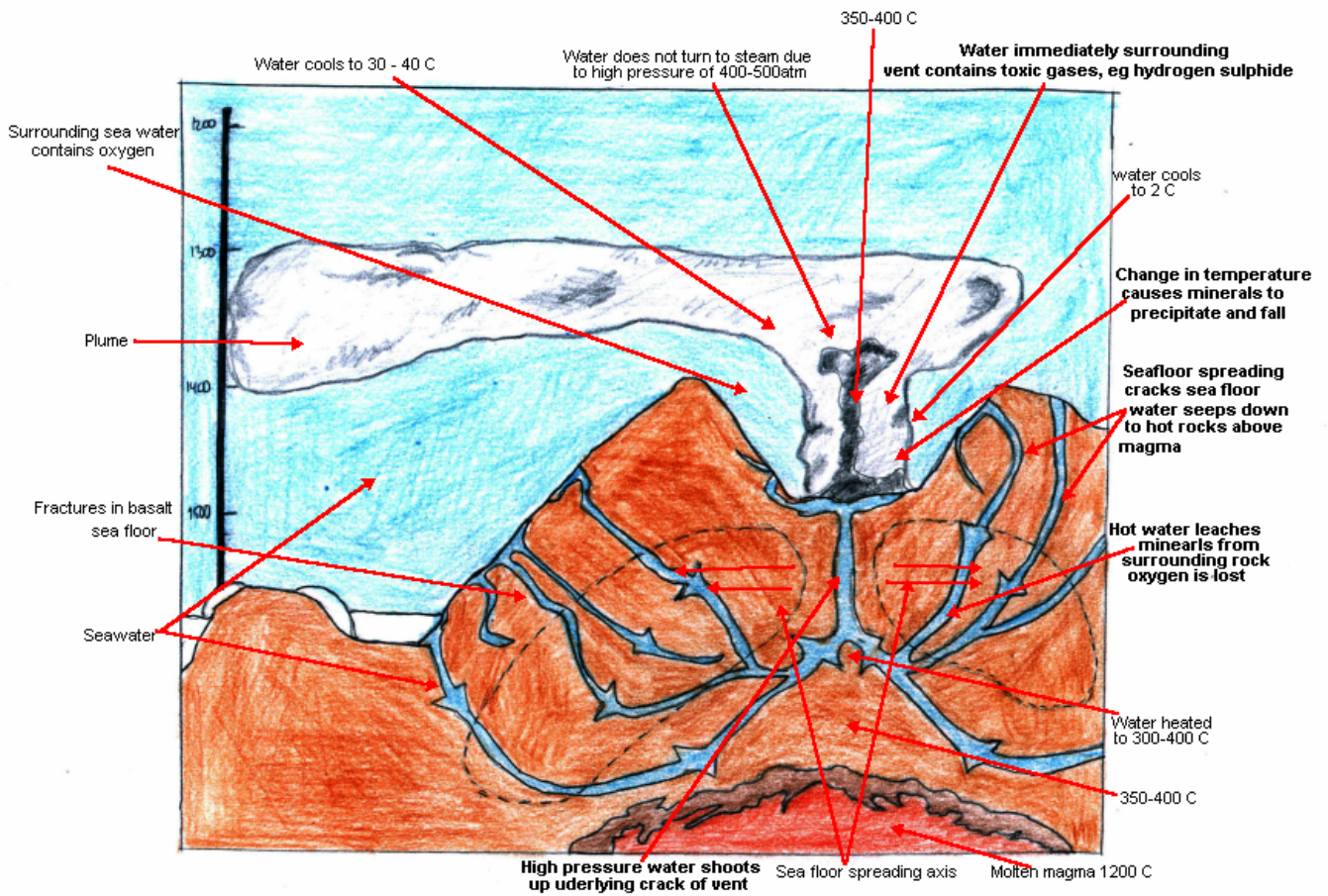
FIGURE 1 – MID OCEAN RIDGES SHOWN BY WHITE LINES

The significance of this is that a relatively narrow zone of volcanic activity occurs along these actively spreading tectonic plate edges allowing for the prediction of likely vent locations.



Thus hydrothermal vent formation is largely governed by tectonic activity, figure 2³ displays a generalised diagram of a 'black smoker' vent which occurs when erupting water is at a temperature of 350-400°C containing iron, copper, zinc, and sulphide which precipitate in cold water appearing as black smoke. Water at 150-300°C forms a 'white smoker' spewing mainly calcium, silica and barium producing a white precipitate.

FIGURE 2 – ‘BLACK SMOKER’



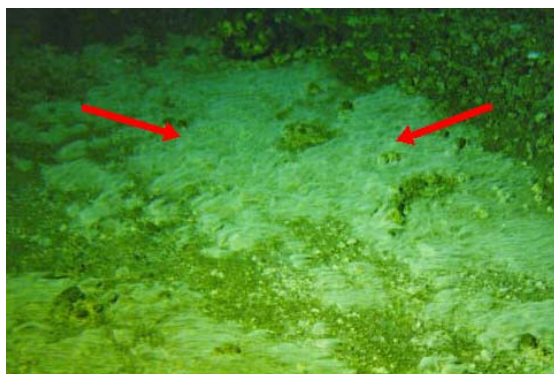
THE BEGINNING OF LIFE –

Initially the birth of a vent resembles an erupting volcano of black or white smoke, after a few days it looks like Christmas. Bacteria originating from beneath the earth's crust are shot out and float around attached to sulphur filaments forming a thick white 'floc' (figure 3⁴) which slowly sediments down forming a white carpet on the floor (figure 4⁵).

