MARINE MINERAL DEPOSITS OF THE COAST AND SHELF

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Summary

The environment for marine mineral deposits in the coastal zone and continental shelf extends from inland tidal waters and beaches to the outer edge of the shelf. The deposits, which for this paper exclude oil and gas, are classified as unconsolidated, consolidated, or fluid depending on their physical characteristics (Figure 1) and are commonly referred to as placers, hard rock, or dissolved deposits.

Unconsolidated deposits are basically granular materials which may include diamonds, platinum, gold, a variety of heavy minerals containing tin, titanium, iron, rare earths or other metals, and sands, gravels, shells or nodules of silica, carbonates or phosphate. **Consolidated deposits** may contain any of the minerals found in bedded, or hard rock deposits mined on land; also found but only briefly discussed are solid hydrocarbons such as coal and methane hydrates, as well as some authigenic crusts peculiar to the marine environment. **Fluid deposits** include fresh water, sea water, and mineralized hydrothermal fluids.

Historically the recovery of marine minerals has been confined to the excavation of beaches, dredging of nearshore alluvial deposits, mining of hard rock deposits from shore entries or by fluidization, and desalination, or extraction of minerals from seawater at coastal plants. Working depths have rarely exceeded 30 meters. Present acrtvities, however, are focussed on the exploration and recovery of deposits in water depth to 100 m and beyond and at distances significantly farther from shore. Examples are given for **sands, aggregates, heavy mineral placers diamonds, phosphorites, crusts and shallow hydrates.** The future potential for mineral recovery from the coastal zone and continental shelf is considered to be excellent in selected cases.

Unconsolidated		*Consolidated*		*Fluid*	
Seabed	*Subseabed*	*Seabed*	*Subseabed*	*Seabed*	*Subseabed*
Conshelf	**Conshelf**	**Conshelf**	**Conshelf**	**Conshelf**	**Conshelf**
Industrial Materials sand & gravel shell sands aragonite coral sands *Mineral Sands* magnetite ilmenite rutile chromite monazite	*Mineral Sands* gold platinum cassiterite gem stones *Bedded Deposits* phosphorites	*Outcrops* exposures of veins, etc.	*Vein, Stratified, Disseminated or Massive Deposits* coal phosphates carbonates potash ironstone limestone metal sulfides metal salts	*Seawater* magnesium sodium uranium bromide and salts of 26 other elements	*Freshwater Springs*
Ocean Basins		**Ocean Basins**	**Ocean Basins**	**Ocean Basins**	**Ocean Basins**
Muds or Oozes metalliferous carbonaceous siliceous calcareous baritic *Nodulus* manganese cobalt nickel copper		*Crusts* phosphorite cobalt manganese *Mounds and Stacks* metal sulfides	*Vein, Stockwork, Stratbound or Massive Deposits* metal sulfides	*Seawater* magnesium sodium uranium bromine and salts of 26 other elements	*Hydrothermal Fluids*

Figure 1: Classification of marine mineral deposits (after Cruickshank and Morgan 1993)

Introduction

The coastal zones and continental shelves form the seaward edges of continents and islands and for the most part have been subjected to rising and falling sea levels above and below the present datum as much as 200 meters. They contain the complete suite of mineral resources presently found onshore as well as other deposits formed from the overlying seawater. Deposits which may be mined on the shelf include glacial and alluvial sands and gravels, biogenic materials such as shells, coral sands, or precious corals, detrital mineral sands, phosphorites, indurated sedimentary beds laid down in shallow seas, and other hard rock deposits such as veins and massive deposits typical of a continental environment (Cruickshank1974). The potential for sustainable development of these marine minerals will be influenced by their ecommomic value per unit volume of material in place, the physical and chemical nature of the deposits, the environment within which they are found, both natural and socio-political, and the technology available for removal and separation of the saleable constituents.

Economic Mineral Targets

Marine **sands and gravels** are usually formed from erosion products transported by glaciers or rivers and sorted by waves and currents or, from the breakdown of seashells or coral beds. Aragonite, glauconite, or phosphorite sands, are authigenic minerals formed by precipitation in shallow seas. Shelf deposits of sand and gravel used for construction are the bases for major industries in Japan and Europe, and reef derived carbonate sands are becoming of paramount importance in tropical Pacific Islands where they may be the only source of materials for construction and beach maintenance. Over-production has caused serious problems in many island countries leading to beach loss and flooding of the hinterland. An apparent Pacific-wide still-stand of sea level with extensive strand line sand deposits at about 100 m depths now appears to be a major target for sustainable development. Extensive shallow banks of aragonite are mined extensively in the Bahamas.

