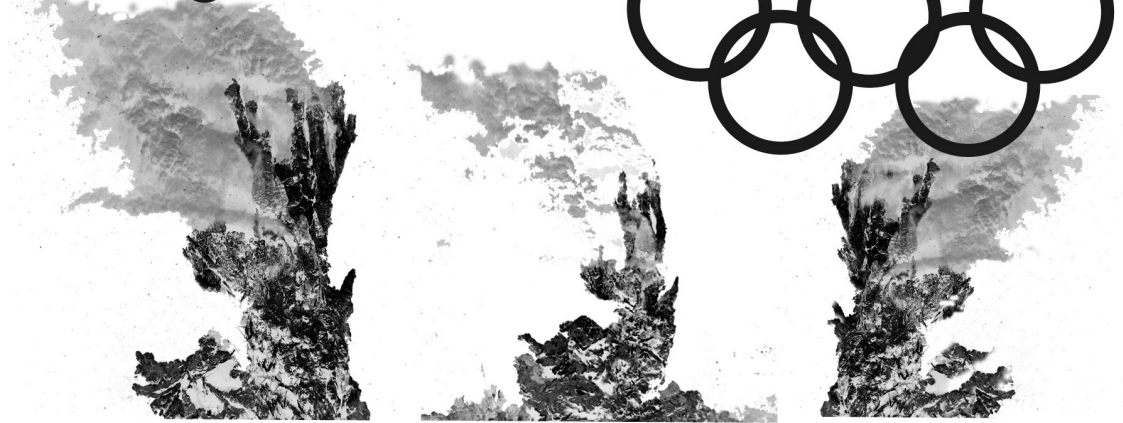
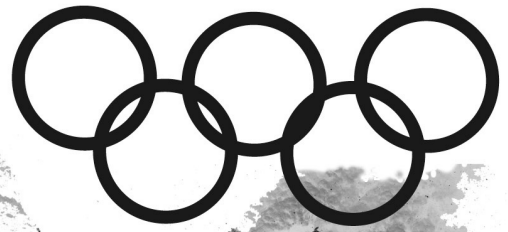


# Going for Gold!



*Who will win the race to exploit ores from the deep?*

**Maria Baker and Christopher German**

Gold, copper, zinc, lead, silver, barium, nickel and cobalt are just some of the metals whose ores deep within the ocean are becoming economically ripe for exploitation. Three decades ago, it was generally thought that the primary activity for the mining industry in the deep sea would be recovery of manganese nodules for their commercially valuable trace constituents, notably nickel, copper and cobalt. Between 1974 and 1982, more than 1 billion US dollars was spent by private companies and governments on manganese nodule investigations, but none of these endeavours resulted in commercial success, owing in large part to overestimates of the potential resource, high extraction costs, political intervention and collapsing metal prices, particularly in the case of nickel. However, today, renewed efforts in deep-sea metal extraction are underway as a result of soaring metal prices (notably for gold and copper) in response to demands from fast-growing 'new' economies such as India, China and Brazil.

In international waters, oversight of the deep sea floor outside any national jurisdiction is provided by the International Seabed Authority (ISA) – an autonomous international body established when the UN Law of the Sea Convention came into force in 1994 (see Box on p.13). There are currently eight groups from around the globe with contracts with the ISA for sea-bed exploration of manganese nodules in international waters. During the last few years, another extremely viable commodity found in the marine environment has begun to be pursued – sea-floor massive sulphide (or 'SMS') deposits formed by submarine hydrothermal venting. SMS deposits are more or less homogeneous masses of metal sulphide, which when fresh are dark metallic greys and golds, and age to rusty oranges and browns. They contain significant concentrations of base metals such as cadmium, lead and copper as well as more precious metals such as platinum, silver and gold. Although at a very early stage of exploration, the SMS industry is already extremely active, with the potential to eclipse manganese nodule mining in the race to extract minerals from the deep marine environment.

Mining in the marine environment is certainly not a new pursuit. Throughout much of the past century and in some cases even earlier, there has been mining of alluvial deposits for heavy metals (gold, tin, titanium, zirconium and others), and of diamonds and aggregates, from beaches and from shallow waters. Advanced marine technologies are currently in use on the sea-bed off the Atlantic

coast of southern Africa to recover gem-quality diamonds, down to depths of 250m. Deeper waters (down to ~4000m) have recently become a standard operating environment for the offshore hydrocarbon industry, and with the infrastructure that has resulted – not least the worldwide availability of deep-diving remotely operated vehicles (ROVs) – the sea-floor mining industry is poised to follow suit.

## **Formation and occurrence of SMS deposits**

Massive sulphide deposits can be formed at the sea-floor wherever cold seawater comes into contact with hot, fresh, volcanic or magmatic rocks – at mid-ocean ridges, at ocean islands and seamounts, in the flanks of island arcs and at back-arc spreading centres.\* The very first hydrothermal deposits to be discovered were in the deep axial basins of the Red Sea in the mid-1960s, but it was in the late 1970s that the first actively circulating hydrothermal systems were discovered on the Galápagos Spreading Centre in the eastern Pacific. Not only did these hydrothermal systems have massive sulphides associated with them,

\*At mid-ocean ridges basaltic magma rises to the sea-bed and erupts to form new ocean floor. Oceanic islands and seamounts are also formed by volcanic activity; back-arc spreading centres are special forms of mid-ocean ridge that arise, as their name suggests, landward of the island arcs that are formed whenever the ocean floor of one tectonic plate is thrust (subducted) beneath the ocean floor of another. The most famous examples of such arcs (e.g. the Marianas Arc) occur in the western Pacific.