FIGURE 3 – BACTERIAL FLOC



FIGURE 4 – BACTERIAL MAT

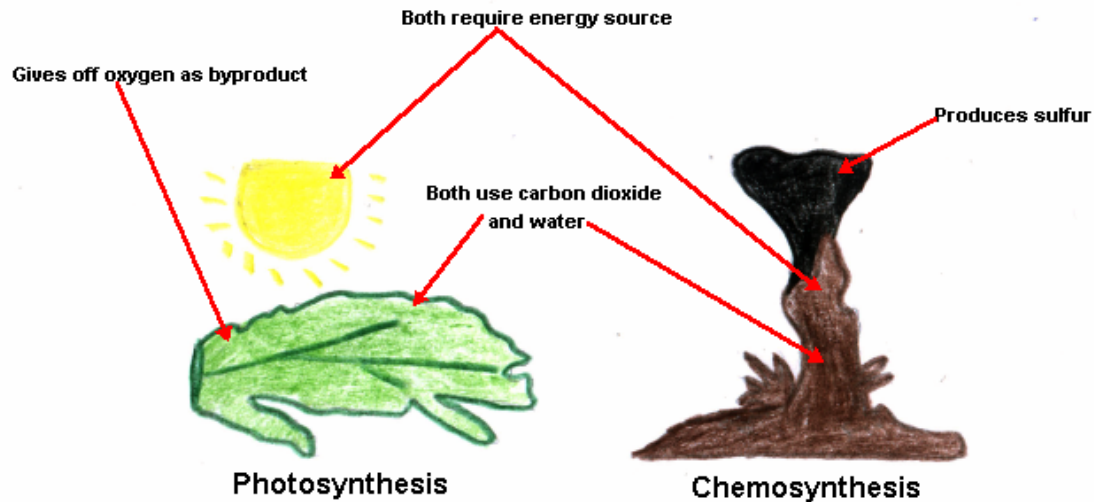


CHEMOSYNTHESIS –

Although the erupting water is full of toxic chemicals, here specialised creatures thrive. However in order for this habitat to become colonised and support a community, the vent must first be colonised by chemoautotrophic

bacteria so called because they oxidise expelled chemicals to produce energy via a process entitled chemosynthesis⁶ (figure 5⁷).

FIGURE 5 – COMMON FEATURES TO CHEMOSYNTHESIS / PHOTOSYNTHESIS



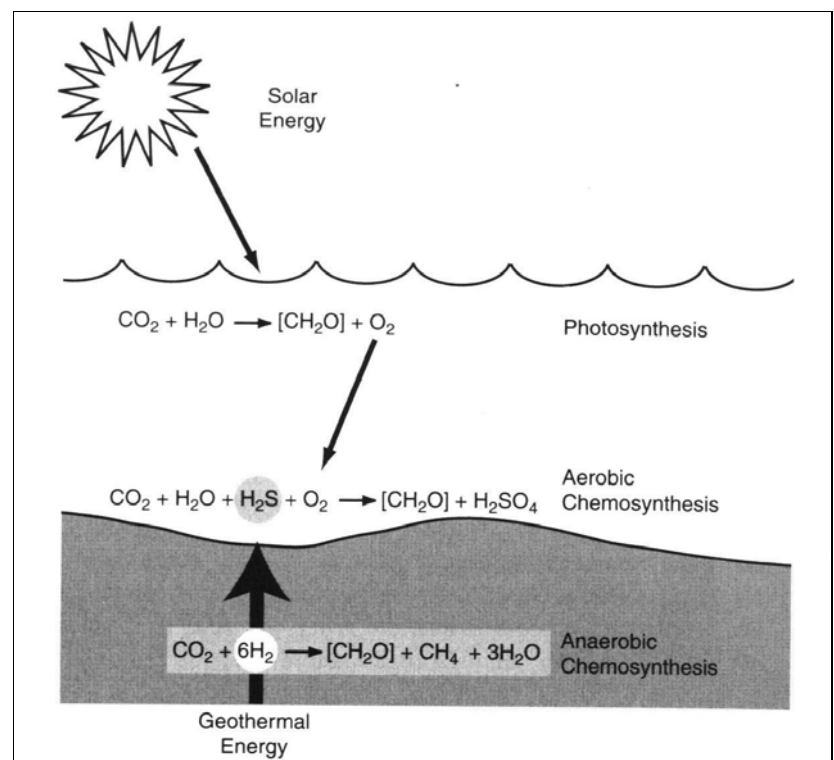
Two types of chemosynthesis may occur; aerobic, requiring oxygen and anaerobic, in the absence of oxygen (figure 6⁸).

FIGURE 6 – TYPES OF CHEMOSYNTHESIS

AEROBIC -

Aerobic chemosynthesis uses energy released by the oxidation of sulphur by oxygen; looking at the two main constituents of this pathway it is evident why aerobic chemosynthesis is the dominant metabolic pathway. Firstly sulphur is highly abundant in an active vent as it is constantly being spewed out as hydrogen sulphide mixing with oxygen in the surrounding seawater⁹.

Whilst sunlight is not the primary energy source, it is essential to producing



oxygen in the sea. However one limitation using this pathway is that bacteria must remain near an active vent in the zone where hydrogen sulphide is mixed with oxygenated water.