Precious corals have been important in the Philippines, Taiwan and Hawaii although over-production has caused serious damage to many of the beds. Restrictions on their taking are now region wide. In some countries they are managed by the fisheries authorites and in others under the mineral laws.

Mineral sands containing gold, diamonds, or minerals of tin (cassiterite), titanium (rutile, leucoxene, ilemenite), and other metals, derived from the breakdown of igneous rocks, are distributed widely throughout the coastal areas of the world and many of them are recoverable at the present time. In many cases the deposits have been concentrated by high energy coastal processes and reworked, buried, or exposed during passage of the littoral zone between high and low stands of sea level. Although many nearshore deposits are known, the outer shelves are virtually unexplored, and indications of high energy activity near the shelf edge during earlier periods of low sea level suggest a high potential for alluvial type deposit formation in these areas(Cruickshank and Rowland 1974). Improvement in the characterization of still-stands of sea level would assist in the identification of these resources.

At one time **alluvial gold** was a prime target for beach and nearshore mining in Alaska and Phillipines. The last significant operation at Nome, Alaska started in 1987 and employed a converted tin dredge originally built for digging to 35 m in south easr Asia. Conditions in Alaska turned out to be very different; the gold was contained in the first few meters and the presence of large boulders added to the problem. Environmental controls were also deemed excessive and the operation was closed after a few years. The successful testing of a small underwater dredgein the deposit indicated that economic operations might be re-started at a later date. About the same time proposed operations in Camarines Norte in the Phillipines were similarly constrained by environmental problems.

Offshore **diamonds** now represent a $1.5 billion per year industry along the coasts of Namibia and South Africa. Most of the marine diamonds are high quality gemstones, having traveled thousands of kilometers from their source inland and then subjected to intensive wave action over several cycles of sea level change. Mining and processing activities are being carried out by De Beers and a few other smaller companies in an industry which has grown very quietly, almost secretly over the last 30 years, working with the most sophisticated equipment in a hostile environment where alluvial diamond deposits are found at depths as great as 150 meters. The mining vessels use 4-point anchoring and stay at sea for one year at a time, supplied by tugs and helicopters. In 1997, De Beers Marine, the primary operator maintained seven mining vessels working in depths of around 130 meters with either ROVs fitted with hydraulic pumps and underwater screening systems or drillrig type vessels with 6 meter diam. cutting shoes capable of penetrating the gravels and upper bedrock layer to retrieve the gemstones. Most other operators are using airlifts in depths of 30-50 meters. Nautical Diamonds has currently fitted its new mining vessel "Kovambo" with a new ROV capable of operating in depths from 5 - 150 m. Cost of a new mining device may be as much as $70 million and a shipboard plant to process 4,000 t/hr may cost $17 million . The processing plants on these vessels are state of the art and frequently installed in modular form for ease of replacement or update. The normal circuit is de-watering and screening to minus 200 mm, Dense Media Separation, x-ray sorting and hand sorting. On the De Beers vessels the whole system is automated and the diamonds from the X-ray concentrate are canned, bar coded and helicoptered ashore without human intervention. The reported recovery of diamonds in the Namibian concessions for 1996 was in the region of 650,000 carats at an average value of $180/carat. Over 75% of the production was from De Beers operations and some experts predict that the region contains the world's largest un-mined resource of gem quality diamonds valued between $500 - 1000 billion. The cost of equipping a vessel for marine diamond mining is well under $100 million against an onshore diamond mining development cost of $400-700 million. More recently Namibian Minerals Corporation has developed a mining system which will employ a 1.8 Mw dredge pump with two rotating cutters and water jets for cutting and removing the deposits. The dredge is designed to recover over 1000 tons/hr in 8 meters of clay and sanstone at depths of 200 m. The environmental effects of the mining operations and their mitigation are the subject of serious study and procedures have been developed to minimize the smothering effects of marine tailings disposal.

Since the early 1900s about 30% of the world's **tin** has come from offshore deposits in Indonesia and Thailand in the shallow waters of the Sunda Shelf, but recent declines in the market price of the commodity has considerablty reduced activity in these areas.

Unconsolidated deposits of marine **phosphorites** vary in character depending on their genesis and are found as sands, crusts and nodules in shallow basins, in tropical lagoons and the slopes of islands. Such deposits are known off California, Baja California, the Blake Plateau off the eastern US, New Zealand and southern Africa (Riggs *et al* 1987)

Few traditional hard rock deposits have been discovered offshore, due mainly to the lack of appropriate exploration. Those worked in the past, such as the Laurium lead mines of ancient Greece, or the Levant tin mines in Cornwall, UK, have all been extensions of deposits originally worked on shore. The potential for minerals discovery on the continental shelves, however, may be assumed to be equivalent to the potential on adjacent terrestrial lands.

