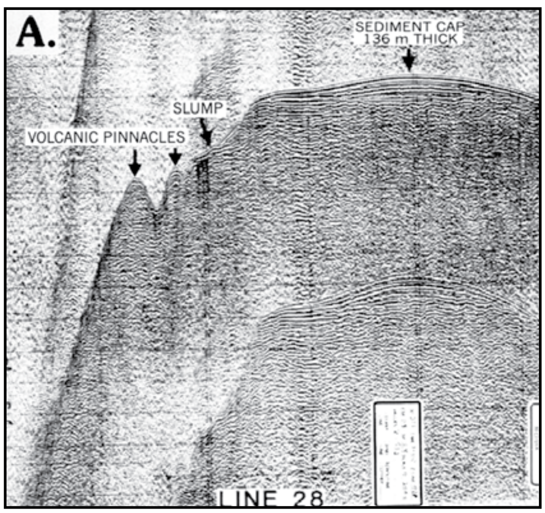
Cobalt-Rich Crusts

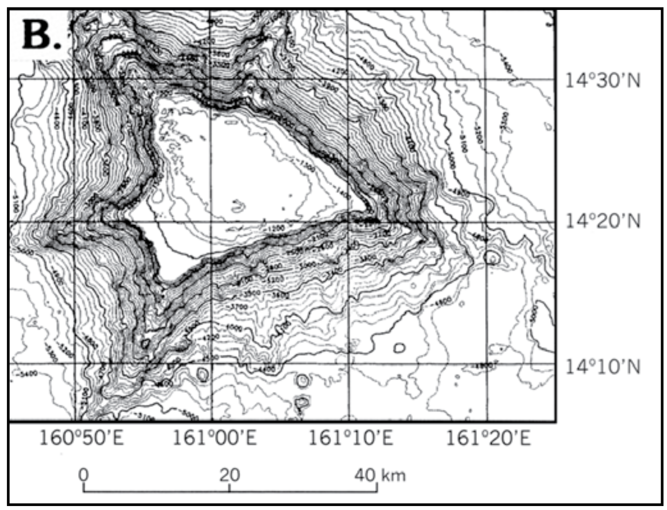
Under the 1982 United Nations Convention on the Law of the Sea, the International Seabed Authority is responsible for controlling all resource-related activities in the international seabed area. One such resource is cobalt-rich ferromanganese crusts, which are found on the flanks and summits of seamounts throughout the world's oceans. Since 2001, the Authority has been considering the nature of a regulatory system that would govern prospecting and exploration for these resources. Like the regulations adopted in 2000 covering exploration for polymetallic nodules, the proposed new rules would regulate the activities of the Authority and of any private and public entities that might contract with it to investigate deposits of these resources in the international seabed area of the deep ocean, beyond national jurisdiction.

Occurrence, Formation and Distribution

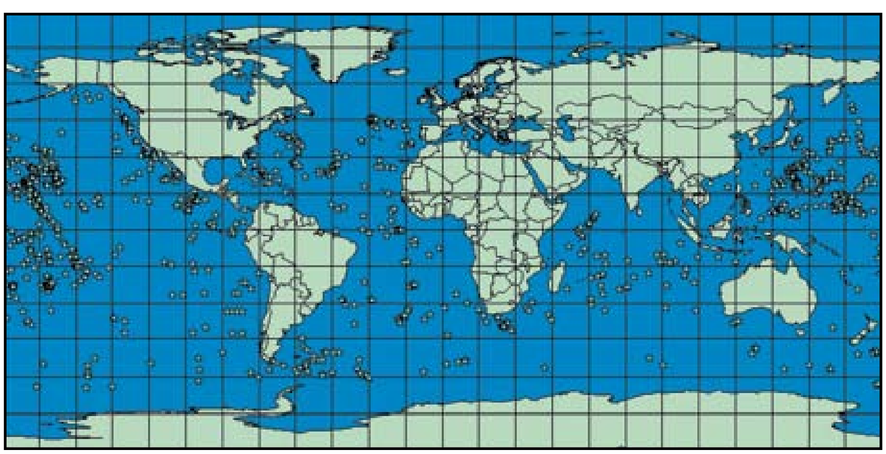
Oxidized deposits of cobalt-rich ferromanganese crust are found throughout the global oceans on the flanks and summits of seamounts (submarine mountains), ridges and plateaux, where seafloor currents have swept the ocean floor clear of sediment for millions of years. These seamounts can be huge, some as large as mountain ranges on the continents. Only a few of the estimated 30,000 seamounts that occur in the Pacific, where the richest deposits are found, have been mapped and sampled in detail. The Atlantic and Indian oceans contain far fewer seamounts but have been far less sampled.