*The photograph in the title artwork is used by courtesy of the University of Bremen.*

but they were also teeming with life previously unknown to science: this discovery has recently been recognized as one of the top 30 scientific discoveries of the entire 20th century!

The common basics to all hydrothermal circulation are as follows: as cold oxygenated seawater penetrates downward into young crust it becomes progressively warmer and undergoes a series of chemical exchange reactions with the rocks with which it is in contact (Figure 1(a)). As oxygen and other relatively oxidized chemical species are consumed (e.g. by iron(II) oxidation), the circulating fluids become anoxic as well as acidic, and acquire high concentrations of numerous metals dissolved from the host rock – notably iron, manganese, copper, zinc and lead, but also precious trace metals including silver, platinum and gold. Eventually, a point is reached at which this chemically laden fluid is heated to such an extent that it becomes buoyant and begins to rise back toward the sea floor. It is the delivery of this ore-forming fluid from below, followed, as it reaches the sea bed, by mixing with overlying cold oxygenated seawater, that gives rise to the formation of massive sulphides, both at the sea floor (often in the form of chimneys 10s of metres tall) (Figure 1(b)), and in the underlying ‘stockwork’ – the network of fluid-flow channels that feed an active vent system at the sea floor (cf. Figure 1(a)).

These massive sulphide deposits range in size from several thousand tonnes to around 100 million tonnes and are highly enriched in copper, zinc, lead and cadmium, in addition to gold and silver. The ore bodies are made up of loose material such as fallen chimneys, along with recrystallized sulphides. They are very similar to ores that are being mined on land, which formed in ancient oceans almost 3000 million years ago. In the past 30 years, many more deposits of this type have been discovered around the globe at both active and inactive vent sites. Most vents found to date are located at depths between 1500 and 3500 m, although a few have been discovered in far shallower waters.

### The biology of hydrothermal vents

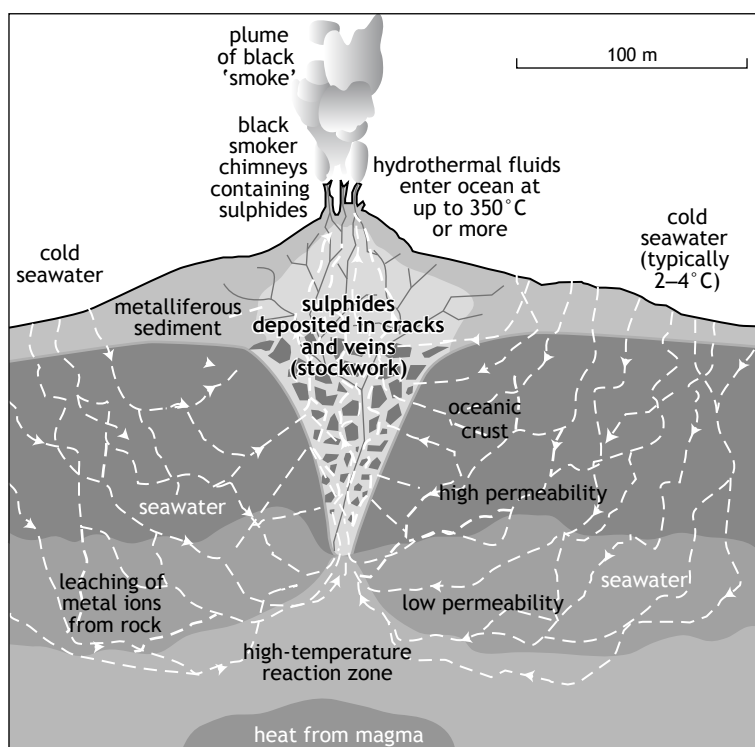
Close investigation of hydrothermal vent sites has revealed a remarkable way of life for many of the local inhabitants. These environments are extreme for life owing to the ever-changing gradients of chemistry and temperature of the fluids emanating from vents, and the ephemeral nature of the vent fields. Nevertheless, most active (established) vent sites studied to date are characterized by dense communities of exotic fauna which are sustained by the process of chemosynthesis, relying on chemo-autotrophic microbes which use chemicals such as hydrogen sulphide or methane supplied by the hydrothermal vent as their energy source. More than 500 species new to science have been discovered in the first 30 years of vent research, making an average rate of one new species every two weeks.

These animals are specially adapted for life at the vents and are different from the fauna in the surrounding deep sea. Some of the key inhabitants associated with hydrothermal venting are tubeworms, large bivalves, shrimp, gastropods

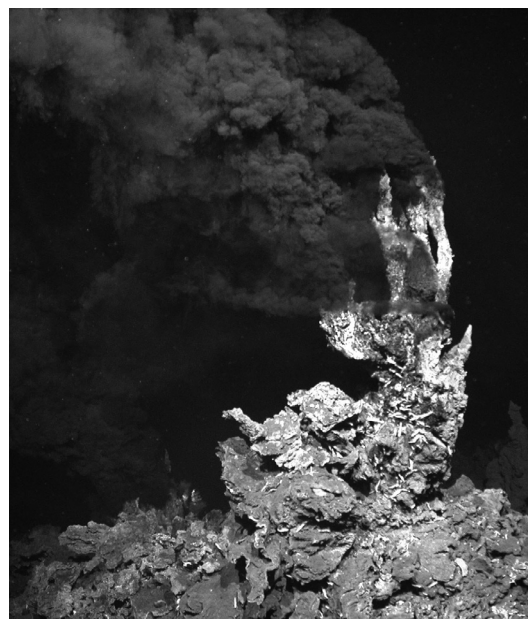
**Figure 1 (a)** Schematic diagram to illustrate the environment in which massive sulphide deposits are formed within the ocean crust and at the sea-bed. Black smoker chimneys result when the metal-rich fluid reaches the sea-bed without having mixed with cold seawater in the upper part of the crust; when significant mixing occurs, the resultant fluids can be substantially cooler and are typically much less chemically enriched as they enter the ocean, having deposited much of their mineral content within the crust (these fluids are often also those most preferred by chemosynthetic organisms).

