Marine Pollution

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1 What is pollution?

1.2 Definitions

Contamination is, *sensu stricto*, used to describe the fact that a certain chemical compound is present in a certain habitat and/or the organisms living there, at a concentration higher than normal or the background value, and this due to non-natural causes.

Pollution can then be defined as any form of contamination in an ecosystem with a harmful impact upon the organisms in this ecosystem, by changing the growth rate and the reproduction of plant or animal species, or by interfering with human amenities, comfort, health, or property values. In a broader sense, the terms contamination and pollution also include any physical modification that alters the energy or radiation flow in an environment (such as a heat source or a radioactive elements), or even the presence of an invasive species.

Hence, marine pollution as defined by the Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP), as part of the basic framework of the UN Convention on the Law of the Sea (UNCLOS) 1982 (Article 1.4), is:

> *"the introduction by man, directly or indirectly, of substances or energy into the marine environment (including estuaries) resulting in such deleterious effects as harm to living resources, hazards to human health, hindrance to marine activities including fishing, impairment of quality for use of sea water, and reduction of amenities."*

1.3 Classification of pollution forms

Pollutants can be classified in different ways.

- First of all, they can be distinguished **according to their physicochemical constitution**.
  - Some are **inorganic** compounds (like the atmospheric pollutants NO, NO_2, and SO_2 or like metal ions);
  - other types of pollution are more **organic** in nature (like wastewater, the nitrogen and phosphorus-laden run-off of agricultural land or petroleum derivatives).
  - Newer forms are even **not chemical in origin** (sound, light).

- The **physical state** is another parameter to distinguish between different pollutants.
  - Some types are found in **solid** form, such as the plastic debris, but also the remains of sludge after bagger works.
  - Other types are found in the atmosphere, either as **drifting solids** (flying ashes, heavy metals adhering to dust particles and particulate matter),
  - or as **gases** (like volatile organic compounds).
  - Rivers will carry a number of **solutes** (nitrogen fertilizers, agricultural run-off, remains of antibiotics, medication and hormones).
- A third way to classify pollutants uses **their persistence** in the environment.
  - Some pollutants are **biodegradable** (i.e., they will be mineralized by bacteria or otherwise assimilated in the metabolism of any of the organisms in the environment) and therefore **will not continue to exist**

in the ecosystem for a long time, e.g. cooking waste, sewage and manure.

- Other pollutants **dissipate spontaneously (rapidly) and lose their damaging**:
  i. heat, discharged with the cooling water of a power station;
  ii. acids and bases, due to the buffering capacity and the large volume of the ocean in which they end up;
  iii. cyanides, produced in metallurgical industries, also dissociate and dilute quickly in seawater (with only the immediate neighborhood of the discharge feeling negative effects of the poison).
- A third group of pollutants are **conservative or persistent**. They are not subject to bacterial attack and are not dissipated, but are reactive in various ways with plants and animals causing harmful effects. Examples are:
  i. Heavy metals (mercury, copper, lead, zinc and so on)
  ii. radioactive sources,
  iii. chlorofluorocarbons in the atmosphere, dioxins and pesticides.
  iv. Even more so, apolar pollutants usually display a tendency to bioaccumulate, i.e. animals at higher trophic levels accumulate significantly higher levels of these chemical compounds.

- Lastly, pollution can be classified as **point source or nonpoint source** pollution.
  - **Point source pollution** can be traced back to a single, identifiable spot where the pollutant originated – for example, a sewage pipe from a company, the noise from a windmill or the leak of the Deep Horizon oil drilling platform.
  - **Nonpoint source pollution** cannot be attributed to a specific location or time, and has a rather diffuse source. Examples comprise agricultural runoff, dust from strip mining, or urban storm water runoff. Nonpoint source pollution is the leading cause of water pollution in the United States today, with polluted agricultural runoff the most important form.