A. Seismic-reflection profile of a seamount in the central Pacific



B. Bathymetric map of a Marshall Islands (west-central Pacific) flat-topped seamount (guyot)



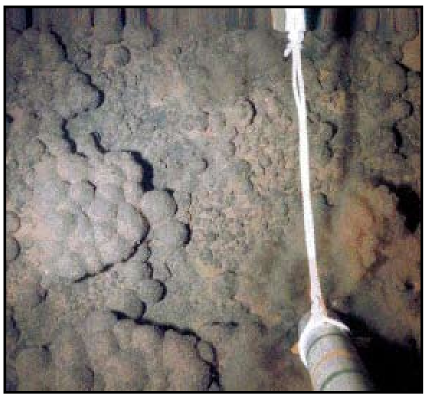
Cobalt-bearing ferromanganese crusts sampling points in the world's oceans

The minerals in crusts have precipitated out of the cold ambient seawater onto the rock surface, likely with the aid of bacterial activity. The crusts form pavements up to 25 centimetres thick and cover an area of many square kilometres. According to one estimate, about 6.35 million square kilometres, or 1.7 per cent of the ocean floor, is covered by cobalt-rich crusts, translating to some 1 billion tonnes of cobalt.

Crusts do not form in areas where sediment covers the rock surface. They are found at water depths of about 400-4,000 metres, in contrast to the 4,000-5,500 metres at which manganese nodules occur. The thickest crusts, richest in cobalt, occur on outer-rim terraces and on broad saddles on the summits of seamounts, at depths of 800-2,500 metres.

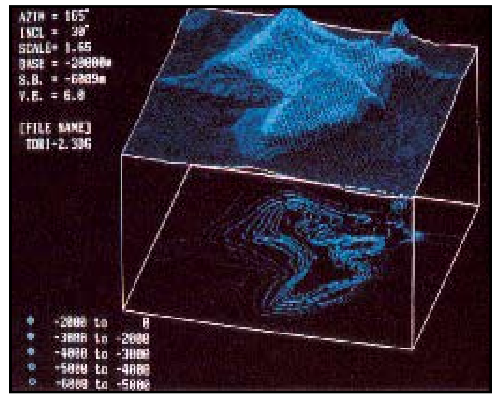
Crusts generally grow at the rate of one molecular layer every one to three months, or 1-6 millimetres per million years, one of the slowest natural processes on earth. Consequently, it can take up to 60 million years to form a thick crust. Some crusts show evidence of two formative periods over the past 20 million years, with an interruption in ferromanganese accretion during the late Miocene epoch 8 to 9 million years ago, when a layer of phosphorite was deposited. This separation between older and younger materials can be a clue in identifying more ancient and thus richer deposits. The occurrence of richer deposits at depths where the water contains minimum oxygen has led investigators to attribute part of the cobalt enrichment to the low oxygen content of the seawater..

Based on grade, tonnage and oceanographic conditions, the central equatorial Pacific region offers the best potential for crust mining, particularly the exclusive economic zones around Johnston Island and Hawaii (United States), the Marshall Islands, the Federated States of Micronesia and international waters of the mid-Pacific. Moreover, crusts from shallow waters contain the greatest concentration of minerals, an important factor for exploitation. (Exclusive economic zones are ocean areas extending 200 miles offshore from coastal baselines, within which coastal States have exclusive rights over resources.



Ferromanganese crusts on a seamount (CoRMC-H, Auki)

Section of a Ferromanganese crust (CoRMC-H, Auki)



A model of a seamount containing ferromanganese crusts (CoRMC-H, Auki)

Characteristics and Composition

In addition to cobalt, crusts are an important potential source for many other metallic and rare earth elements such as titanium, cerium, nickel, platinum, manganese, phosphorus, thallium, tellurium, zirconium, tungsten, bismuth and molybdenum. Crusts are composed of the minerals vernadite (manganese oxide) and feroxyhyte (iron oxide). Moderate amounts of carbonate-fluorapatite occur in thick crusts, while most crusts contain minor quantities of quartz and feldspar. Crusts contain a high content of cobalt, up to 1.7 percent, and large areas of individual seamounts may contain crusts with average cobalt content of up to 1%. These cobalt proportions are much higher than in land-based ores, which range from 0.1 to 0.2 % cobalt. Other than cobalt, the most valuable of the crust metals are titanium, cerium, nickel and zirconium, in that order.