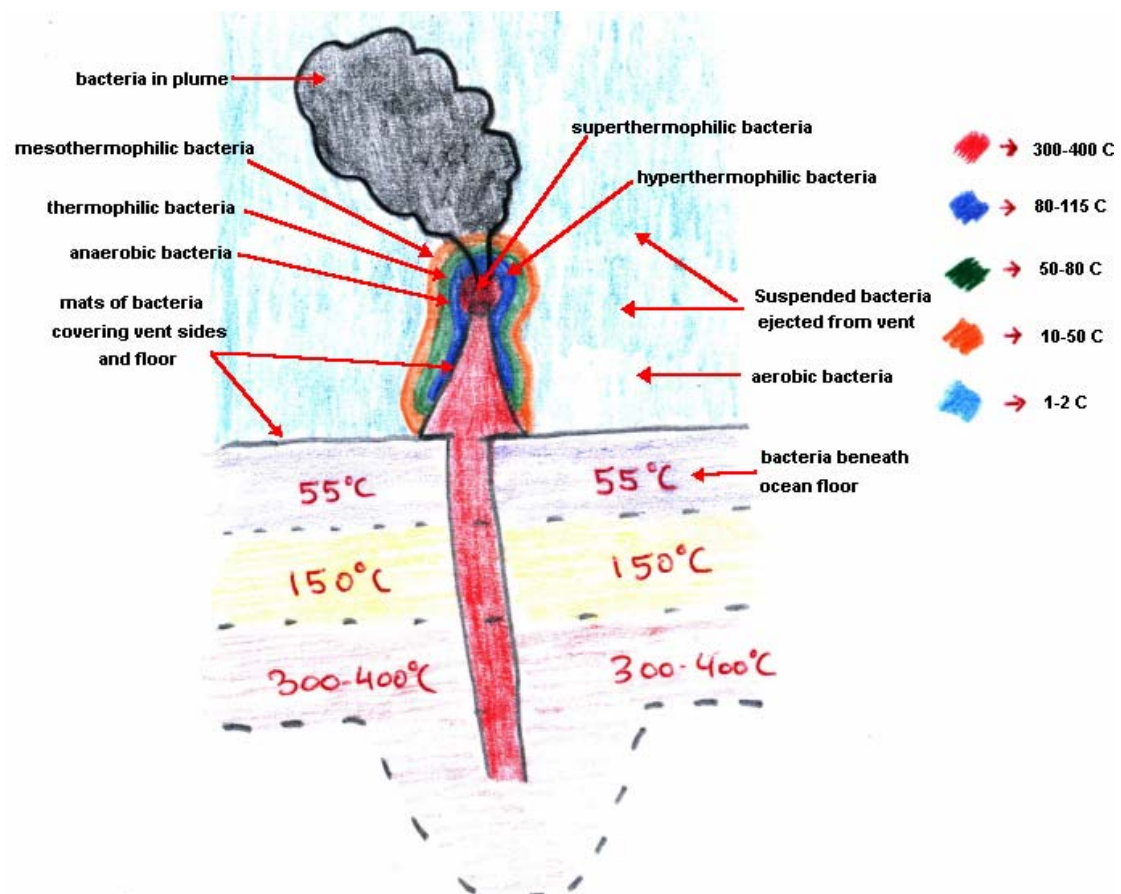
ANAEROBIC -

Since this pathway relies on hydrogen as the principle electron donor, the majority of bacteria use the aerobic pathway as there is a plentiful supply of sulphur and oxygen; anaerobes are found mainly beneath the ocean floor.

MICROBIAL DIVERSITY –

Due to the physical properties of the vent ecosystem bacterial populations are highly diverse, influenced by oxygen, chemicals and heat (*figure 6*).