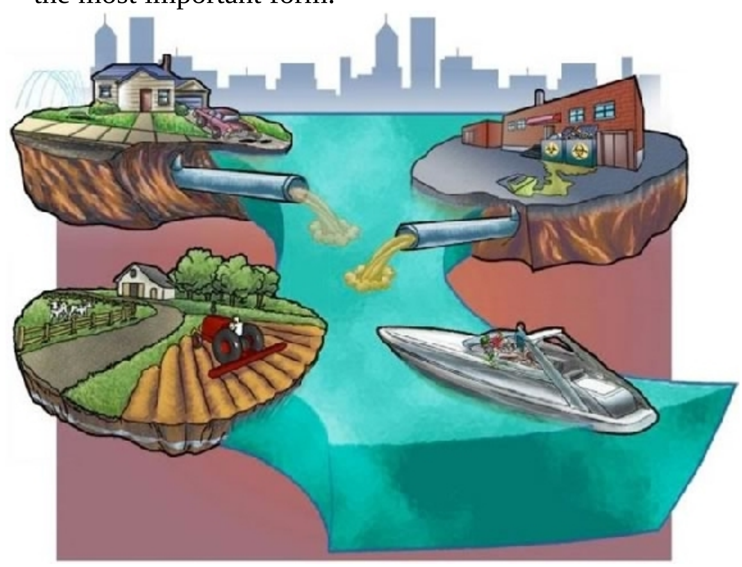

Fig. point source and nonpoint source pollution

Type	Primary Source	Effect
Nutrients	Runoff approximately 50% sewage, 50% from forestry, farming, and other land use. Also, airborne nitrogen oxides from power plants, cars, etc.	- Promote algal blooms in coastal waters. - Decomposing algae depletes water of oxygen, killing other marine life. - Can spur algal blooms (red tides), releasing toxins that can kill fish and poison people.
Sediments	Erosion from mining, forestry, farming, and other land-use; coastal dredging and mining.	- Cloud water; impede photosynthesis below surface waters; clog fish gills. - Smother and bury coastal ecosystems. - Carry toxins and excess nutrients.
Pathogens	Sewage, livestock.	- Contaminate coastal swimming areas and seafood. - Cause cholera, typhoid and other diseases.
Alien Species	Several thousand per day transported in ballast water; also spread through canals linking bodies of water and fishery enhancement projects.	- Out-compete native species and reduce biological diversity. - Introduce new marine diseases. - Associated with increased incidence of red tides and other algal blooms, a problem in major ports.
Persistent toxins (PCBs, heavy metals, DDT, etc.)	Industrial discharge; waste-water discharge from cities; pesticides from farms, forests, home use, etc.; seepage from landfills.	- Poison or cause disease in coastal marine life, especially near major cities or industry. Contaminate seafood. - Fat-soluble toxins that bio-accumulate in predators can cause disease and reproductive failure.
Oil	46% from cars, heavy machinery, industry, and other land-based sources; 32% from oil tanker operations and other shipping; 13% from accidents at sea; remaining sources include offshore oil drilling and natural seepage.	Low level contamination can kill larvae and cause disease in marine life. - Oil slicks kill marine life, especially in coastal habitats. - Tar balls from coagulated oil litter beaches and coastal habitat. - Oil pollution is down 60% from 1981.
Plastics	Fishing nets; cargo and cruise ships; beach litter; wastes from the plastics industry and landfills.	- Discarded fishing gear continues to catch fish. - Other plastic debris entangles marine life or is mistaken for food. - Plastics litter beaches and coasts and may persist for 200 to 400 years.
Radioactive substances	Discarded nuclear submarine and military waste; atmospheric fallout; industrial wastes.	- Create "hot spots" of radioactivity. - Can enter food chain and cause disease in marine life. - Accumulate in top predators and shellfish, which are eaten by people.
Thermal	Cooling water from power plants and industrial sites.	- Kill off corals and other temperature sensitive sedentary species. - Displace other marine life.
Noise	Supertanker, other large vessels and machinery.	- Can be heard thousands of kilometres away under water. - May stress and disrupt marine life.

Table 1-1. Types, sources, and effects of marine pollution.

