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Review Paper

Marine Mineral Resources: A Newfangled Treasure to Explore

Khan A. Arbab[1*], Khan Shayinda[2], Khan Zadan[3] and Mizan A. Sayed[4]
[1,3]Department of Geology, Aligarh Muslim University, Aligarh 202002, INDIA
[2]Department of Geography, Jamia Millia Islamia, New Delhi, 110025, INDIA
[4]National Geophysical Research Institute, Hyderabad, INDIA

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Abstract

Prior to the knowledge of marine mineral deposits, the minerals were extracted only from the terrestrial deposits, and this extraction was so vigorous that these minerals started diminishing very fast. So, the discovery of an alternate source of minerals, i.e. the marine minerals, has been proved to be a great relief in terms of the extinction of many minerals. Moreover, there are some more minerals that have been discovered on the ocean floor. The marine deposits are a vast source of various minerals, they possess immense economic benefits. But these benefits are yet to be yielded, as, the task of the practical extraction is still to be achieved. The researches and studies are being carried out for the utilization of these vast resources, legislations are being framed and agencies are being set up for the appropriate extraction, protection and ownership of these marine mineral deposits.

Keywords: International seabed authority, marine minerals, placers; polymetallic nodules, cobalt rich crust, seafloor massive sulfides.

Introduction

Along with the advances in Geological researches, our knowledge about marine mineral resources have also increased. It has been only since last few decades that our knowledge of marine mineral deposits and recovery of these minerals has substantially recorded a fast pace, yielding significant economic returns and adding more and more supplies to the world resource base. Prior to this, the exploration, extraction and exploitation of solid minerals, commercially, was limited to those originating from chemical and mechanical weathering of terrestrial rocks and transported to the offshore areas. It means that earlier, the mineral exploration activities were limited to the offshore areas only, but with the growing demands accompanied with technological advancements, the mineral deposits at the ocean floor are also being explored.

Many of the newly-explored marine mineral deposits are far richer than any of the land deposits. Some of these deposits owe their origin partly to the terrestrial processes and partly to the natural processes that take place in deep ocean beds. Keeping in mind, the potential of these mineral resources, the International Seabed Authority was assigned with the task of protection of this potentially valuable industry by the United Nations Convention on the Law of the Sea, in 1982. The International Seabed Authority is concerned with the organization and promotion of the development of deep sea mining in the areas where there is no National jurisdiction. This authority, in 2000, adopted the regulations regarding the prospects and exploration of Polymetallic nodules and has been recently working on the framing of a set of regulations for various marine mineral deposits like marine sand and gravel, marine solutes, Manganese nodules, cobalt rich crusts and Polymetallic sulfides, etc.

Classification of Marine Mineral Resources

As discussed earlier, the marine mineral resources can be broadly classified into three categories, on the basis of the source of their origin. These categories are: Marine mineral deposits from terrestrial sources; Marine mineral deposits from combine terrestrial and deep ocean resources; Marine minerals from sources in ocean basins.

Marine mineral deposits from terrestrial sources: This category includes all the mineral resources that originate from the chemical and mechanical disintegration of rocks on land areas. After being disintegrated, these rock debris are eroded and transported to the oceans by rivers, where they are sorted by the wave action on the basis of their density (density of their constituent minerals).

The distance to which a mineral can be transported, without any change in its state, depends upon its resistance towards the mechanical action during the transport (i.e. hardness, cleavage, density, solubility, etc.)[1]. The median distance of transport from a bedrock source to an offshore placer deposit is 8 km^2.

The marine minerals derived from terrestrial sources contain heavy metallic elements like Barium, Chromium, Gold, Iron, Tin, Thorium, Tungsten, Zirconium and non-metals like Diamond, Lime, Siliceous and Gravel and other rare earth elements. The significant quantities of these minerals have been detected on the shores of many countries reportedly, India, Australia and Brazil. Gold is mined, mainly, from the shores of Thailand, Myanmar and Indonesia.

