



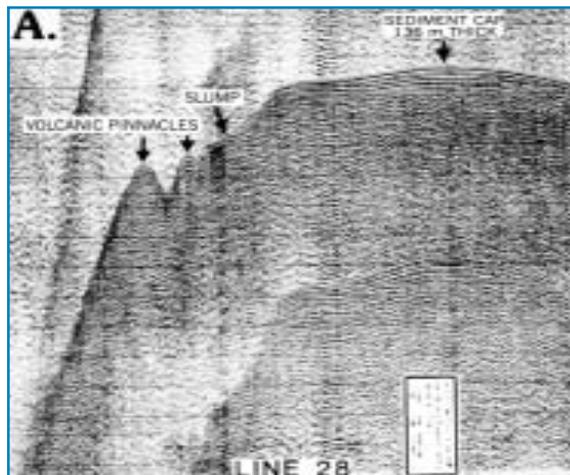
Cobalt-Rich Crusts

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- Industrial Uses
- Economic Factors
- Future Regulations

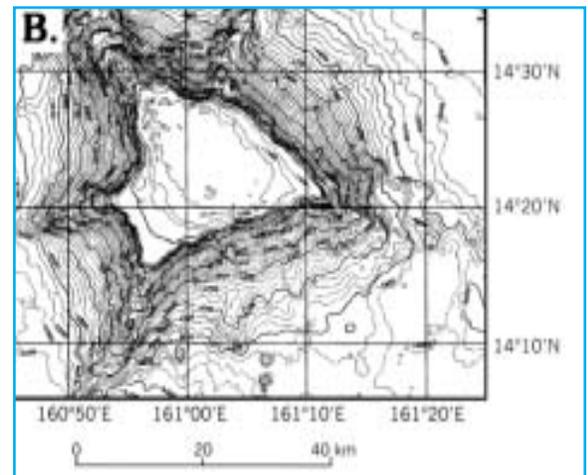
Under the 1982 United Nations Convention on the Law of the Sea, the International Seabed Authority is responsible for organizing and controlling all resource-related activities in the international seabed area. In 2001, the Authority took up a proposal to devise regulations that would govern prospecting and exploration for two recently discovered oceanic mineral resources, polymetallic sulphides and cobalt-rich crusts. Like the regulations it had adopted the previous year covering 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

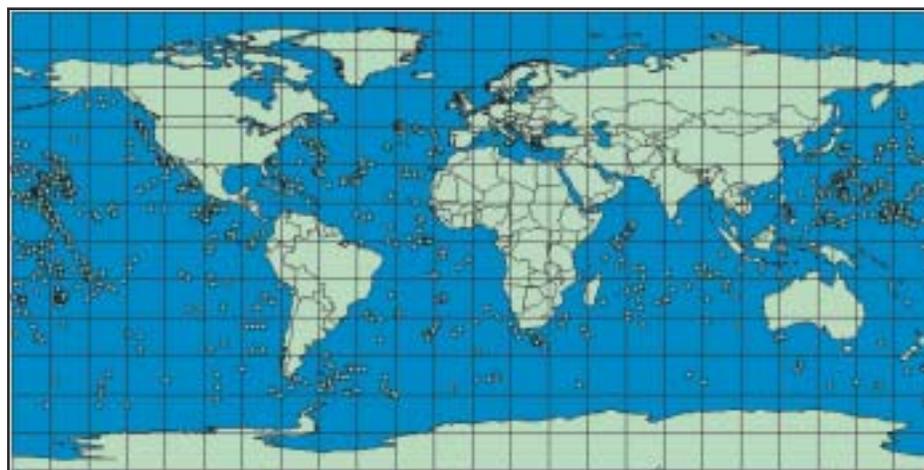
Oxidized deposits of cobalt-rich ferromanganese crust are found throughout the global oceans on the flanks and summits of seamounts (submarine mountains), ridges and plateaux, where seafloor currents have swept the ocean floor clear of sediment for millions of years. These seamounts can be huge, some as large as mountain ranges on the continents. Few of the estimated 50,000 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.



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



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



Cobalt-bearing ferromanganese crusts sampling points

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 many square kilometres in area. 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 4,000-5,000 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.

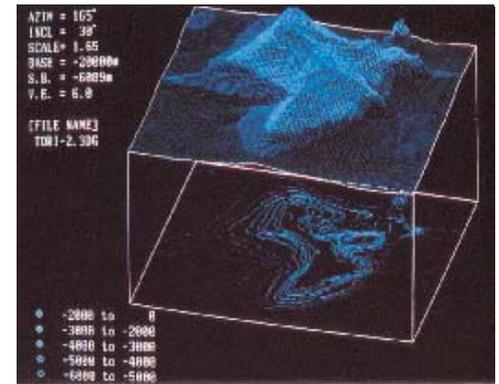
Based on grade, tonnage and oceanographic conditions, the central equatorial Pacific region offers the best potential for crust mining, particularly the exclusive economic zones around Johnston Island and Hawaii (United States), the Marshall Islands, the Federated States of Micronesia and international waters of the mid-Pacific. Moreover, crusts from shallow waters contain the greatest proportion 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 (CoRMCH. Auki)