FIGURE 6 – BACTERIAL DIVERSITY

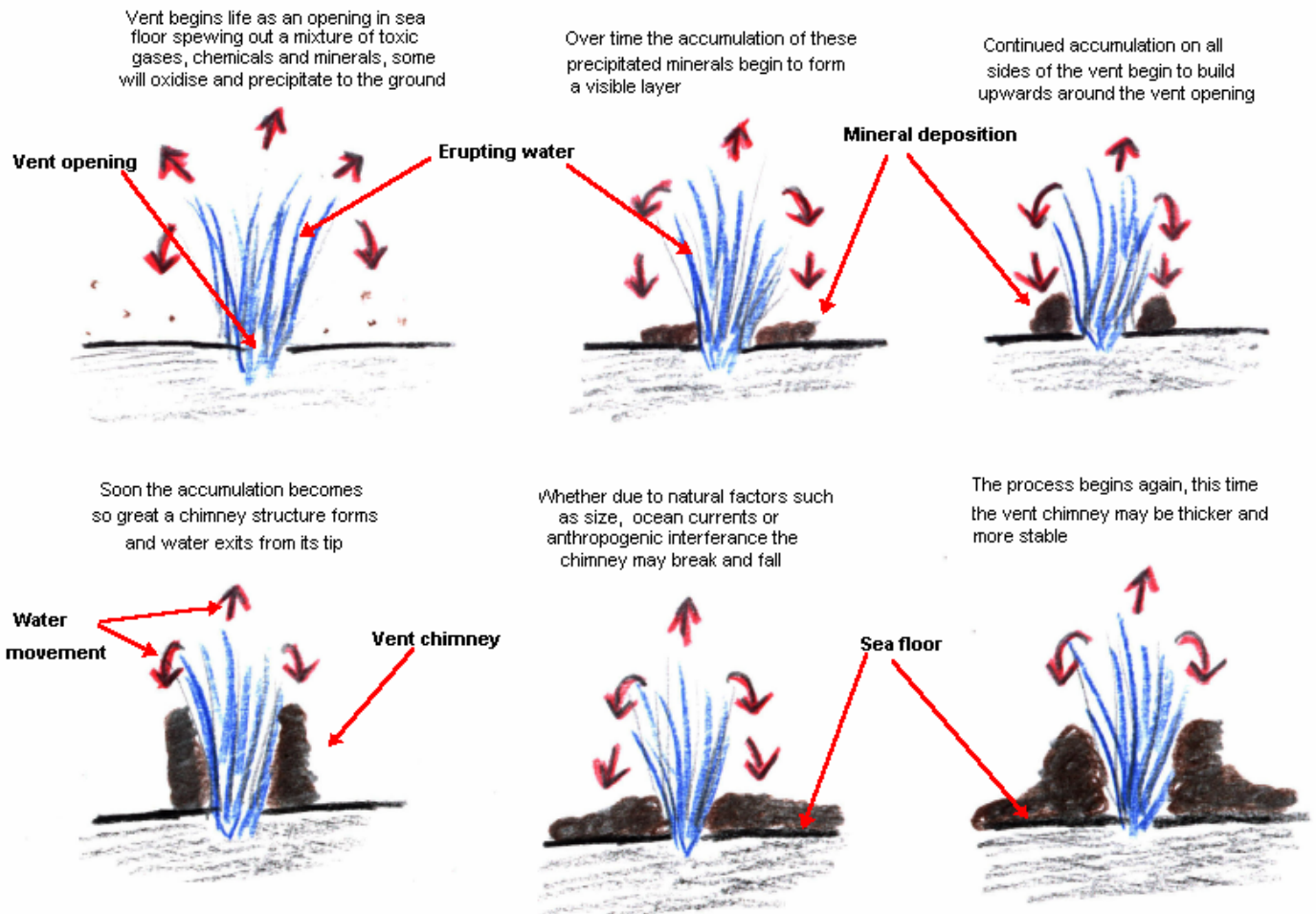


VENT CHIMNEYS -

Biological diversity increases during the formation and presence of a vent chimney (*figure 7*), some of which reach 100 feet tall (e.g. *Godzilla*¹⁰), though few achieve this size. Not only do these structures become colonised by bacteria but also by other species, some of which remain attached throughout their whole life. However this is a dangerous and fragile habitat as once the chimney collapses many of the animals will

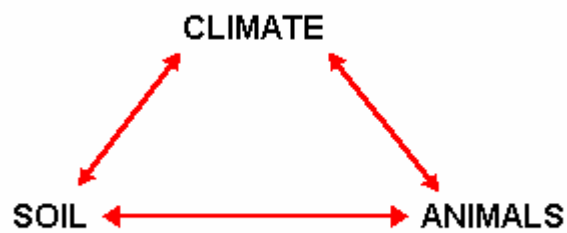
die; ultimately it is the chemical composition of the chimney which determines its stability.

FIGURE 7 – CHIMNEY FORMATION



Before discussing this ecosystem it is first important to step back and look at the system as a whole. It is defined as an ecosystem as the vent and its immediate surroundings include all organisms within that given area, which subsequently interact with each other and the physical environment. A trophic structure, or food chain, is possible due to the presence of chemoautotrophic bacteria which consequently allow a flow of energy, biotic diversity and material cycles to exist within this allochthonous ecosystem. Although the vent is self-sustaining spewing out plentiful chemicals to be used by bacteria, the system itself is not infinite and may temporarily regress in advancement if the chimney walls should collapse, or permanently cease to exist when the vent dies.

Therefore hydrothermal vents have some associated and interlinked components typical of any ecosystem (*figure 8*).

FIGURE 8 – ECOSYSTEM COMPONENTS

One feature missing is the absence of vegetation normally present where sunlight is the primary energy source. At the bottom of the sea floor no sunlight penetrates and vegetation is unable to grow.

CLIMATE -

Most would describe the vent climate as harsh, toxic and unforgiving, but to the organisms that live there they call it home. There are no external climatic factors in the sense of rain or wind but a more localised microclimate of temperature, chemical and oxygen gradients which vary due to ocean currents.

SOIL -

There is no soil at the vents only volcanic, dark grained, igneous rock called basalt. Cracks appear due to tectonic activity allowing water to seep down and leech minerals before it is spewed up again and covers the area with mineral deposits, creating chimneys and mounds. Topographical organisation will again produce microclimates, providing organisms with their ecological niche.

ANIMALS -

A common feature to vent ecosystems is the abundance of symbiosis, bacteria and invertebrates working together where both partners benefit. Some organisms will live near the vent opening or on the sides of the chimney where they will experience varying temperatures.

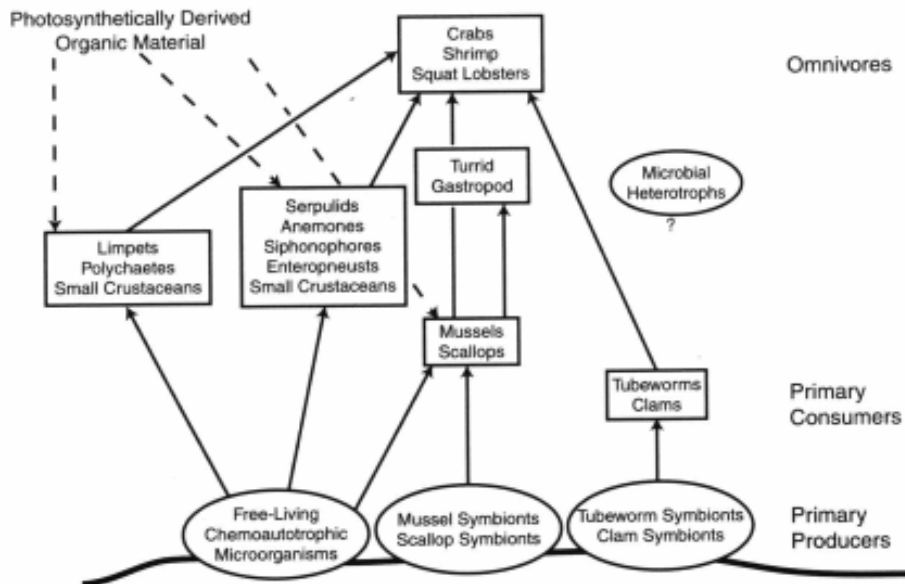
INTERLINKED FACTORS -

Ecosystems function by components interacting together, one example is a climate that alters constantly, therefore most organisms must adapt by interacting with the rocks to be where vent water meets oxygenated seawater.

ANIMAL LIFE -

Around 400 different kinds of animals are found at vents including tube worms, giant clams, mussels, crabs, shrimp and starfish all at varying levels of the food chain, with chemoautotrophic bacteria at the bottom (*figure 9¹¹*).