Another important consideration is the contrast in physical properties between crusts and the rocks on which they grow. Their occurrence on a wide variety of rock types makes it difficult to tell them apart from their substrate when using conventional remote sensing techniques. However, crusts can be distinguished from their rock base by their much higher levels of gamma radiation. Thus, remote sensing of gamma radiation may be a useful tool when exploring for crusts located under thin sediment cover, and for measuring crust thickness on seamounts.

Prospective miners are likely to look for a number of special characteristics in their search for exploitable crusts. These include large seamounts shallower than 1,000-1,500 metres, older than 20 million years and not capped by large atolls or reefs, located in areas of strong and persistent bottom currents, with a shallow and well-developed oxygen-minimum zone in the overlying water, and isolated from an abundant influx of river and wind-blown debris. Moreover, they will look for a fairly level bottom without excessive undulation, located on summit terraces, saddles or passes, with stable slopes and no local volcanism. Guyot type features are considered favourable for cobalt crust occurrences. Their preference will be for average cobalt content of at least 0.8% and average crust thickness no less than 4 centimetres.

Mineralogical Composition of Seafloor Polymetallic Sulphide Deposits

	Back-Arc Deposits	*Mid-Ocean Ridge Deposits*
Fe-sulphides	**pyrite, marcasite, pyrrhotite**	**pyrite, marcasite, pyrrhotite**
Zn-sulphides	**sphalerite, wurtzite**	**sphalerite, wurtzite**
Cu-sulphides	**chalcopyrite, isocubanite**	**chalcopyrite, isocubanite**
silicates	**amorphous silica**	**amorphous silica**
sulphates	**anhydrite, barite**	**anhydrite, barite**
Pb-sulphides	**galena, sulphosalts**	
As-sulphides	**orpiment, realgar**	
Cu-As-Sb-sulphides	**tennantite, tetrahedrite**	
native metals	**gold**	

Industrial Uses

The types of metals occurring in cobalt-rich crusts – notably cobalt, manganese and nickel -- are used to add specific properties to steel, such as hardness, strength and resistance to corrosion. In industrial countries, between one fourth and one half of cobalt consumption is used by the aerospace industry in super-alloys. These metals are also employed in chemical and high-technology industries, for such products as photovoltaic and solar cells, superconductors, advanced laser systems, catalysts, fuel cells and powerful magnets, as well as for cutting tools.

Investigations to Date

The first systematic investigation of crusts was carried out in 1981 in the Pacific Ocean. Early work was carried out by groups from Germany, the United States, the Union of Soviet Socialist Republics (later the Russian Federation), Japan, France, the United Kingdom, China and the Republic of Korea. Field studies by the United States, Germany, the United Kingdom and France have been completed. The most detailed studies concerned deposits in the equatorial Pacific, mostly within the exclusive economic zones of island nations. Between 1981 and 2001, about 42 research cruises studied cobalt-rich crusts along with other deep-sea mineral deposits in Pacific waters, incurring total expenditures of about $US 70-100 million for fieldwork and research. Many of these were carried out by Japan on behalf of the developing island States belonging to the South Pacific Applied Geoscience Commission (SOPAC), in a 15-year project that began in 1985. The only known occurrence of cobalt rich crusts in the Indian ocean is at the Afanasiy–Nikitin Seamount in the Equatorial Indian Ocean. India is presently undertaking a long term exploration programme on these deposits.

Future Exploration and Mining

To locate areas likely to be productive, prospective miners will first have to develop detailed maps of crust deposits and a comprehensive, small-scale picture of seamount topography, including seismic profiles. Once sampling sites are identified, dredge hauls, core samplers, sonar and video cameras can be deployed to ascertain crust, rock and sediment types and distribution. Large, well-equipped research vessels will be needed to operate bottom acoustic beacons and towed equipment, and to handle a large number of samples. Manned submersibles or remotely operated vehicles will be required in later stages. For environmental assessment, current-meter moorings and biological sampling equipment will have to be deployed.