1.4 Sources

Overall, the pollution that ends up in the seas and oceans, originates from **four distinct sources**. As represented in Figure 1-1, the major part of all pollution comes from the land, either through run-off and discharges (via waterways; 44%) or through the atmosphere (33%). Only 12% of all pollution is due to maritime activity and shipping accidents. Dumping of garbage and sewage, as well as the consequences of offshore drilling and mining make up for the rest (resp. 10% and 1%).

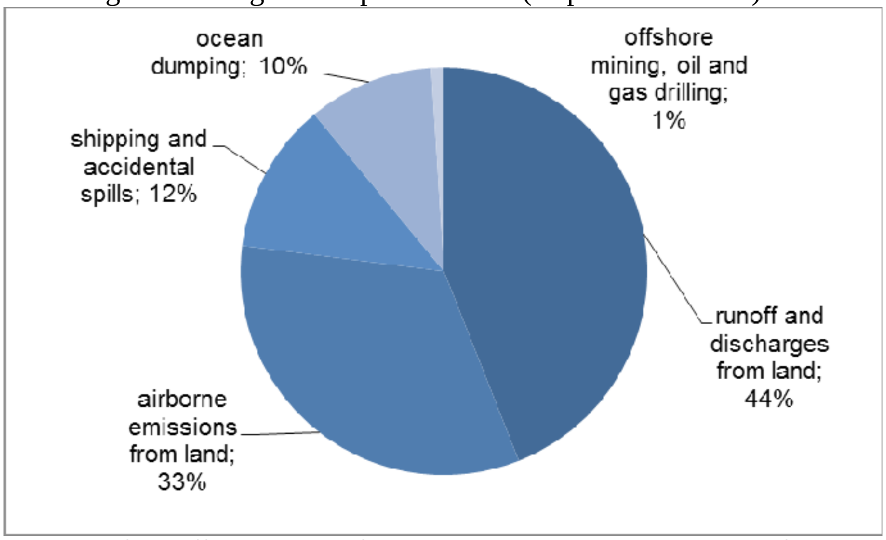

Figure 1-1. Share of the different sources of pollution into the marine environment (After IMO 2012)

1.4.1 Runoff from the land

The main transport of pollutants from the land to the sea occurs, evidently, through rivers. Rivers take up different forms of waste material from the land, which ends up in the oceans. The most direct load of pollutants comes from the urban and industrial sewage systems that are dumped in the rivers, often preceded by a sanitation step in a water sanitation installation (and even more often not).

This urban and **industrial runoff**, together with **agricultural run-off**, also contains high levels of nitrogen and phosphorus. These two elements are essential for plant life (and in fact, for the establishment of any food chain in any ecosystem on the planet), but are often only present in the ocean in a limiting concentration to allow for abundant organismal growth. A constant influx of nutrient-rich water from the land can therefore upset any balance in the aquatic ecosystems in coastal areas. As the levels of nitrogen and phosphorus rise, the microalgae populations find themselves less and less restrained in their growth. This often results in so-called **algal blooms**: massive growth of the unicellular algae in the sea. When they die, the remaining biomass is mineralize by bacteria, which thereby consume so much oxygen that the water beneath these blooms becomes anaerobic. Any fish or invertebrate life there is bound to die. Hence, the so-called **eutrophication** due to the influx of nutrients is bound to cause severe distortion to the balance of the marine ecosystems.

A third source is the runoff from dust particles coming from metal ore and metal mines, washing away in the rivers. These metals can then wreak havoc with the normal metabolism of plant and animal life. According to the US Environmental Protection Agency (EPA), over 40% of watersheds in the western continental US have been contaminated with metals. A large proportion thereof ends up in the oceans.

Lastly, there are the large chunks of plastic that are being dumped along the coast, in rivers, etc…. Once they arrive in the ocean, they float along on the oceanic gyres which concentrates this kind of debris in the different oceans. This waste material is the main killer of life in the ocean and may take up to 450 years to be degraded.