Section of a ferromanganese crust (CoRMCH. Auki)



A model of a seamount containing ferromanganese crusts (CoRMCH. 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 ferrosilite (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. After cobalt, the most valuable of the crust minerals 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 ordinary 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 low-oxygen zone in the overlying water, and isolated from an abundant influx of river and wind-blown debris. Moreover, they will look for a bottom without too many ups and downs, located on summit terraces, saddles or passes, with stable slopes and no local volcanism. 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

	<i>Back-Arc Deposits</i>	<i>Mid-Ocean Ridge Deposits</i>
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 Central 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. About 42 research cruises (1981-2001) 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 have been 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.

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

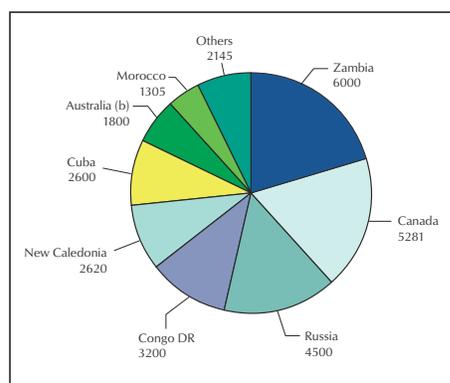
More research is needed into the nature of biological communities that inhabit seamounts in order to develop a sound basis for recommendations on environmental impacts of crust exploration and mining. Little is known about these communities beyond the fact that they are complex and variable; two seamounts at the same depth can have completely different biological components. Their make-up and characteristics are determined by current patterns, topography, bottom-sediment and rock types and coverage, seamount size, water depth and seawater oxygen content.

It is also essential to understand the ocean currents around 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. The effects of these currents are greatest at the outer rim around the summit region, where the thickest crusts are found.

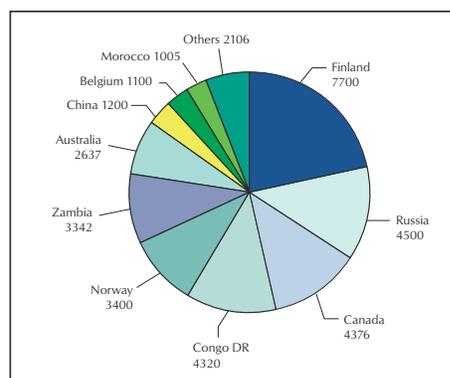
Economic Factors

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. With the continued production decline in that country, by 2000 Zambia, Canada and the Russian Federation together accounted for more than half of world mine production of about 29,500 tonnes (see figure below).

Production of Cobalt, 2000 (in tonnes)



cobalt mine



refined cobalt

The spot-market price of cobalt, like that of many other base metals, has declined steadily over the 30 months since May 1999 from more than \$20/lb to below \$10/lb. 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. If a supply problem is perceived the price may still double over a relatively short period.

One reason for the supply uncertainty is the fact that, in the major producers of Zaire and Zambia, cobalt production is a byproduct of copper mining. Consequently, the supply of cobalt is tied to the demand for copper, which is also true for the supply of tellurium. This uncertainty has caused industry to look for alternatives, resulting in only a modest growth in markets.

If substantial alternative sources of these metals are developed, then there should be a greater incentive to reintroduce them back into products, thereby increasing consumption. Demand for one or more of the many metals concentrated in crusts, other than cobalt, may ultimately be the driving force for 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 (1999 \$US/kg)	Mean Content in Crusts (ppm)	Value per Metric Ton of Ore (\$US)
Cobalt	\$39.60	6899.00	\$273.20
Titanium	7.70	12035.00	92.67
Cerium	28.00	1605.00	44.94
Zirconium	44.62	618.00	27.58
Nickel	6.60	4125.00	27.23
Platinum	13,024.00	0.5	6.37
Molybdenum	8.80	445.00	3.92
Tellurium	44.00	60.00	2.64
Copper	1.65	896.00	1.48
Total	–	–	\$480.03

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

Future Regulations

Issues concerning the prospective regulations on prospecting and exploration for polymetallic sulphides and cobalt-rich crusts in the international seabed area were first discussed in substance in August 2002 by the 36-member Council of the Authority and by the Council's Legal and Technical Commission. 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 in 2001, taking account of comments by participants in a scientific workshop on the topic held by the Authority in 2000.

Among the questions to be resolved is whether these two categories of resources should be covered by separate sets of regulations and how these should differ from the existing regulations for polymetallic nodules, which the Authority approved in 2000. 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. Crusts and sulphides, by contrast, occur in more concentrated areas, are more unevenly distributed and vary more in metal content from place to place. Another difference is that most of the known crust and sulphide deposits are in areas under national jurisdiction, so that their development would compete with that in the international area. One suggested solution is that, rather than exploiting areas of its own, the Authority might enter into joint ventures with contractors.

The Authority will continue work on this topic in 2003.