Very extensive deposits of bedded marine phosphorites are indicated offshore of the eastern United States and extensive deposits of phosphorite and manganese-rich crusts have been mapped on the Blake Plateau, a seaward and deeper extension of the shelf off the Carolinas. Similar crusts, rich in cobalt, are found on the sides of islands and on the tops and sides of seamounts and plateaus in the Pacific and some of these have been extensively mapped (JRA 1992).

Recent discoveries of **metal sulfide** deposits associated with tectonic plate movements in the coastal waters of New Zealand and the Bismark Basin of Papua New Guinea have resulted in some intensive exploration to characterise their economic potential. The development of an exceptionally rich gold deposit associated with an active tectonic area on the island of Lihir was followed by reports by Australian, Canadian and Japanese scientists of rich gold, silver, copper, and zinc sulfide deposits in 1200 - 1700 m water depth in the Manus Basin in territorial waters off the coast of Papua New Guinea. This resulted in the award, in 1997, of exclusive exploration leases to Nautilus Mineral Corporation PL, an Australian corporation. Metal content of samples from the areas being studied have ranged from 10-15% copper, 3-26% zinc, 15-21 g/t gold, and 130-200 g/t silver. The deposits are described as surficial masses and chimneys formed around high temperature hydrothermal vents of mineralized fluids or "smokers" resulting from tectonic activity associated with the movement of oceanic plates. With drilling for oil and gas now becoming state-of-the-art in similar water depths, the transition to active mining development using off-the-shelf equipment appears likely in the near future. Exploration for similar deposits is being carried out in other areas.

In 1998, congressional interest in the US resulted in a Bill to promote the research, identification, assessment, exploration, and development of **methane hydrate** resources, until recently regarded as an academic curiosity, or as an expensive nuisance causing the clogging of oil and gas pipelines. The frozen, crystalline gas hydrates, also known as clathrates, have been demonstrated to be more widely distributed in the marine environment than originally anticipated. There is every indication that this ubiquitous material represents a potential source of energy that, on a global scale, is significantly greater than all other forms of fossil fuel energy combined. The formation and stability of the crystals are dependant on the combination of high pressure, low temperature, and a source of gas. Fossil hydrates formed during the ice age are found onshore and throughout the continental shelf in high latitudes. The deep seabeds are host to hydrate deposits that are forming at the present time. Methods of extraction of theses deposits, which may be up to hundreds of meters in thickness over areas measured in tens of km^2, are being studied in some detail in India and Japan (Offshore 1999) where they are considered to be serious contenders as national sources of energy. One method of recovery proposed would be to drill directionally underneath the deposit and remove the gas below the hydrates. The subsequent reduction in pressure of the gas would result in sublimation of the crystalline hydrate cap resulting in a continuous release of additional gas. They may also constitute a hazard to oil and gas operations in terms of sea floor instability and it is suggested that they may be a significant factor in the presence of atmospheric greenhouse gases as the result of temperature changes in the oceanic environment causing major gaseous releases from the seabed and influencing global climate.

The production of **minerals from sea-water** is presently limited to a few commodities including sodium chloride, magnesium, gypsum, potassium and bromine. Uranium has been produced on an experimental basisin the US and Japan but it is not yet commercial. Fresh water is one of the more important commodity at the present time and the advent of low cost power may make it amore viable source in the future. There is a potential for extraction of deuterium from seawater but experiments to date have not shown it to be economic.

Future

In the last few years there have been some significant advances in our understanding of marine minerals, and our ability to manage them as sustainable resources has been enhanced by the passage of significant legislation. The most important understanding is that, despite the difference in the geological environment of the seabeds compared to land, the potential for mineral occurrence, hectare for hectare, is equivalent in both. On this basis, the global mineral resource base has recently been increased by a factor of four and three quarters of it is underwater! About one half of this area lies within the world's Exclusive Economic Zones (EEZs) including the continental shelves.The most important legislation has been the Law of the Sea, which has become a major contributing factor in what may be the most far reaching re-distribution of natural resources in human history. It divides the ownership of the seabeds among the EEZ states and the International Seabed Authority. It has resulted in a peaceful subdivision of jurisdictions which should significantly affect the world's mineral markets and the balance of economic powers, at least in the Pacific, for as long as we are dependent on the use of mined materials. In the long term, however, the minerals in seawater may represent the most significant source of mineral raw materials available to us on a sustainable basis.

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