The placer deposits are chiefly of three types:

Disseminated Beach Placers: This category contains mainly the light minerals viz., Rutile, Ilmenite, Magnetite, Monazite, Sillimanite, Zircon, Garnet, etc., which gets transported to the offshore areas by the action of sea waves and currents[3].

Drowned Fluviatile Placers: These usually comprise of comparatively heavy metals like Casserite and Gold, along with the coarse sand and gravel which lie over the bottom of river channel.

Eluvial or Lag Deposits: These comprise of heavy metals.

Placers deposits may be found at the present sea level or above or below it. According to the Geological record, the fluviatile placer deposits are the most important from economic point of view[4]. For example; the archean Gold deposits in the Witwatersrand Basin of South Africa[5]. Some of the important marine mineral or placer deposits are discussed below:

Phosphorites: Phosphorites are sedimentary rocks with high concentration of phosphate bearing minerals (hydroxyapatite and fluroapatite). World's 80 phosphorus come from phosphorites and mainly use in fertilizer industries. This is found in shallow waters as phosphorite muds and sands containing 15%-20% phosphate, and as nodules on the continental shelf and slope environments, contain about 30% phosphate. Phosphorus deposition occurs from chemical precipitation, glacial runoff, some cosmic activity, hydrothermal volcanic activity, and deposition of organic material but the principal inflow of dissolved phosphorus is from terrestrial weathering, carried out by rivers water to the ocean. This material is then processed by both micro- and macro-organisms. Zooplankton, Diatomaceous plankton, and phytoplankton, process and dissolve phosphorus in the water. Large deposits of phosphorite nodules are known to occur off Mexico, Florida, Peru, Chile, Australia, California, Japan etc. Phosphorites deposits are found on both east and west coast of India.

Marine Sand and Gravel: The sand and gravel present on the land areas are carried by the rivers, which dump them into the seas and oceans. This sand and gravel is then transported to the offshore areas and beaches due to the wave action and the ocean tides and currents and concentrates there. At present, the sand and gravel remains the most extensively mined, utilized and valuable because of its worldwide application for the purpose of construction, beach restoration, shore protection and deepening of sea harbors[6]. The estimated global annual production of marine sand and gravel for the year 2000 was about U.S. $ 3,000 million.

Marine Solutes: These are the minerals that get dissolved in sea or ocean water like Rock Salt (NaCl), Magnesium, Bromine and metal compounds. But above all of these, the extraction of freshwater from the oceans, through the process of desalination is most important, as the adequate and safe supply of freshwater is necessary for domestic as well as agricultural and industrial processes. Although other processes for desalination like Reverse Osmosis System, are present, but they are energy and money intensive, so it is more convenient in monetary terms to extract water from oceans and use it after desalination.

The extraction of freshwater from the oceans continues to exceed that from the extraction of all minerals, in importance, as the demand for freshwater is ever-increasing due to increase in population, urbanization and industrialization. Moreover, the developments of alternative energy sources for desalination are being devised[7-10].

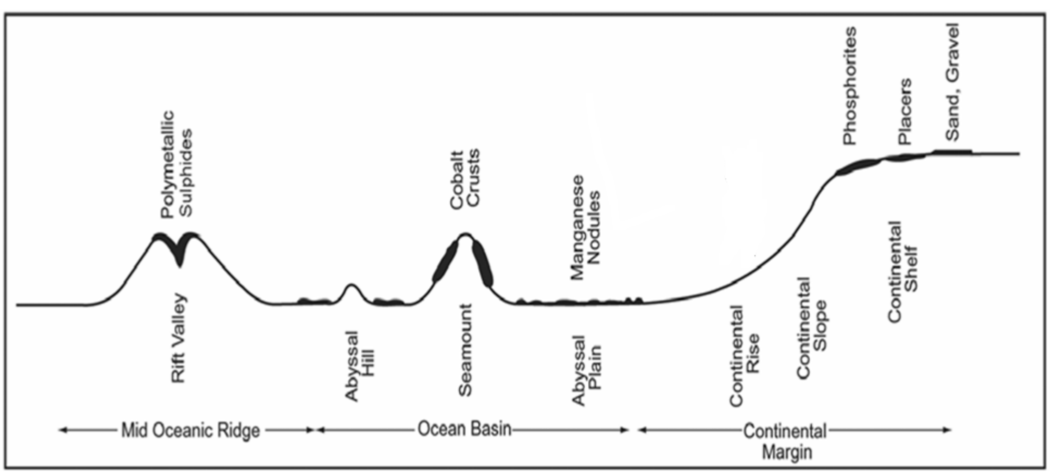

Figure-1
Distribution of Marine minerals on Different Seafloor Topographic Features