**(b)** The black smoker chimney ‘Candelabra’, formed at one of a number of hydrothermal vents located within the Logatchev hydrothermal field at ~15°N, at around 3000 m depth on the Mid-Atlantic Ridge. The black ‘smoke’ is mainly metal sulphide particles, but also oxides and hydroxides.

Photo courtesy of MARUM, University of Bremen

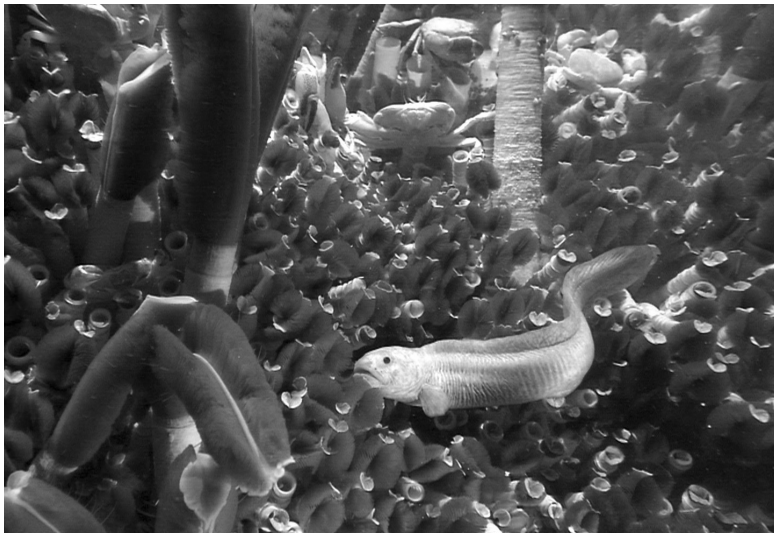


(a)



(b)

SMS deposits are found at the sea bed in the form of chimneys, and within the stockwork at shallow depths within the ocean crust



Active vent sites support flourishing communities of unique animals that could be adversely affected by mining of SMS deposits

**Figure 2** Giant tubeworms, *Riftia pachyptilla*, with zoarcid fish (commonly known as eelpouts) and galatheid crabs (also known as squat lobsters) inhabit an active vent at 2600m depth on the East Pacific Rise (to the west of Mexico). The tubeworms are distinct from those found at vent sites on the Juan da Fuca Ridge in the north-east Pacific, as are the invertebrates and fish that live in association with them.

Courtesy of Emory Kristof

and crabs (Figure 2). In addition, the chemosynthetic bacteria can grow into thick mats which can attract grazing animals from the surrounding waters and sea-bed.

Scientific investigations have only just begun to unravel the potential for exciting discoveries in these environments. Currently, there are major gaps in our knowledge of life at vents in terms of the adaptation of animals to long-range dispersal and (often rapid) colonization processes, and of genetic diversity and variability at vents among and between different ocean basins. In particular, there is a lack of knowledge about what fauna might inhabit extinct/inactive sulphide deposits which, inevitably, will be far more attractive to future economic exploitation than the active sites, spewing hot acidic fluids, that have attracted most scientific attention to date. There are likely to be hundreds, if not thousands, of undiscovered vents around the globe, in all ocean basins.

Over 200 active vent sites have been discovered to date and only a small number of these have been studied in any detail in terms of their fauna. Nevertheless, six discrete biogeographic provinces of hydrothermal vent fauna are already evident and are distributed around the Pacific, Atlantic and Indian Oceans, indicating the isolated nature of vent communities. Figure 2 shows a group of animals typical of active vents on the East Pacific Rise.

It is inevitable that additional biogeographic provinces will be distinguished as more vent systems are discovered. These discoveries will bring increased understanding of the ecology of vent fauna and the limits to life, as well as great potential for fundamental discoveries for biotechnology and biomedical applications.