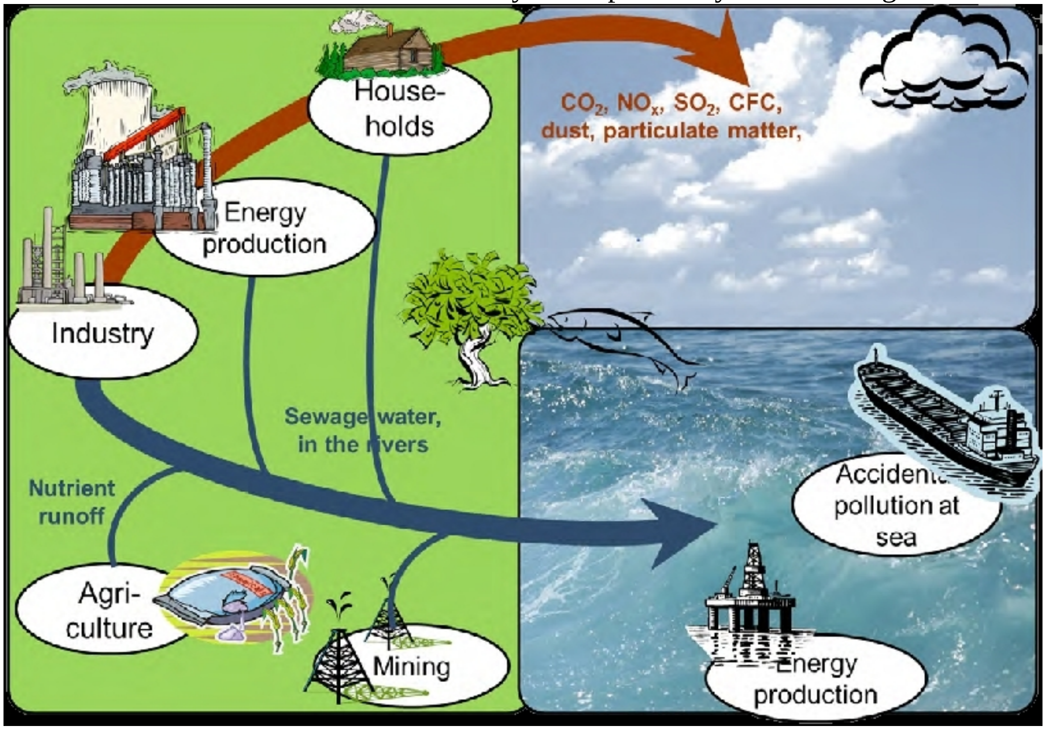

Figure 1-2. Inputs of pollution into the marine environment

1.4.2 Atmospheric pollution from the land

The atmosphere is another way for pollutants to reach the ocean.

- **Lighter dust** fractions and debris will be taken up by the wind and blown towards the ocean. A great number of dust particles will carry metal traces, which are spread out this way.
- A second type of atmospheric pollution which affects the marine environment are the **greenhouse gases**, which, by warming the earth, also raise the temperatures in the oceans. A secondary consequence seems to be that the increased concentration of CO_2 in the atmosphere contributes to ocean acidification.
- Thirdly, **combustion processes** (like car engines) produce a significant amount of SO_2 and NOx as well. These will increase the occurrence of acid rain.

1.4.3 Ships

Shipping activity may pollute the atmosphere in two major ways (Figure 1-4):

- **Ship's engines as well as the incineration of garbage: first** of all, ship's engines as well as the incineration of garbage produce CO_2, SO_2 and NO_x, which will add to global warming and acid rain formation.
- Furthermore, **cooling systems** may still be operating on freons and other chlorofluorocarbons, and occasionally some halon gases (fire extinguishing agents which are gaseous when discharged) are still at hand for fighting specific fires. Their accidental release and subsequent escape of these gases to the stratosphere furthers the build-up of chlorofluorocarbons (CFCs) in the ozone layer and the degradation of the latter. It needs to be said, though: in many

instances, these gases are being traded in for more environment friendly alternatives.