Marine Mineral Deposits from Combined Terrestrial and Deep Ocean Sources: These include the marine mineral deposits that derive their origin from both the terrestrial as well as deep sea sources. Some of the significant marine mineral deposits of this type are discussed under.

Polymetallic nodules: Polymetallic nodules or Manganese nodules have been the very first mineral to be extracted from the sea floor through the Challenger Expedition of 1872-76[11]. In 1965, Mero drew the attention towards the potential economic value of Manganese nodules with comparatively less costs of extraction and refining[12]. This discovery and insight into the economic potential of this mineral led to the development of UNCLOS (United Nations Convention on the Law of the Sea), to assure the proper sharing of the expected incoming wealth among the developed and developing nations.

The Manganese nodules are usually found up to a depth of 5 Km in the oceans on the abyssal plains. The accumulation of Manganese occurs in two ways, viz. some nodules that protrude above the ocean surface, precipitates hydrogenetically from metals present in ocean water, while some of the nodules precipitate diagenetically from the metals present in pore water of the ocean sediments[13,14]. The rate of formation of these Manganese nodules varies in accordance with the influx of Manganese to the site of accumulation and the rate of radial growth in oceans (i.e. 2-10 mm/million years)[15]. On the basis of the calculation of geochemical mass balance, the influx of Manganese from the rivers as well as from the sea floor hydrothermal discharge are more or less equal[16] and the influx is sufficient for the accumulation of Manganese in the form of nodules. The formation of these nodules takes place by the combination of Manganese with other metals. As the result, a mixture is formed by the combination of Copper, Nickel, Manganese, Cobalt and Iron, which varies from region to region depending upon the proximity to the sources like rivers, phytoplankton, hydrothermal vents, etc., which transport these metals to the upper zone (i.e. the photic zone).

The total estimated amount of terrestrial Manganese deposits account for about 6.4×10^9 tons, while, those formed in deep sea in form of nodules accounts for about 10^{11} tons Manganese, i.e., 16 times the Manganese derived from terrestrial deposits[17]. Although, the Manganese in these deep ocean floor Manganese nodules is economically significant but the commercial extraction and production is being delayed because of some political issues over the ownership as well as low market prices of Copper and Nickel, that are found in combination with Manganese.

Cobalt-rich Ferromanganese Crusts: The precipitation of Cobalt-rich Ferromanganese crust occurs just like the Manganese nodules. These crusts are usually found on hard rock platforms, like ocean ridges, abyssal hills and plateaus, etc. which are cleared off the sediments by the ocean waves and currents. The Ferromanganese crusts comprise of Cobalt, Nickel, Platinum and Titanium along with Manganese and Iron, accumulated upto a thickness of approximately 25 cm and are found between the depths of 400-4000m. 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.

Table-1
Average Elemental Concentration for Manganese Nodules from Different Seafloor Provinces[18] (after: Cronan, 1977, 1980, 2000)

Average elemental content (dry wt. %)	Atlantic Ocean	Pacific Ocean	Indian Ocean
Manganese	15.46	19.27	15.25
Iron	23.01	11.79	13.35
Nickel	0.308	0.846	0.534
Copper	0.141	0.706	0.295
Cobalt	0.234	0.290	0.247
Manganese/Iron	0.67	1.6	1.19

The detailed sampling and mapping for Cobalt-rich Ferromanganese crusts have been done on an estimated 30,000 seamounts that exists in Pacific Ocean. However, the Atlantic and Indian Ocean also have seamounts but are not yet sampled to a required extent.