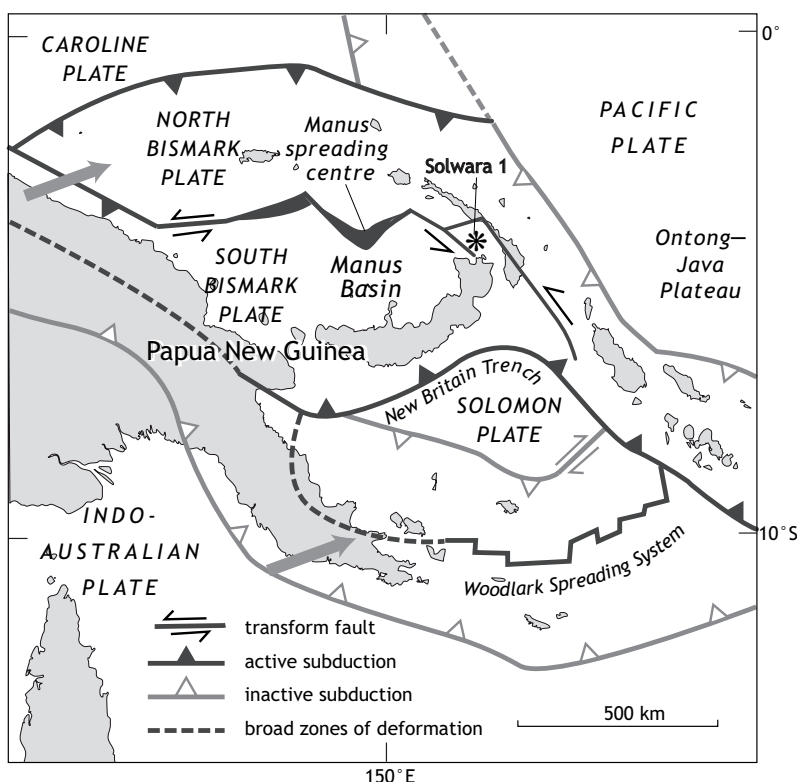
### Current SMS mining pursuits

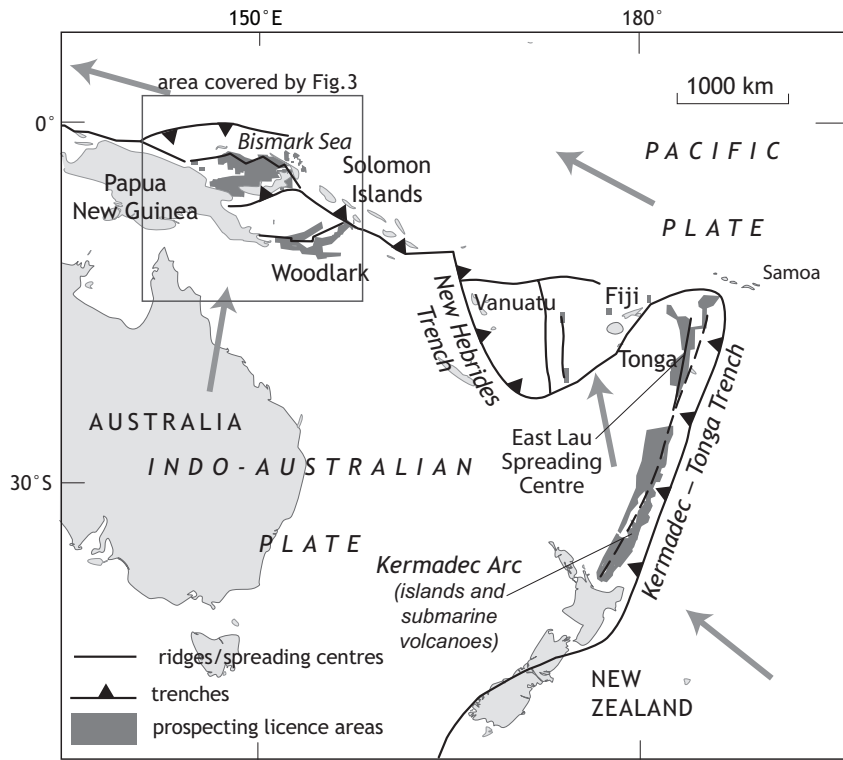
Thus far, commercial interest in the mining of deep-water massive sulphides has been restricted to the deep waters of individual nation states' exclusive economic zones (cf. Box, p.13) and, in this regard, two companies have been particularly prominent in the past few years – Nautilus Minerals Inc. ([www.nautilusminerals.com](http://www.nautilusminerals.com)) and Neptune Minerals ([www.neptuneminerals.com](http://www.neptuneminerals.com)). Both are now listed on the London stock exchange, with Nautilus also listed on the Toronto stock exchange.

In recent years, Nautilus Minerals Inc. has undertaken exploratory investigations and environmental baseline assessments incorporating sampling, drilling, side-scan sonar and ROV-based studies, in the eastern Manus Basin of the Bismarck Sea, Papua New Guinea, at depths of around 1500m. In total, however, Nautilus has already licensed a cumulative area of > 521 000 km<sup>2</sup> (more than twice the area of the UK) in a combination of tenement licenses (i.e. leases) and exploration applications in waters off Papua New Guinea, Fiji, Tonga, the Solomon Islands and New Zealand – including much of the axis of the East Lau Spreading Centre, the focus of much international back-arc basin/mid-ocean ridge and hydrothermal research (cf. Figure 4). Nautilus Minerals Inc. is aiming to bring their first site (Solwara 1, in the territorial waters of Papua New Guinea; Figure 3)

Nautilus's Solwara 1 site is on a volcanic mound in a zone of rifting between two transform faults

**Figure 3** Tectonic map of the area around Papua New Guinea, showing the position of the Solwara 1 site at the eastern end of the Manus back-arc spreading centre system. This is just one area under investigation by sea-bed mining companies; for the positions of prospecting areas (both granted and under application) in the vicinity of Papua New Guinea, see Figure 4. (Grey arrows indicate relative plate motions.)





**A tectonically active region with extensive zones of hydrothermal activity, the south-western Pacific is a focus of interest for the SMS industry**

**Figure 4** Map of the south-western Pacific, showing sites of prospecting areas (licences both granted and under application) in relation to active plate boundaries and various tectonic features. Grey arrows indicate relative plate motions. The boxed area is that covered by Figure 3.

into full production by 2010, subject to the granting of appropriate permits.