- **Most of marine pollution is simply by accident**: When it comes to the amount of pollution that goes into the water, it needs to be said that **most of it is simply by accident**. As there are a good number of international regulations that forbid express dumping of all different kinds of waste above certain levels. For example, garbage has to be either delivered to shore or burnt in incinerators onboard. Incineration is prohibited in special areas (MARPOL Annex V).
  The quantitatively largest aquatic form of accidental pollution (Figure 1-4) caused by the maritime sector is also the one that has been highlighted the most: **oil spills**. As crude oil consists of a wide range of different hydrocarbon molecules with different molecular weight and properties, it is not easy to give a concise view of the total damage that is done by an accidental spill. Apart from the highly visible heavy oil that covers the water, the animals and the shores, a large number of lighter components are present as well. These lighter components are likely to do even more damage in the long run, as they are stored in the adipose tissue of different animals in the food chain. Examples of these lighter components comprise the monocyclic and polycyclic aromatic hydrocarbons, which are difficult to clean up, and bound to cause cancer and other health problems after a few years of continuous exposure. We will discuss this in more detail in Chapter 4, Oil and organic pollution.

- **A certain quantity of polluted sewage water is being produced by people:** As people live on ships, a certain quantity of “grey water” (polluted sewage water) is being produced, in the kitchen, the showers…. Part of that goes overboard, the oceans are able to deal with raw sewage through natural bacterial action. On the other hand, the regulations in Annex IV of MARPOL prohibit discharging sewage water within a certain distance of the nearest land, unless the ship is equipped with a certified installation .

- **bilge water**: One specific compartment, designed to capture all water that does not drain off over the side of the deck, is the bilge. This water may be from rough seas, rain, minor leaks in the hull, or interior spillage. Bilge water can be found aboard almost every vessel. Depending on the ship’s design and function, bilge water may contain water, oil, urine, detergents, solvents, chemicals, pitch, particles, and other materials. Cleaning out the bilge tank is therefore bound to release a quantity of pollutants. Customarily, there is a distinction between engine bilge and all the other forms of bilge water. Again, the International Maritime Organization has imposed a number of strict rules to limit the impact of the shipping sector on the marine environment. In this case, no water exceeding 15 parts per million (ppm) of oil can be discharged overboard (MARPOL Annex I – see also 6.3.2).

- **Biological contamination** The risk for biological contamination is more tricky to contend with. To start with, when **ballast water** is taken up, it is bound to contain a number of microscopic life forms, such as algae and larval forms of invertebrates that belong to the specific region the ship resides in. When the ballast water is pumped out, possibly even after a few weeks, organisms may end up thousands of kilometres away from the region where they belong.

Figure 1-3. Biofouling organisms. Top: Left: Barnacle *Semibalanus balanoides* (Source: Kim Hansen, Wikipedia) – Right: Polychaete *Hermodice carunculata* (Source: NOAA). Bottom, Left: hydroid *Pennaria disticha* (Source: NOAA) – Right: Mollusc *Dreissena polymorpha* (the zebra mussel (Source: NOAA).

Similarly, there are the organisms that attach themselves to the ship hull in a process called **biofouling**. Calcareous fouling organisms (protected by a calcium-enforced exoshell) include barnacles, bryozoans, molluscs, polychaetes and tube worms. Examples of non-calcareous (soft) fouling organisms are seaweed, hydroids, algae and bacterial biofilms. Together, these organisms form fouling communities on all kinds of maritime objects.

