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Significance of Deep-sea mining, Mineral contents and its impact on Ecosystem diversity

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Abstract

Deep-sea bed, being Earth's final frontier and exploring its mineral contents, microbial fauna and flora with advanced extraction tools could be anew summon task in the biological research. Deep-sea minerals which sustain extreme temperature, pressure for thousands of years in the sea belt has potential application in information technology, satellite designing, biomedical research and advance nanotechnology. The nutraceuticals, pharmaceuticals and bio toxins developed from isolated microbial fauna and the ecosystem diversity under deep-sea environment could have important biological functions. The refined or balanced deep-sea water contains minerals with many health benefits. The purposes of the review focus on understanding the importance of deep-sea mining and exploring its flora, fauna, and ecosystem diversity at physiological, metaphysical, biochemical, and molecular level.

Keywords: Deep-sea, Polymagnetic crust, Ecosystem diversity, Ferromanganese crust, Mining.

Introduction

The main objective is to explore the unexplored microbial fauna, flora, mineral contents and ecosystem diversity dwelling in the deep-sea environment or hydrothermal vents and investigating what functions the ecological balance that maintains the ecosystem. Deep-sea mining or extraction may have economic, environmental, clinical, and technological advantage [1]. Poly metallic nodules, called as ferromanganese or manganese nodule in the form of hydroxide are embedded on the sea floor making it one of the most interesting features for the deep-sea mining operations [2]. Sea floor sulphides are the only metal bearing deposits of commercial significance occurring at the oceanic ridges at the depth of 800 to 50000 meter [3]. Massive accumulation of sulphide has also been reported even at temperature greater than 300°C of hydrothermal vents. The major deposits contain high concentration of minerals like copper, zinc, lead, arsenic, cobalt, silver, gold and other metals [4]. Ferromanganese crust such as layered manganese and iron oxides with associated metals are also deposited on hard substrate rock of sub-sea mountains and the ridges had metals like Mn, Co, Ni, Cu, Te, Mo, Zr, Ti, Ni, Atlantic oceans [5].

Geology of deep-sea mineral contents

Different types of deep-sea bedded mineral deposition had been influenced by geological, geophysical, and geochemical factors [6]. Abyssal plains, mid oceanic ridges, seamounts, and ocean trenches are the major physiographic zones of deep-sea. To understand the formation of this zone we need to understand the plate tectonic process. The plate tectonic theory proves that lithosphere is divided into several plates [7-8]. The plate moves in different process like spreading and subduction. Spreading occurs when the hot magma fueled by upwelling in the mantle rises and cools to form new oceanic crust [9]. Variation of tectonic, sedimentary, and magnetic process from one zone to another influencing the composite rocks and minerals contents makes the subduction process complex phenomena [9-11]. Subduction zones are highly prone to volcanic activity with variety of geochemical and geological components [12]. An oceanic plate boundary is the transformed fault which is formed by differentiation in the plate motion at divergent boundaries [13-14].

Polymetallic nodules

It contains manganese and ferromanganese substances consisting of spherical mineral concretions ranging from 5 to 10 cm in diameter. The principal components of these nodules contain manganese and iron hydroxides. They also had Ni, Cu, Co along with traces of lithium, molybdenum, and rare elements [15]. Polymetallic nodules are formed from specific sedimentary and chemical process which took place in abyssal environment. Slow sedimentation rate which in turn reduces the mineral deposition characterized this environment. When dissolved metal compounds precipitate around small nucleus, typically some debris or fossilized bone, shark tooth, shell fragment, the Polymetallic nodules were formed [16-18]. The various factors that influence the nodule composition, growth, distribution, and abundance includes topography, local and regional hydrodynamic conditions, bioturbation, primary productivity of the overlying surface water, sedimentation rate and the bacterial activity [19]. Clarion – Clipperton Fracture zone (CZZ) in the Central pacific was the most expensive nodule recovery zone.

Polymagnetic crust

The ferromanganese crust occurs throughout the ocean at depth ranging from 400 – 7000m and could reach thickness of 25 – 30 cm. High concentration of iron, manganese hydroxide, cobalt, copper, and nickel are also the constituent of Polymagnetic crust. The formation of ferromanganeses crust is favored by hydrogenous process and upwelling condition that foster geochemical condition favoring the precipitation of metals and other elements [20-23]. Ferromanganese

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Table 1: Distribution of deep-sea minerals.