Neptune Minerals have also been establishing extensive exploration programmes across the western/south-western Pacific with, in their case, a particular initial focus on New Zealand waters. Their recent success includes the discovery of two hydrothermally inactive massive sulphide zones along the Kermadec Arc region offshore North Island (Figure 4). Their currently granted exploration license areas in the EEZs of New Zealand, Papua New Guinea, Vanuatu and the Federated States of Micronesia, total > 278 000 km<sup>2</sup>. They also have pending exploration applications covering 436 000 km<sup>2</sup> in the territorial waters of New Zealand, Japan, Palau, the Commonwealth of Northern Mariana Islands and, closer to home, in the Mediterranean, off Italy. Ultimately, Neptune is seeking to undertake extensive sampling operations and assessment of the characteristics and extents of the SMS deposits within these territorial waters, as part of a 'staged' commercialization process. At present, they have committed to focus upon massive sulphide deposits from inactive hydrothermal sites, in an attempt to minimize impacts on chemosynthetic fauna. Pilot mining operations, in which systems and equipment are to be fully trialled and tested on a reduced scale, are planned for the end of 2010, followed by full-scale mining thereafter.

It seems highly likely, therefore, that economically viable extraction of sulphides from the deep sea floor may begin within the next few years, and become established within the next decade, providing markets with metals for which the demand seems destined only to grow.

### Marine minerals and the Law of the Sea

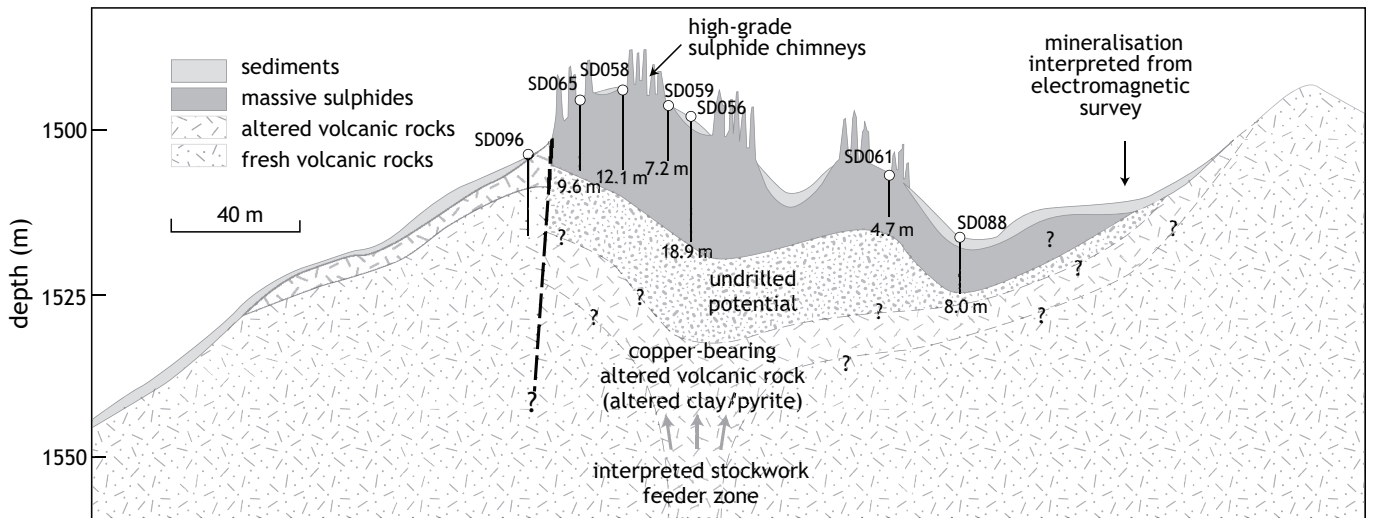
The legal instrument that covers exploration for, and exploitation of, marine mineral resources is the 1982 United Nations Convention on the Law of the Sea (UNCLOS), which came into force in 1994 and is binding on those states that have ratified or acceded to it.

Under UNCLOS, coastal states have complete control over exploitation of sea-bed resources (and living resources) in their territorial seas, which are typically 12 nautical miles (n.m.) wide.

Within their exclusive economic zones (EEZs), which extend out to 200 n.m., coastal states have sovereign rights over sea-bed resources and can lease exploration/exploitation rights to foreign companies as they see fit. UNCLOS places special emphasis on coastal states' responsibility for protecting and preserving the marine environment within their EEZs.

Areas of ocean beyond EEZs, i.e. international waters (also known as the high seas), are underlain by the International SeaBed Area (or the 'Area'), which is defined as 'the seabed and ocean floor and subsoil thereof beyond the limits of national jurisdiction'. All activities in the Area are organized and controlled by the International Seabed Authority (ISA). The ISA acts on the principle that the Area and its resources are the common heritage of all mankind (including people in developing countries and landlocked states), but by the time UNCLOS came into force in 1994 its approach to managing sea-bed resources had become more commercial. Environmental protection has nevertheless remained one of the ISA's highest priorities.

The ISA's Mining Code regulates prospecting, exploration and exploitation of marine minerals in the International Seabed Area and sets out standard terms for exploration contracts. Environmental provisions are a major part of the obligations that the Authority placed on itself and on sea-bed contractors in its regulations. In 2000, the ISA adopted regulations governing prospecting and exploration for polymetallic nodules (i.e. manganese nodules). In August 2002, work began on regulations covering polymetallic sulphides (i.e. SMS deposits) and cobalt-rich ferromanganese crusts. Contentious issues still remaining include the definition and configuration of areas to be allocated to contractors for exploration, the fees to be paid to the ISA, and the question of how to deal with overlapping claims.