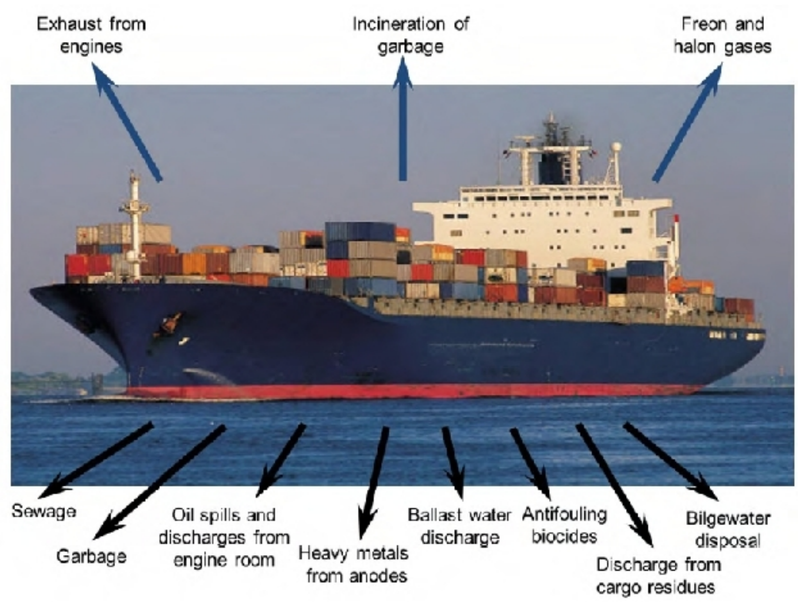

Figure 1-4. Pollution finds its way off the ship

Roughly 90% of the species that are transported unknowingly does not survive the transition to a new habitat. The remaining 10% is able to stay alive and happens to be seen now and then. They cause no harm whatsoever. 1% of the transported species, however, is able to establish a firm presence in its new home. These are called **exotic species**, or, with a more popular term, “aquatic hitch hikers”. About 10% of these exotics even ends up threatening the normal ecological processes around them, chasing the local (endemic) organisms out of their habitat and niche, taking over the region, spreading new diseases, etc…
These species are called **invasive**. They are allegedly responsible for more than $120 billion in annual losses in the US alone (Pimentel et al. 2005).

The top ten of the most invasive species in marine ecosystems can be found on http://globallast.imo.org/poster4_english.pdf

On the other hand, **prevention of biofouling** presents an environmental danger in itself, to be found in the layers of paint and antifouling agents covering all sides of the ship. Many of these chemical mixtures contain biocides – products that are designed to kill the different sea organisms that try to attach themselves to the hull, thereby favouring corrosion or decreasing the hydrodynamic character of the ship. Over time, these biocides will dissolve from the paint matrix they were originally applied in, and end up in the sea.

Similarly, there is the zinc and aluminium coming from corroding sacrificial anodes: a highly active metals that are used to prevent a less active material surface on hull of the ship from corroding. The sacrificial anode will be consumed in place of the metal it is protecting, which is why it is referred to as a "sacrificial" anode. The zinc ions that dissolve from these anodes end up in the water surrounding the hull.

cargo lose Lastly, there is the possibility that ships sometimes lose part of their cargo, due to human error, storm wind and waves. Some estimate that over 10,000 containers are lost accidentally at sea every year.

Figure 1-5. Imposex in dog whelks. The doc whelk (*Nucella lapillus*) is used as an ecological indicator in the North Sea. Their population is greatly diminished due to containing TBT containing ship coatings, causing an imbalance of in the sex hormones, which resulted in the female genitalia changing into their male counterparts, so that the females could no longer reproduce. Source: Luis Miguel Bugallo Sanchez, Wikimedia.

1.4.4 Deep sea mining

A last source of pollution is deep sea mining. This process attempts to unearth the deposits of sulfides and important and precious metals (such as silver, manganese, copper, gold and zinc), which are often created near hydrothermal vents, at about 1400–3700 m below the ocean surface (Figure 1-6). The mining occurs with hydraulic pumps and buckets being taken up and down to reach the ores and transport them to the surface.