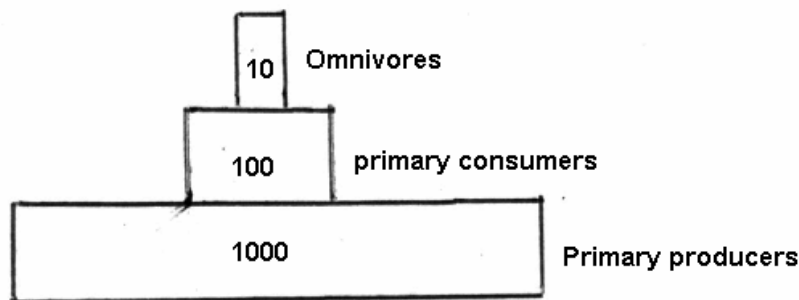
FIGURE 9 – VENT FOOD WEB



Whilst it was a surprise to find bacteria tolerating extreme temperatures, most shocking was the presence of so many organisms. Here biodiversity is low, meaning only a few species make up the majority of a big population resulting in a large biomass (*figure 10*) with high productivity.

Bacteria are essential for this process as they are food for animals, symbiotic with others and eaten indirectly by animals which feed on species that harbour them. Thus the presence of the bacteria themselves attracts other animal species which in turn attract others until a food chain with a trophic structure is formed.

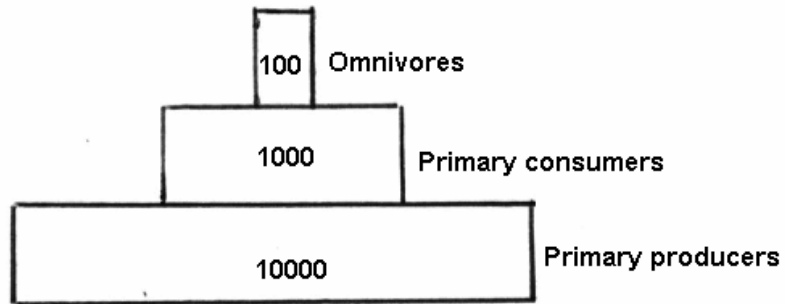
FIGURE 10 – BIOMASS PYRAMID



The pyramid shows dry weight in Kg which decreases at each trophic level, largely due to the flow of energy between levels (*figure 11*).

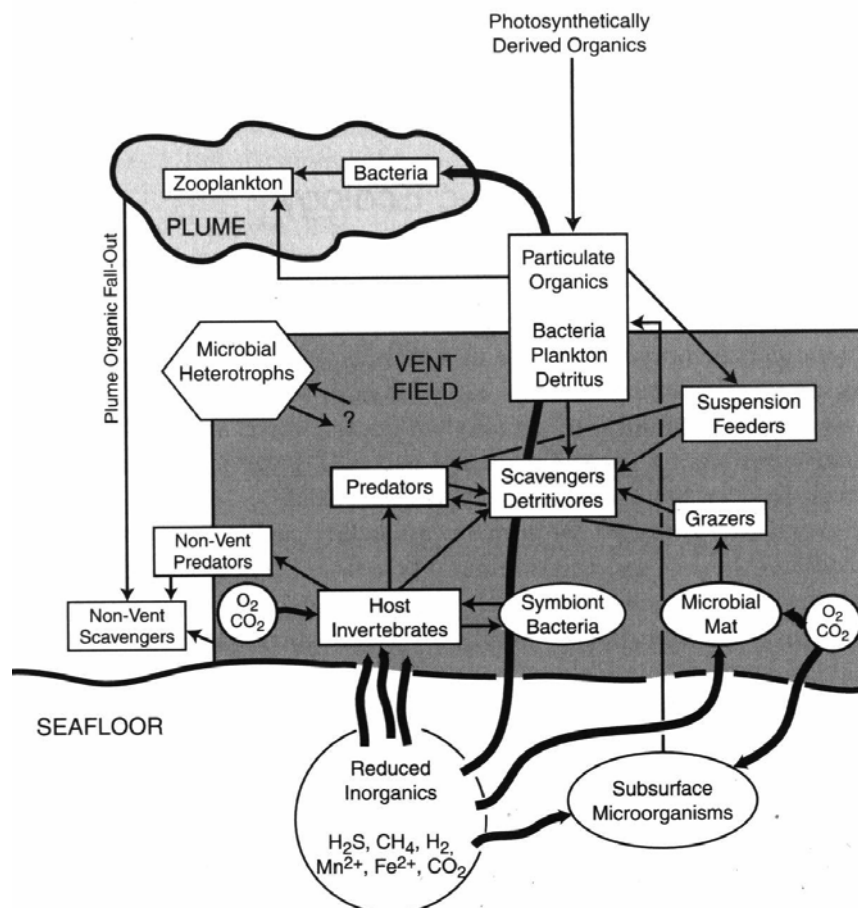
FIGURE 11 – ENERGY PYRAMID

As the food web showed the flow of energy, the energy pyramid shows energy at each trophic level in kcal/m³/yr. Energy lost in the form of growth and movement reduces



the total amount passed onto the next level making net production less than gross production. However in this ecosystem productivity is still higher than it would be on land as the cold temperature and limited movement of the organisms means less energy expenditure. As trophic levels rise, the amount of available energy to the next level decreases as the organisms become more active. Also, not all energy inputs are harnessed as the vast majority of chemicals, like hydrogen sulphide, are lost to the upper ocean layers in the vent plume.

Similarly it is the level of interaction between these trophic levels (*figure 12¹²*) which ultimately decides the flow of energy.