**Figure 5** Cross-section of an area of hydrothermal chimneys being explored by Nautilus, providing an example of typical spacings and depths of drill cores. (Note the exaggerated vertical scale.)  
 Courtesy of Nautilus Minerals Inc.

**Geophysical surveys and grid-drilling are used to assess the average ore grade of a massive sulphide deposit and predict its extent and volume**

**Technology for SMS mining**

Much of the technology that will be used for sea-floor mining of massive sulphides will undoubtedly be adapted from that already developed for the offshore hydrocarbon industry. For example, technologies are required to explore for and locate deposits (mapping, sub-sea-floor geophysics), for sample-collection (e.g. for resource char-

acterization and site-evaluation; Figures 5 and 6), and for transportation and processing. One of the key challenges that designers of deep-sea mining equipment might face, especially if they need to be

**Figure 6 (a)** A hydrothermal massive sulphide deposit, being sampled by means of an ROV. The deposit is rusty gold in colour, and the snails (*Ifremeria sp.*, which prefer waters of ~ 6 °C) are a few centimetres across.

**(b)** The Senior Geologist of Teck Cominco Ltd (under secondment to Nautilus) with a sample of massive sulphide (part of a chimney) recovered from the Solwara 1 site, at ~1500 m depth in the Bismark Sea, off Papua New Guinea (cf. Figure 3).

**(c)** High-grade Solwara 1 copper/gold chimney sample ~ 0.5 m across. The voids are the 'pathways' that the metal-rich fluids rise up through.  
 Courtesy of Nautilus Minerals Inc.

**Collecting hydrothermal sulphide samples from the deep sea floor has become much easier since the widespread availability of deep-water ROVs**



(b)



(a)



(c)

prepared to work at active hydrothermal sites, will be to develop technology that can operate safely and efficiently, and with minimal environmental impact, in extreme environments where extraordinarily steep chemical and thermal gradients may be encountered under conditions of immense pressure, amongst extremely rugged topography.

Exploratory techniques for locating deep-sea vent sites have recently been revolutionized with the recognition that AUVs (autonomous underwater vehicles) can be used for this purpose. Active vents can be located from their plumes, which can disperse some 10s of kilometres through the water column but can be tracked back to their vent-source. In essence, pin-pointing the position of a vent can be conducted in three discrete phases. First, dispersing hydrothermal plumes can be traced over several kilometres, using both chemical and physical sensors, and the cores of these plumes located to within less than 1 km. Next, using a combination of high resolution multibeam mapping and/or sonar imaging, coupled with continued use of *in situ* physical and chemical sensors, individual sites of venting and their geological setting can be determined to within length-scales less than 100 m. Finally, AUV- or ROV-based photographic surveys can be used to fully characterize the lateral extent of individual sites and the ecosystems that they host.

While inactive and active vents can often be found in close proximity, locating inactive vents away from sites of active venting remains a challenge. For this reason, very little is yet known about the geology, chemistry and biology of inactive deep-sea hydrothermal systems – and yet such understanding will be fundamental to the baseline survey of any inactive hydrothermal site selected for commercial exploitation. Consequently, we would argue that multidisciplinary investigations of both active *and* inactive SMS systems should be an urgent target for future international research.

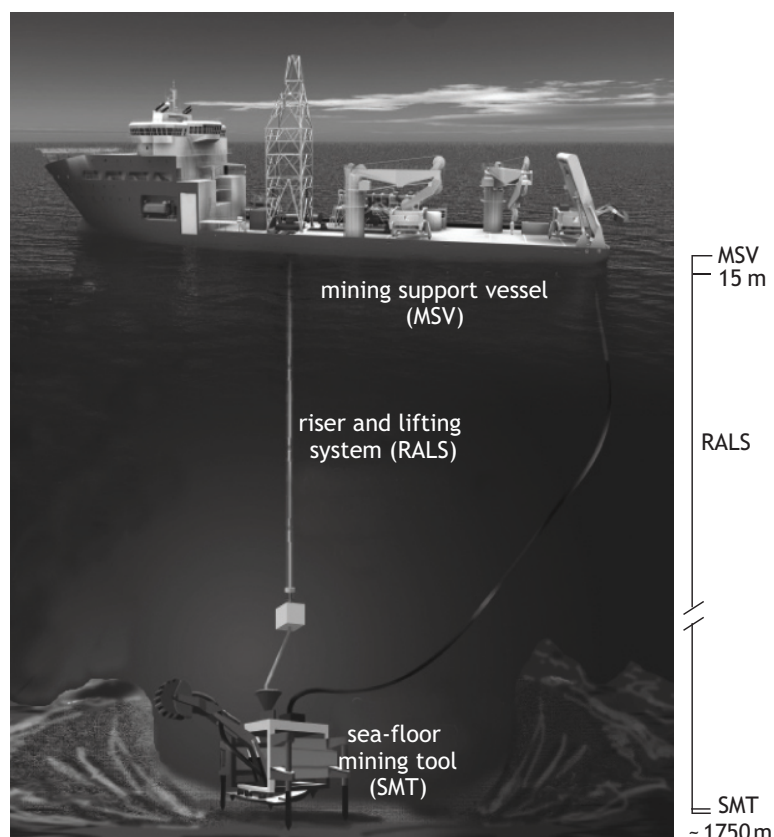
Once located, more detailed investigation of a massive sulphide deposit is required using a combination of geophysical surveys and geochemical analyses of samples recovered from the deposit. This work is conducted to determine the massive sulphide ore-grade (i.e. the concentrations of valuable metals that it contains) and the tonnage of the deposit. If initial samples from the surface of the deposit combined with sonar investigations and mapping of its areal extent indicate a potentially high-grade ore, of commercially exploitable size, then coring ± further geophysical surveys are required to determine its three-dimensional form and, hence, full extent. Grid-drilling, for example, can be used to determine the average ore grade throughout the body of a deposit and to determine its volume (cf. Figure 5). Such drilling operations may be carried out by drill ship or using dedicated sea-floor ROVs and instruments.