Mineral	Composition	Metals	Deposits
Polymetallic nodule	Layered iron, manganese oxide	Mn, Ni, Cu, Co,Mo, Zn,Zr,Li, Pt, Ti, Ge, Y, REEs	Peru basin, Clarion Clipperton zone, central Indian ocean
Ferromanganese crust	Layered manganese, iron oxide	Co, Ni, Cu, Mn, Te, Mo, Zr, Ti, Bi, Pt, W, REEs	Central Atlantic ocean, Equatorial Pacific Ocean
Sea floor massive sulphide	Concentrated deposits of sulphidic minerals	Pb, Zn, Co, Cu, Au, Ag, As, Al, Si, REEs	Red sea, mid oceanic ridges, oceanic hotspot

crust on the sea mount in central pacific are estimated to contain about four times the cobalt, three and half times more yttrium and nine times more tellurium than the entire known land reserves of these metals [24]. Sea floor sulphide deposition: Sea floor massive sulphides are mostly located in association with oceanic ridges. Sulphide deposition also occurs in volcanic island and the island arc system at depth of 850 – 5500m [25]. High temperature hydrothermal vent is found to have maximum sulphide deposition. Depending on the tectonic content, high concentration of copper, zinc, lead, arsenic, cobalt, silver, and gold are also found along with the deposits. The formation of sea floor, massive sulphide is the result of circulation of slow spreading ridges generating hydrothermal vents which favours the massive sulphide deposition [26-29]. Rapid spreading ridges create an unstable hydrothermal vent which slows down the sulphide deposition. Zinc, silver, and gold are also found along with sulphide deposits [30].

Deep-sea ecosystem diversity

Below the depth of 200m, deep-sea covers 60-65 % of the planet's surface. Due to extreme harsh conditions like low or no light intensity, immense pressure, low but consistent temperature and varying oxygen level, life here faces food scarcity, relying and limited to the organic material [31]. The microbial diversity isolation could have potential applications in biotechnology, nanotechnology, and space research [32]. The ecosystem diversity could have been altered by deep-sea mining. Formation of poly metallic nodule, abyssal plains, poly metallic crust sea mounts, hydrothermal vents and seeps could slow ecological variations [33].

Abyssal ecosystem

The main features consist of fine-grained sediments like silt, clay, and the remains of microorganisms. Smooth mud supporting low level biomass shows high profile to species diversity like protozoan, bacteria, and invertebrates. Invertebrates include worms, crustaceans, sponges, mollusks and echinoderms like sea cucumber, starfish, brittle star, and sea urchin [34]. Vertebrate like deep-sea pelagic, dermal fish, gulper cells, angler fish, viperfish, and rattails. Bacterial diversity in abyssal play crucial role in organic matter and recycling. The feeding communities, ecological functions and the importance of poly metallic nodule influence the presence of life and understanding behavior supports the ecosystem [35-36].

Sea mount ecosystem

Characteristics like size, shape, climatic hydro dynamic setting condition favor the abundance of deep marine fauna. The sea mount ecosystem is considered as biodiversity hotspots with 600-900 species of fish like tuna, sharks, cetaceans, sea turtles etc. Corals and sponges dominated the sea mount [37-38]. Hydrodynamic conditions made possible the rich biodiversity. The strong hydrodynamic condition enhances vertical mixing and upwelling of nutrient rich deep water to surface leading to the maximum primary productivity [39].

Hydrothermal vent ecosystem: The ecosystem found along the mid ocean ridge and island arc, ancient plate, boundaries and in association with volcanoes [40]. When the mineral reach superheated fluid reacts with cold and oxygenated sea water causing more dissolved material to precipitate forming vents chimneys and minerals deposits on sea floor [41]. Despite extreme temperature it is home to unique ecosystem with a rich array of life [42]. The primary producer relies on the chemosynthesis due to absence of photosynthesis. It shows the presence of chemosynthetically active microorganism [43].

Back – arc basin ecosystem: The ecosystem developed unique fauna and enriched deep-sea minerals. An investigation of back – arc basin ecosystem is urgency to the mining companies, industry, and the scientific community [44].