FIGURE 12 – TROPHIC INTERACTIONS

VENT COMMUNITIES –

Apart from bacteria, tubeworms are one of the first organisms to colonise the vent, shortly followed by mussels (*figure 13¹³*). Grazers (*shrimp*) and deposit feeders (*crab*) which eat bacterial mats are next and will attract predators (*squat lobsters*) which feed on them, these external predators suggest that vents may be a transition zone between the vent and sea ecosystems, so vents could be called an ecotone.

FIGURE 13 – EARLY PIONEERS



succession resulting from outside forces like tectonic activity, with each series of change called a seral stage.

SUCCESSION -

Communities change over time by a process called succession, of which two main types occur; primary and secondary, either by autogenic succession; change caused by community organisms or

or allogenic

PRIMARY SUCCESSION -

Primary succession must first occur by the creation of a vent site by the allogenic process of tectonic activity. Accompanying this seral stage is the release of chemoautotrophic bacteria from the underlying rock, forming first a floc and then a bacterial mat. This is the first stage of succession and will in turn attract other organisms which either rely on the bacteria for nourishment and water detoxification or feed on the bacteria themselves. However the important point is that the bacteria are pioneer organisms which provide a foothold in the ecosystem allowing other organisms to follow.

FIGURE 14 – VENT SUCCESSION

SECONDARY SUCCESSION -

Once the community is in a stage of climax whereby nutrient flow occurs between predator and prey or decomposers, secondary succession may occur; typically during collapse of chimney and subsequent death of some organisms. At this stage the community was already established, it is not virgin, and a



a new set of organisms will replace those who died as the vent develops again (*figure*

14¹⁴). Thus as the ecosystem matures and moves through the seral stages diversity increases, being a good example of succession as it is constantly broken down, reformed and recolonised.

FORCES DRIVING SUCCESSION –

The force driving the process of succession could initially be said to follow the facilitation model whereby the pioneer organisms, bacteria, enrich the environment and favour the establishment of other organisms. However it could also be argued that shortly after this, the tolerance model may occur. This could be applied to mussels and tubeworms which both colonise the vent early on, but due to the rapid growth of the mussel, tubeworm growth may be retarded in the sense that they are dominated by mussel populations which occupy most of the available space.

FIGURE 15 – SPIDER CRAB



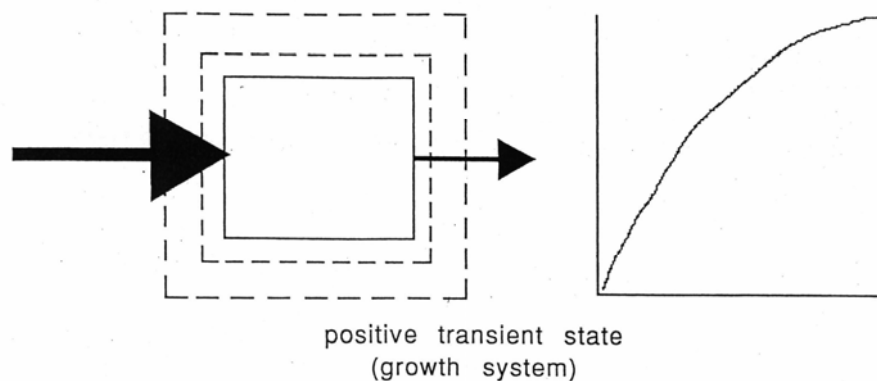
R AND K STRATEGISTS -

This could even be taken further by saying that the mussels and tubeworms are R strategists, that is, they develop rapidly and may disappear suddenly due to a dynamic environment. Conversely K strategists such as the spider crab (*figure 15¹⁵*), appear during later stages of succession and are more stable as a population

CYBERNETIC MODELS –

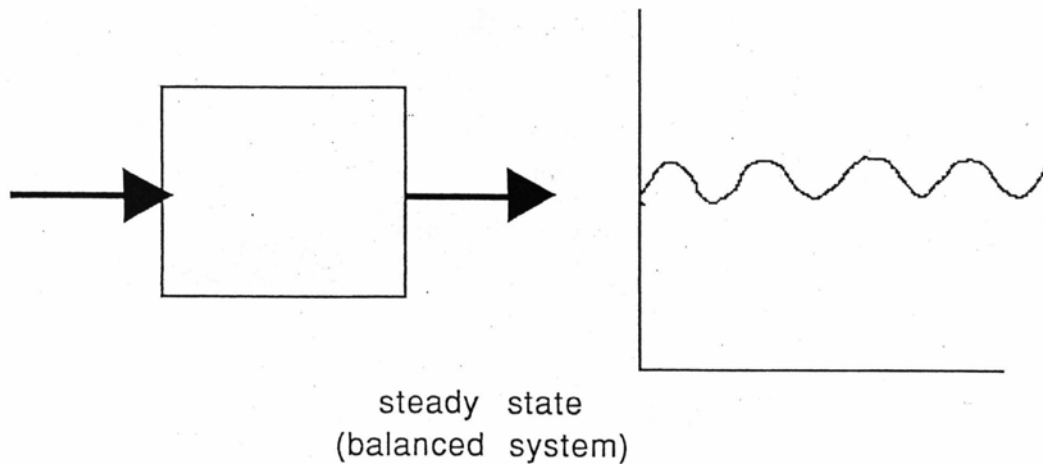
Cybernetic principles may be applied to the vent as during its creation it is in a positive transient state; a growth system (*figure 16¹⁶*), whereby more energy is put in than taken out. This occurs initially by the release of bacteria during vent birth and the subsequent biotic diversity it attracts.