If positive results are obtained from the coring process, trial mining may begin and this requires new extractive technologies based upon previous crust and nodule mining systems, themselves modified from terrestrial coal and ocean diamond mining methods. Progress in this field is swift

– large mining machines are already being used to dig pipe trenches for moving oil and gas to shore from deep-sea wells. In December 2007, Nautilus Minerals Inc. awarded a contract worth around £33 million to Soil Machine Dynamics (based in the UK) for the design and build of two Seafloor Mining Tools (SMTs). A second contract with a \$116 million target price was awarded to Technip USA Inc. in April 2008 to develop the Riser and Lifting System (RALS) components (Figure 7). In June 2008, a third contract was awarded to North Sea Shipping Holding AS to provide a specialist Mining Support Vessel (MSV).

The SMTs – gigantic crab-like mining robots with multiple claws – are capable of digging out 100 cubic metres of rock per hour at SMS deposit sites. The crushed material will then be pumped to the surface as slurry through the steel riser pipe onto the MSV. It is envisaged that the commercially valuable cargo will then be dewatered onboard ship before being transported to a nearby port facility by barges. The waste water will be filtered and released at a predetermined depth in the water column to be ascertained through impact assessment.

*The extractive technologies being developed to exploit SMS deposits are based on systems developed to exploit manganese nodules and crusts*



**Figure 7** Artist's impression of Nautilus's planned sea-floor mining system (see text). The first step in the mining process involves cutting the massive sulphide and drawing it into the suction mouth of the Seafloor Mining Tool as slurry. The slurry is then transported to a pumping module and lifted up a steel riser pipe to the Mining Support Vessel on the surface, where the material is dewatered.

Adapted from an image supplied by Nautilus Minerals Inc.



**Gigantic mining robots known as 'crawlers' are capable of digging out 100 cubic metres of rock per hour**

**Figure 8** Marine and Mineral Projects of South Africa are currently adapting this deep-sea 'crawler' (which moves on tracks, visible here) for the mining of SMS deposits. It is linked to the mining support vessel by an 'umbilical' that provides power and allows it to be remotely controlled from above (cf. Figure 7). Material which is sucked from the sea-bed takes just 25 seconds to travel up the 'riser' to the vessel at the surface.

By courtesy of Nautilus Inc.

### Potential environmental impacts

The true nature of the environmental impacts of massive sulphide mining will remain uncertain prior to the onset of commercial deep-sea mining activity or at least the trial-mining stage. However, attempts may be made to try to minimize any impacts prior to the proposed new industry commencing in 2010. The design and application of the technology to be used in deep-sea mining, and the standards adopted by both regulators (where appropriate) and the industry itself, will largely determine the impacts on the environment. There are a number of potential environmental effects of mining that are of concern to some stakeholders. These include: direct physical damage to the sea-bed at the operation site and the surrounding area; production of sediment plumes and deposition of sediment, which will affect marine life by smothering or inhibiting filter-feeders; alteration of fluid-flow paths at the vent, on which the benthic (often sessile, i.e. permanently attached to the substrate) vent fauna rely; noise pollution; waste water disposal; and equipment failure which may result in leakage.

It is very difficult to assess the impacts of such disturbances. Whereas some effects will be obvious and inevitable (e.g. the detrimental short-term effects on fauna living at or close to the mining site), other consequences are not so clear. For example, increased concentrations of nutrients in the upper water column could occur as a result of water pumped up during the mining process being released after dewatering of the mined rock. This could lead to localized eutrophication, an increase in primary productivity, and consequent changes in structures of biological communities. The rate of recovery of the local marine commu-

nity post-mining operations, and knock-on effects with respect to neighbouring vent communities, are difficult to predict. To be able to predict impacts, one first has to thoroughly understand the functioning of the unperturbed system. But we still know so little about the dispersal mechanisms of animals from one vent to another and about recolonization and recovery processes, that attempts to gauge such impacts are severely impaired. There is uncertainty about the degree of endemism at particular vent sites (the extent to which organisms are uniquely found there), especially in the case of active sites. Baseline studies of the first SMS mining sites are therefore crucial if we are to enhance our knowledge of these matters, and so help in the development of regulatory mechanisms for the industry.

To date, there have been very few impact studies of potential SMS mining sites. However, some information may be gleaned by looking at the extensive array of studies that have been conducted relating to the mining of deep-sea nodules (see Further Reading). Although many factors differ greatly between the two habitat types (such as depth, topography and thickness of overlying sediments) some overlaps may be evident, such as the generation and effects of sediment plumes.