Crust mining is technically much more difficult than manganese-nodule mining. Recovery of nodules is easier because they sit on a soft-sediment substrate, whereas crusts are weakly to strongly attached to substrate rock. For successful crust mining, it is essential to recover the crusts without collecting too much substrate, which would substantially dilute the ore quality. One possible method of crust recovery consists of a bottom-crawling vehicle attached to a surface vessel by a hydraulic-pipe lift system and an electrical umbilical. Articulated cutters on the miner would fragment the crusts while minimizing the amount of substrate rock collected. Some innovative systems that have been suggested include water-jet stripping of crusts from the rock, chemical leaching of the crusts while they are still on the seamounts and sonic separation of crusts. Outside of Japan, there has been limited research and development on mining technologies for crusts. Although various ideas have been floated, research and development of this technology are in their infancy.

Seamount Environment

Seamounts are prominent features of deep-sea topography, often supporting high levels of biodiversity and unique biological communities. However, their ecology and ecosystem function are poorly known on a global scale. Estimates predict that there could be 100,000 seamounts in the world's oceans yet less than 500 have been explored. More research is needed into the nature of biological communities that inhabit seamounts in order to develop a sound basis for recommendations on environmental impacts of crust exploration and mining.

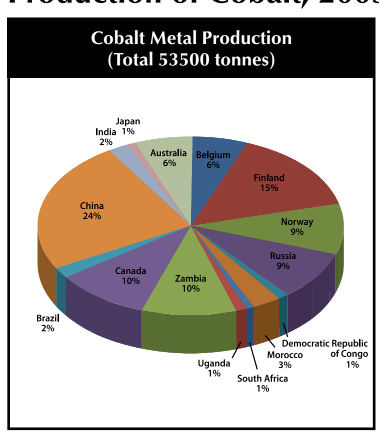
Whilst there has been increased interest in seamount biodiversity in recent years, little is known about the communities that are found on seamounts, particularly those in the most likely regions for crust exploration and mining, beyond the fact that they are complex and variable; two seamounts at the same depth can have completely different biological components. Their make-up and characteristics are determined by a variety of factors, including current patterns, topography, seamount size, water depth, seawater oxygen content, bottom-sediment and rock types and coverage. The International Seabed Authority is actively collaborating with major research programmes in order to improve the knowledge of seamount ecology and biodiversity.

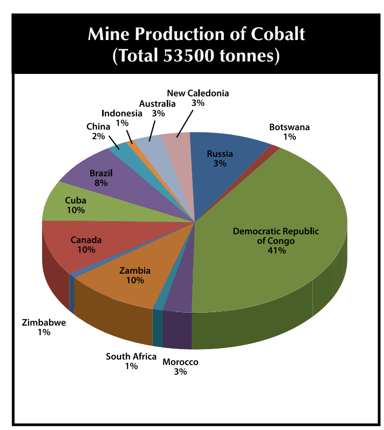
It is also essential to understand the complex water currents associated with seamounts so that appropriate mining equipment and techniques can be developed, and dispersal routes of disturbed sediment particles and wastes can be determined. Seamounts obstruct current flow, generating a wide array of stronger eddies and upwelling, which increases primary biological productivity and will also affect how, and over what scale, any impacts affect the environment. The effects of these currents are greatest at the outer rim around the summit region, where the thickest crusts are found.

Economic Factors

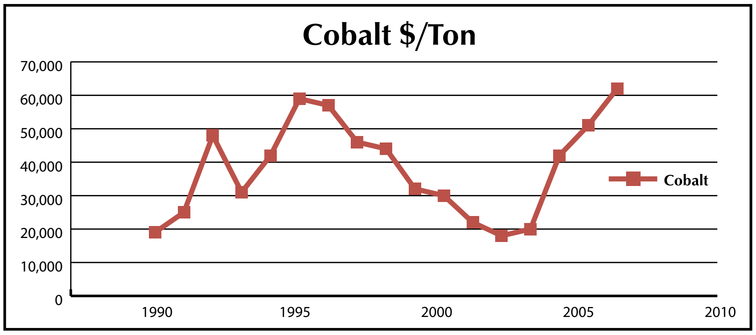
Besides the high cobalt content compared to abyssal manganese nodules, exploitation of crusts is viewed as advantageous because high-quality crusts occur within the exclusive economic zones of island nations, in shallower waters closer to shore facilities. Recognition in the late 1970s of the economic potential of crusts was enhanced by the fact that the price of cobalt skyrocketed in 1978 as the result of civil strife in the mining areas of Zaire (now the Democratic Republic of the Congo), then the world's largest producer of cobalt. By 2005, Democratic Repblic of Congo, Zambia and Canada together accounted for more than half of world mine production of about 53,500 tonnes.