FIGURE 16 – GROWTH SYSTEM



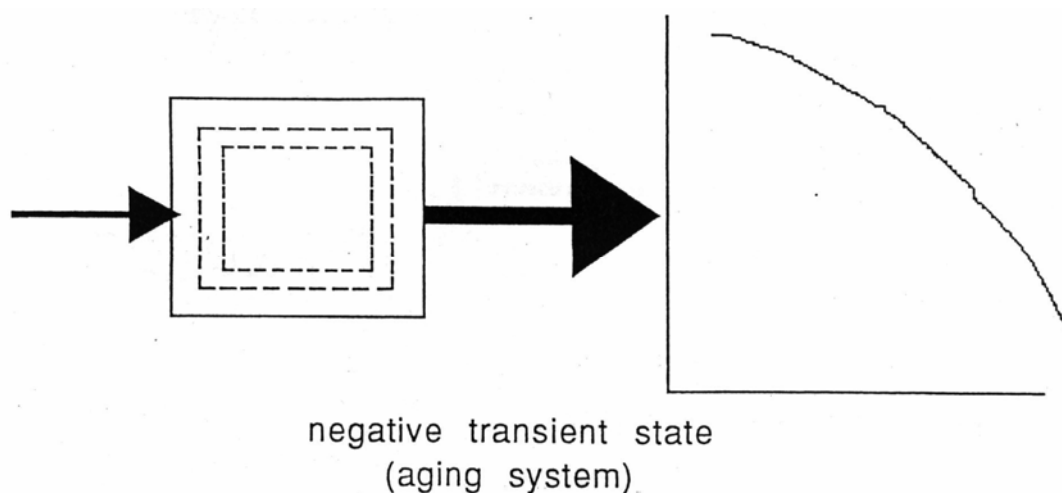
As the vent matures it may be said to exhibit a stable state or balanced system (*figure 17¹⁷*). Again this will occur as the vent ecosystem is extremely dynamic, whereby the collapse of a chimney may cause a depression in energy inputs, but this is soon balanced out by the rebuilding of the chimney and subsequent re-colonisation of the vent, thus it is a constantly fluctuating system.

FIGURE 17 – BALANCED SYSTEM



However the death of a vent shows a negative transient system (*figure 18¹⁸*) whereby more energy is output than input. This begins as magma beneath the surface cools and eventually stops ejecting water with its chemical and mineral load. Decline does not occur immediately as there may be rich sulphide deposits around the vent which provide a finite supply of nutrients for the bacteria to utilise. However once this finite supply is exhausted the system will ultimately die, showing that it is chemicals and not heat which is important.

FIGURE 18 – AGING SYSTEM



POPULATION –

An ecosystem needs to be self sustaining and be able to support the organisms within it, therefore depending on what cybernetic system it is in will determine how well it can provide for those organisms, whereby a growth system provides plentiful nutrients for increased growth and an aging system, a declining finite supply.

However population in a balanced system tends to be more influenced by biotic factors such as death, birth, immigration, emigration, food, and predation. Defined as a group of organisms of the same species, entire collective populations may be grouped into a population pyramid (*figure 19*).

FIGURE 19 – VENT POPULATION PYRAMID

INTRA/INTERSPECIFIC COMPETITION –

Intraspecific competition occurs within species and is usually a race for optimal position in order to obtain the maximal amount of nutrients, this type of competition will occur between the pioneer organisms like mussel populations due to their rapid growth. Interspecific involves competition between species such as for space and nutrients, and may include predator-prey relationships, occurring less frequently as biotic diversity is low.

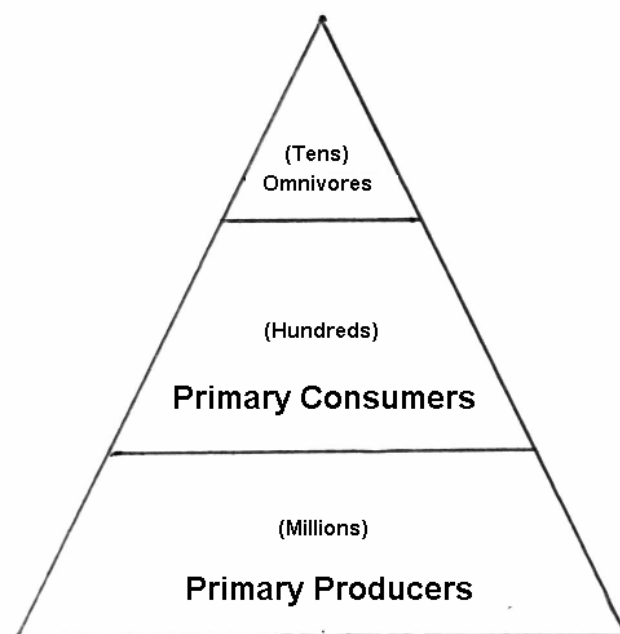


FIGURE 20 – VULCAN OCTOPUS



POPULATION DISTRIBUTION –

Coinciding with the varying trophic levels will be species distribution¹⁹. Primary producers will largely be confined to the zone of mixing between vent and seawater in order to meet their aerobic requirements, by floating or living inside other organisms which reach into this zone. Primary consumers will also be limited to this zone if they are dependant on symbiosis for nutrition.

The degree of freedom tends largely to occur with the omnivores such as the Vulcan Octopus (*figure 20*²⁰) which emigrate into the ecosystem.

SYMBIOSIS -

Most populations are symbiotic²¹, with invertebrates and chemoautotrophic bacteria sharing a mutualistic relationship.

GIANT TUBEWORM –

Tubeworms (*figure 22²⁵*) are one of the best examples of symbiosis and resemble a large worm growing at 3mm per day, reaching a maximal size of 2-3 meters. Living inside a tube structure attached to the chimney or vent base, it has bright red gills full of specialised haemoglobin that stick out of the tube and withdraw when threatened.