Recovery rate of deep-sea fauna

Abyssal animal mainly relies on settled particulate matter from water column or suspension feeders because most of them are surface deposits feeder [45]. Habitats of abyssal nodule are relatively stable. Sea mount fauna consists of sessile organisms like corals and sponges being the dominant benthic fauna the slow growth rate and high longevity make recovery from disturbances either unlikely or very long term especially on isolated sea mounts [46]. In case of vent fauna, major difference in the fauna re identified at active and inactive vent site. Active vent fauna is correlated with volcanic activity appears to recover relatively rapidly from major disturbances like volcanic eruptions [47]. Mining affects the physiological conditions of the active fauna vent and thereby leading to the unstable ecosystem diversity. Although it can be recolonized after mining but there is no uncertainty how species interaction might take place and how long recovery might take [48].

Methods of mining and extraction

The way to mine for minerals deposit under deep-sea level surface is by digging hole, tunneling to deposit beneath the surface or directly drilling into it. The deposited mined were then transported, processed, and refined to marketable product [49-50].

Recovery process

Recovery of poly metallic nodule by using Continuous Line Bucket (CBL) recovery system, Poly metallic crust recovery from sea mounts and Poly metallic sulphide recovery are the major extraction or recovery process employed by most mining industry. In case of mining, Nautilus mining system is widely employed [51]. It is followed by refining to downstream processing till the production of marketable minerals.

Importance of deep-sea water

Minerals from deep-sea water (DSW) like CA, Mg, Cl, Na, K, Se and V shown to have good nutrient source and providing potential health benefits. Mg plays important role in metabolism, enzyme function and beneficial to people with cardiovascular disease slowing down the adipocyte cell deposition [52-53]. Ca as cofactor provide pivotal role in bone development. DSW also prevents arthenogenesis with its hardness of 300, 900 and 1500 decreased the arthenogenic index. DSW has enormous anti-obesity properties, diabetes control, skin, and hepatic, fatigue, stomach ulcer, anticancer, recovery from osteoporosis [54]. DSW mineralization shows show the improvement in cholesterol profile.

Expected outcome and futuristic applications

The metallic deposits with diverse variation in chemical and physical properties prove to serve as important raw material because of the presence of Ni, Cu and Mn [55]. Ferromanganese and nodules regarding economical and marketable values can be mixed for technical and economic importance in today's sight. The technical system of exploration and mining has considered on marine environment and biology. Numerous valuable drugs could have been discovered from the deep-sea environment [56]. Long term marine biotechnological research on the marine microbial fauna and flora could result into discoveries of numerous novel compounds with biological activities [57]. The notable example isolated from hydrothermal vents is the pseudoterosins – one of the most potent anti-skin inflammations known [58]. Harnessing the bioactive product from vast marine biota occurring at Indian and Pacific water is still progressively well developed. Neutraceuticals containing right number of vitamins, lipids, proteins, carbohydrate, minerals depending on their phases shows impeccable clinical importance [59-60]. Marine flora like brown, blue, blue green and red algae contains minerals providing neutraceuticals benefits in addition to being an important component of diet. Marine bio toxin with has potential to inhibit the beta amyloidal precursor of Alzheimer disease [61]. The mineralized marine product can be used in developing satellite with optimal, low cost, reliable and strong material for withstanding the extreme pressure of space [62]. Nano material coated marine chips can be used in developing advanced computing system, mobile phones, missile technology, aircraft etc. Omega 3 fatty acid (EPA, DHA) contained enormously in deep-sea fish with highest level of antioxidants such as iodine, selenium, and hydroxyl butyrol. Horseshoe crabs, jelly fish, sea weeds, sea cucumber, mussels have advanced medical applications. The extensive study of ecological behavior, principles, diversity would foster in maintaining a well-balanced ecosystem [63]. Marine products are used as anticancer drug in treating primary and metastatic cancer. With this vast diverse application, we the scientific community should look forward in exploring the unknown biological phenomena in deep-sea environment.