Production of Cobalt, 2005





Source: World Mineral Statistics, British Geological Survey



Source: USGS and Mining Journal.

Historically the price of cobalt has tended to be volatile: during the 1979 disturbances in Shaba Province of the former Zaire, the price quadrupled within a matter of weeks. At that time Zaire provided almost half of world supply. Output is now much less geographically concentrated, but demand tends to be price-inelastic in the short to medium term. After reaching peak price in 1995, the price of cobalt slumped steadily and came down to 1990 levels in 2002-03.

However, over the past four years there has been a sharp increase in cobalt prices, which stand now at around 54.5 $/kg. If demand continues to increase, or if a supply problem is perceived, the price may increase further over a relatively short period.

Since 2001 there has been steady increase in demand for both copper and cobalt metal which is evident from the increased production. In 2001, the world cobalt metal production was 38,000 tonnes where as in 2005 it was 53,500 tonnes. Demand for one or more of the many metals concentrated in crusts, in addition to that of cobalt, may ultimately be the driving force for seabed mining.

Despite the economic and technological uncertainties, at least three companies have expressed interest in crust mining. Several evolving circumstances may change the economic environment and promote mining in the oceans - for example, land-use priorities, fresh-water issues and environmental concerns in areas of land-based mines. There is a growing recognition that cobalt-rich crusts are an important potential resource. Accordingly, it is necessary to fill the information gap concerning various aspects of crust mining through research, exploration and technological development.

Value of metals in one metric tonne of cobalt-rich crust

	Mean price of metal (2007 $US/kg)	Mean Content in Crusts (ppm)	Value per Metric Ton of Ore ($US)
Cobalt	54.56	6,899.00	376.41
Titanium	14.66	120,350.00	176.36
Cerium	88.00	1,605.00	141.20
Zirconium	150.00	618.00	92.70
Nickel	26.72	4,125 .00	110.22
Platinum	54,481.00	0.50	27.24
Molybdenum	56.76	445.00	25.26
Tellurium	242.00	60.00	14.52
Copper	6.90	896.00	6.18
Total	--	--	**$970.09**

Kg is kilogramme; ppm is parts per million, which equals grams per tonne.

Future Regulations

The International Seabed Authority has been examining issues concerning the future regulation of prospecting and exploration for cobalt-rich crusts in the deep ocean beyond national jurisdiction since 2001. The topic had been brought to the Authority by the Russian Federation in 1998. A partial set of model clauses was prepared by the Secretariat, taking account of comments by participants in a scientific workshop on the topic held by the Authority, which placed special emphasis on the need to protect the affected ecosystems from any adverse effects due to exploration and eventual mining. Since then, the Authority has convened a number of seminars and technical working groups to consider specific aspects of the future regulatory system as it relates to cobalt-rich crusts as well as polymetallic sulphides.

The questions raised in relation to these new categories of resources are highly technical and politically sensitive. In contrast to polymetallic nodules, which are relatively well known and studied, crusts and sulphides occur in more concentrated areas, are more unevenly distributed and vary more in metal content from place to place. Data and information to enable the Authority to determine the appropriate size and configuration of areas for exploration is lacking. The parallel mining system envisaged by the Law of the Sea Convention, in which seabed areas allocated to prospective miners are split evenly between those contractors and the Authority, was devised to deal with nodules, which are scattered over broad seabed areas that can be divided up more equitably rather than, as in the case of cobalt-rich crusts, highly concentrated on individual seamounts. One suggested solution is that, rather than exploiting areas of its own, the Authority might enter into joint ventures with future contractors.

In 2006, the Council of the Authority took a decision to proceed, as a matter of priority, with the development of draft regulations for prospecting and exploration for polymetallic sulphides, whilst referring the issue of regulating exploration for cobalt-rich crusts to the Legal and Technical Commission for further study. The Commission commenced this work in 2007 and will continue in 2008. Amongst the core issues to be studied in more detail are the appropriate size of the areas to be allocated for exploration, the fee system to be applied and the system for site allocation between contractors.