Since it has no mouth or gut it relies entirely on its symbiotic relationship²² with bacteria in the trophosome (*figure 21²⁴*) for nutrients. As the bacteria are aerobic, its tentacles must project into the transition zone of vent and seawater in order to obtain oxygen, which both partners need, and hydrogen sulphide which the bacteria need and will breakdown into useable nutrients for the tubeworm²³. Both partners benefit as the bacteria receive a sheltered environment with steady supply of chemicals and the worm a supply of nutrients, but due to the fluctuating transition zone the worm must grow rapidly to reach it.

FIGURE 21 – TUBEWORM TROPHOSOME

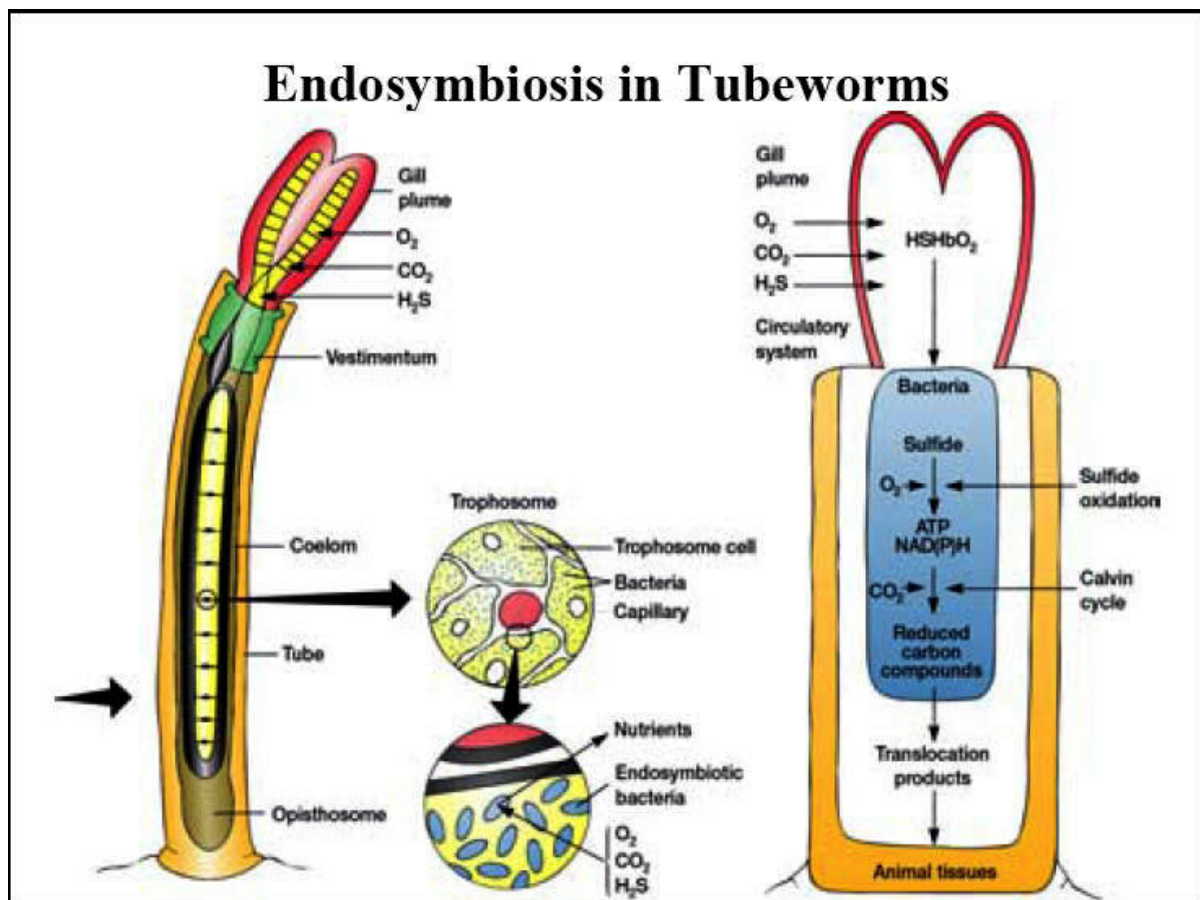


FIGURE 22 – TUBEWORMS

Normally sulphur would bind competitively to haemoglobin and shut down aerobic respiration, this highly specialised variety allows both oxygen and sulphur to bind²⁶, allowing the worm to survive.

Predators include crabs which may cut its tentacles and the worm is virtually defenceless, in order to compensate it is highly fertile and its larvae are of the swimming variety to increase chance of dispersal and further vent colonisation.

MIGRATION BETWEEN VENTS –

Vent ecosystems will eventually die, so organisms must either migrate to another vent or disperse larvae. Since vents occur at regions of actively spreading crust they are usually found in linear alignments, which allow for larvae to float or crawling organisms to walk to a new vent possibly by chemical or heat gradients²⁷.



Some animals may stop at hot springs or at rotting whale carcass²⁸ which release methane and sulphur as they decay, and are colonised by bacteria. From an evolutionary viewpoint one advantage of swimming larvae is that they are more likely to reach a new vent and will remain genetically similar. Those who rely on walking for migration may be separated as a group if some sudden tectonic activity occurs, resulting in each half becoming genetically dissimilar over evolutionary time²⁹.

MEMBRANE ADAPTATIONS –

Due to the high pressure experienced at depths of 4000-5000m organisms have evolved a membrane which is comprised of unsaturated fatty acids with a C=C double covalent bond allowing membrane components to be squeezed tightly together, solidifying the membrane³⁰.

GLOBAL EFFECTS OF VENTS –

Vents are important for circulation ocean waters in a process called hydrothermal circulation, which provides 34% of ocean heat input and much of its chemical composition³¹.

ANTHROPOGENIC INTERFERENCE –

Whilst vent ecosystems have remained undisturbed for millions of years it may only be a matter of time before they are disturbed by man. Since the vents deposit mineral rich substances, when technology becomes available and cost effective they may be mined which could kill many of the animals and destroy the ecosystem.

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