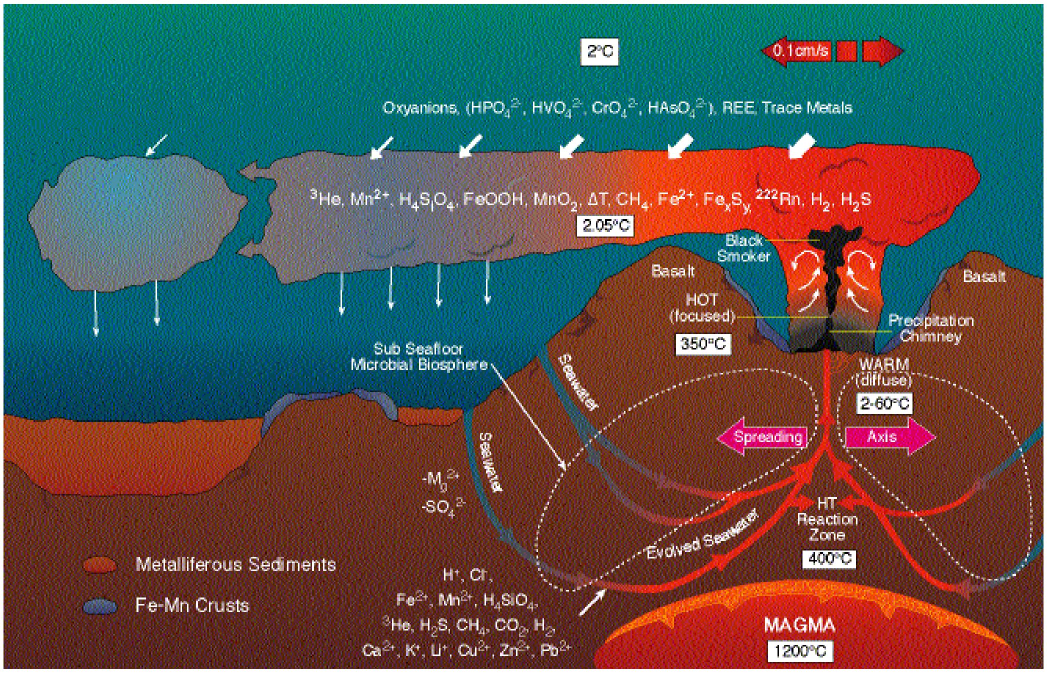

Figure 1-6. Hydrothermal circulation. This occurs when seawater penetrates into the ocean crust, becomes heated, reacts with the crustal rock, and rises to the seafloor. Seafloor hydrothermal systems have a major local impact on the chemistry of the ocean that can be measured in hydrothermal plumes. Some hydrothermal tracers (especially helium) can be mapped thousands of kilometres from their hydrothermal sources, and can be used to understand deep ocean circulation. Because hydrothermal circulation removes some compounds from seawater (e.g. Mg, $SO_4^{\ 2-}$) and adds many others (He, Mn, Fe, H2, CO2), it is an important process in governing the composition of seawater. (Source: http://www.pmel.noaa.gov/vents/chemistry/information.html)

It should not be surprising that **nations and companies turn to the sea to enhance their metal production**.

Ore mining on land has been going on for decades, if not for centuries, and many mines are being overtaxed already, if not bordering on complete exhaustion. Moreover, the **time seems right** for an economically viable exploitation of the metal ores on the ocean floor:

- a lot of the necessary technology is available, reducing the risk and the initial investments to be made; e.g. cables to be laid at such a depth, diamond drills available from deep water oil and gas mining….
- Also, metal prices are high and still rising, leading to a substantial and certified return on investment.
- And lastly, there is an apparent shift in focus from the international waters (and their highly regulated status) towards the exclusive economic zones, controlled by individual states (which are happy to share in the benefits).

Ecological consequences of deep sea mining: So far, with deep sea mining being a rather new technology, the ecological consequences are unknown (Glasby 2000, Yamazuki 2011). However, a number of concerns have already been raised:

- Digging up parts of the sea floor disturbs the benthic ecosystems close to the hydrothermal vents. These ecosystems are often teeming with life, containing many species that are unique to the vents and with a high primary production.

The ecosystems surrounding hydrothermal vents combine superheated and highly mineralized vent fluids with microbes that are capable of using chemicals as a nutritional source. In recent years, such ecosystems have been found to host over 500 species previously unknown to science. In addition, damage to those ecosystems may impact large regions of the benthic zone in the oceans.

- Mining these deposits may result in leakage of the toxic sulfides, altering the composition of the water column.
- Among the impacts of deep sea mining, sediment plumes could have the greatest impact. Plumes are caused when the tailings from mining (usually fine particles) are dumped back into the ocean, creating a cloud of particles floating in the water.

  Two types of plumes are distinguished:

  (1) seafloor plumes, which will affect the local turbidity and clog the feeding apparatus of the benthic organisms down below, and

  (2) surface plumes, which could affect light penetration in the water near the ocean surface, threatening primary production by the phytoplankton, and alter the chemical composition near the surface, affecting all planktonic life forms.

1.5 Read more?

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