Both Nautilus Minerals and Neptune Minerals are currently supporting biological studies to determine the level of biological activity at their potential mining sites. Neptune is undertaking detailed baseline assessments of their sites, which are cold inactive sites. Preliminary research indicates that these inactive sites are colonized by animals from the surrounding area, once venting ceases. Neptune state that their sites of study do not appear to have high levels of biomass or endemism but are composed of cosmopolitan species from the surrounding deep sea. Nautilus is undertaking baseline assessments of both active and inactive sites in their proposed mining area. In collaboration with vent scientists they are currently developing an Environmental Impact Statement for their planned ocean mining operation off Papua New Guinea. These baseline studies of the local habitat and biodiversity will help to inform the scientific community, and will provide information to allow comparison of pre- and post-mined sites and hence define the course of action needed to avoid any long-term damage to sea-floor communities.

Some industrialists and scientists argue that sea-floor mining will be better for the environment than terrestrial mining. Only 30% of our planet is land and, as we know, mining on land leaves a substantial footprint in terms of scarring of the land, polluted waterways, carbon emissions from heavy machinery, and huge amounts of dumped waste rock. The high levels of enrichment of sulphide ore deposits found in the ocean mean that far smaller amounts may be mined profitably, and with far less waste. It may well be easier to plunge through a few hundred or thousand metres of water than it is to drill through a few thousand metres of rock.

## Science and policy involvement

This new and exciting frontier of deep-sea exploration and mining of base and precious metal sulphides raises a significant number of questions about potential environmental impacts and the sustainable use of ocean resources. It is therefore imperative that, without delay, all stakeholders, including industry and scientists, come together to discuss the national and international regulations governing marine exploration and mining activities in order to achieve transparency for all interested parties, and in particular the public who are increasingly concerned about the state of our oceans. It is crucial that updated guidelines are established and followed by the emerging SMS mining industry.

At the time of writing, some guidelines have begun to be developed, relating to activities at hydrothermal vent sites. In terms of scientific input, InterRidge has established a statement of commitment to responsible research practices at deep-sea hydrothermal vents ([www.interridge.org/en/IRstatement](http://www.interridge.org/en/IRstatement)), which has been signed by many vent scientists and endorsed by the Census of Marine Life's ChEss Project ([www.noc.soton.ac.uk/chess](http://www.noc.soton.ac.uk/chess); see also Further Reading). This signatory process is ongoing via the InterRidge website. In the case of industry, a Code for Environmental Management of Marine Mining was established by the International Marine Minerals Society in 2001 and is due to be updated shortly ([www.immsoc.org/IMMS\\_downloads/codefeb2002.pdf](http://www.immsoc.org/IMMS_downloads/codefeb2002.pdf)).

Discussions initiated in 2004, at the 10th anniversary celebrations of the International Seabed Authority, led to a meeting among various stakeholders, hosted by the ISA, in October of that year. While the ISA had previously focussed its attention much more upon policies relating to manganese nodule mining from the deep ocean floor, increasingly it has been turning its attention to SMS deposits and, in 2007, published its first draft regulations on this topic ([www.isa.org.jm/en/documents](http://www.isa.org.jm/en/documents)).

Building on this momentum, the offices of ChEss and InterRidge joined forces in early 2008 to propose, in collaboration with the ISA, a joint scientific and policy discussion meeting to be held in spring 2009. This meeting will comprise two parts: together, ChEss and InterRidge will organize a meeting, targeted predominantly at scientists, to discuss key recent findings and future directions of sea-floor hydrothermal research. Nested within this, in April 2009, a Morss Colloquium will be held in Woods Hole, USA, on the socio-economic and societal impacts of future SMS mining. This will include representatives of the industrial and (national and international) regulatory communities as well as numerous other interested parties, alongside key international scientists. In concert, the aim of these activities will be to identify the highest priorities for future international research, and develop implementation plans to ensure that we bridge serious gaps in understanding.

## Concluding remarks

It seems likely that the marine massive sulphide industry will win out over the manganese nodule industry in the race for exploiting ores from the deep, at least in territorial waters. These are exciting times for both marine mining and hydrothermal research. There is increasing recognition that hydrothermal vents may be much more widespread than was initially apparent, especially along slow-spreading ridges, such as the Mid-Atlantic Ridge. Further, at least some slow-ridge hydrothermal systems (e.g. TAG and Rainbow) are now known to be longer lived and hence to give rise to much larger sea-floor deposits at any one site than is typical along faster spreading ridges such as the East Pacific Rise.

With increasingly positive news regarding the existence of sizeable massive sulphide deposits of high grade, it is perhaps inevitable that we will soon see metals extracted from the sea floor of ocean island states now entering the global economy – not least to sustain the growth of various rapidly emerging manufacturing-based 'new' economies. Exactly what the environmental impacts will be, and what lessons can be learned to steer regulation in international waters, remain to be seen. But this is clearly a field where deep ocean scientists have much opportunity – and a responsibility – to participate, to investigate previously overlooked aspects of deep-sea hydrothermal systems, and to provide national and international regulatory bodies with the best possible advice on how to proceed.

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## See also:

[www.isa.org.jm/files/documents/EN/Brochures/ENG8.pdf](http://www.isa.org.jm/files/documents/EN/Brochures/ENG8.pdf)  
[www.isa.org.jm/files/documents/EN/13Sess/Cncl/ISBA-13C-WPL.pdf](http://www.isa.org.jm/files/documents/EN/13Sess/Cncl/ISBA-13C-WPL.pdf)  
[www.underwatermining.org](http://www.underwatermining.org)

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