The rate of growth of these deposits ranges from 1-6 mm/million years, as a result of which, a thick crust might take approximately 60 million years to form. There have also been evidences indicating two periods of formation of these crusts; the first period of over 20 million years, which was interrupted by the accumulation of Ferromanganese deposits during the late Miocene epoch (i.e. about 8-9 million years ago), interrupted by the deposition of Phosphorite. The identification of younger and older deposits helps in identifying the richer deposits, which are obviously the older ones.

Marine Minerals from Sources in Ocean Basins: These deposits include those which have their origin in the ocean floor, which means these are derived from the disintegration of rocks within the ocean floor and precipitation of minerals therein. The important ones among these are being discussed below.

Metalliferous Sediments: The first hydrothermal deposits accumulated on a fully submerged plate boundary were the Metalliferous sediments of Atlantis 2nd deep. These sediments were discovered in the year 1965 at Red sea[19-21]. It remains the most significant mineral deposit discovered till now. The Atlantis 2nd deep is a parallelogram-shaped basin which remains at a depth (water depth) of 2 Km. It is 12 Km long and 5 Km wide. It is the largest basin that exists between the Arabian and African plates.

Sea-floor Massive Sulfides (SMS): The Sea-floor Massive Sulfides are bodies of metallic sulfides formed at and near the sea floor when submarine volcanic hot-spring fluids with temperature in between 250-350ºC mix with cold seawater, typically at the depths of 1000- 3000m. High pressure causes boiling. It has also been reported that circulation of seawater through the oceanic crust is the primary process responsible for the formation of seafloor massive sulphide deposits in this circumstances. Seawater which deeply penetrates into the oceanic crust at seafloor spreading centres is being modified to a hydrothermal fluid with low pH, low Eh, and high temperature during water-rock interaction above a high-level magma chamber. The Sea-floor Massive Sulfide (SMS) or Volcanic Massive Sulfides (VMS) were first discovered at the crest of East Pacific Rise, in 1979[22-24]. These metal sulfides include Pyrite, Sphalerite and Chalcopyrite.

Although, the economic significance of SMS or VMS is well recognized, but the practical extraction of them is yet to be attempted. The greatest barrier to the aforesaid task is the depth at which these deposits are found.

Table-2
Mineralogical Composition of Seafloor Massive Sulphides Deposits[25]

Sulphides	Mid oceanic ridge deposits	Back arc deposits
Copper sulphides	Chalcopyrite, Isocubnite	Chalcopyrite
Iron sulphides	Marcasite, Pyrite, Pyrrhotite	Marcasite, Pyrite, Pyrrhotite
Zinc sulphides	Sphalerite, Wurtzite	
Lead sulphides	Galena	
Arsenic sulphides	Realgar	
Native metals	Gold	

Conclusion

The above description makes it quite clear that the marine mineral resources are a guaranteed potential source of various minerals like Iron, Copper, Lead, Gold, Tin, Manganese, Zinc Cobalt, etc. But the extraction of these deposits is very harder than that of the terrestrial deposits. Moreover, there needs to be more agencies assigned with the task of the proper analysis, extraction and exploitation of these mineral-rich marine deposits.

The technologies for appropriate investigation and thereafter, the extraction of deposits from ocean floor need to be improved in an economically beneficial way. Therefore, it may be concluded that the marine mineral deposits have great economic potentials, but at the end of the day, it is only through the proper assessment, organizational agencies, political coordination and technological innovations that these economic benefits could be harvested by the nations.

Table-3
Bulk Chemical Composition of Seafloor Massive Sulphides[26]

Element	Intraoceanic Back- Arc Ridges	Intracontinental Back-Arc Ridges	Mid-Oceanic Ridges
Copper (wt %)	4.0	3.3	4.8
Lead	0.4	11.8	0.1
Iron	13.0	6.2	26.4
Zinc	16.5	20.2	8.5
Arsenic (ppm)	845	17,500	235
Gold	217	23,04	113
Silver	4.5	3.1	1.2

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