Conclusion

Below 200m depth in the sea has a wealth of highly enriched unique minerals which have tremendous potential applications. During early ninety's, the deep-sea explorations were impaired by technical constraints had legal uncertainties. Nowadays marine mining and environmental monitoring technology has advanced rapidly since the uncertainties have been resolved. The review aims to enhance interest in exploring the deep-sea environment and understanding its important applications, biological diversity under the extreme temperature and pressure. The deep-sea mining is extremely important for understanding the challenges withstanding the considerable differences in pressure, temperature, acidity, and salinity. The framework agreement, laws that govern the rights and responsibilities utilizing the natural resources under the jurisdiction of UNCLOS, thus details responsibilities to share benefit of deep-seabed exploration and understanding its clinical, medical, technical and bio physiochemical importance. With this interest deep-sea mining is an utmost concern as a promising futuristic approach.

References

1. Armstrong CW, Foley NS, Tinch R, van den Hove S (2012) 'Services from the deep: Steps towards valuation of deep-sea goods and services.' Ecosystem Services 2: 2 13.
2. Hein RJ, Petersen S. (2013) The geology of manganese nodules. 1:7-18.
3. Hannington M, Jamieson J, Monecke T, Petersen S, Beaulieu S. (2011) The abundance of seafloor massive sulphide deposits. Geology 39: 1155–1158.
4. Cherkashov G, Poroshina I, Stephanova T, Ivanov V, Bel'tenev V, et.al. (2010) Seafloor Massive Sulfides from the Northern Equatorial Mid-Atlantic Ridge: New Discoveries and Perspectives. Marine Georesources & Geotechnology 28: 222–239.
5. Hein RJ, Petersen S (2013) The geology of manganese nodules. 1:7-18.
6. Coffin MF, Duncan RA, Eldholm O, Fitton GJ, Larsen HC, et.al. (2006) Large Igneous provinces and scientific ocean drilling. Oceanography 19: 150-160.
7. Desbruyères D (2006) Composition and Biogeography of Hydrothermal Vent Communities in Western Pacific Back-Arc Basins in Back-Arc Spreading Systems: Geological, Biological, Chemical and Physical Interactions. Geophysical Monograph Series 166: 215-235.
8. Fouquet Y (2012) Caractéristiques et processus de formations. 77-102
9. Hein JR, Conrad TA, Dunham RE (2009) Seamount Characteristics and Mine- Site Model Applied to Exploration- and Mining- Lease-Block Selection for Cobalt-Rich Ferromanganese Crusts. Marine Georesources and Geotechnology 27: 160–176.
10. Hein JR, Conrad TA, Staudigel H (2010) Seamount Mineral Deposits: A source of Rare Metals for High-Technology Industries. Oceanography 23: 184 189.
11. Hein JR (2012) Prospects for Rare Earth Elements from Marine Minerals. 2–5.
12. Desbruyères D (2006) Composition and Biogeography of Hydrothermal Vent Communities in Western Pacific Back-Arc Basins in Back-Arc Spreading Systems: Geological, Biological, Chemical and Physical Interactions. Geophysical Monograph Series 166: 215-235.
13. Edmond JM, McDuff RE, Chan, LH (1979) Ridge crest hydrothermal activity and the balances of the major and minor elements in the ocean: the Galapagos data. Earth Planet. Sci Lett. 46:1–18.
14. Kerrey KA, Global Tectonics. Hoboken, NJ, USA: John Wiley & Sons. pp. 84 – 90.
15. Hein RJ, Petersen S (2013) 'The geology of manganese nodules. In: Baker, E. and Beaudoin, Y. (Eds.). Deep-sea Minerals: Manganese Nodules: A physical, biological, environmental, and technical review. Vol. 1B, 7-18pp. Noumea, New Caledonia: Secretariat of the Pacific Community (SPC).
16. Hein RJ, Petersen S (2013a) 'The geology of manganese nodules'. In: Baker, E. and Beaudoin, Y. (Eds.). Deep-sea Minerals: Manganese Nodules: A physical, biological, environmental and technical review. Vol. 1B, 7-18pp. Noumea, New Caledonia: Secretariat of the Pacific Community (SPC).
17. Industry Standard Architecture, (2010) A Geological Model of Polymetallic Nodule Deposits in the Clarion-Clipperton Fracture Zone. Kingston: International Seabed Authority.ISA Technical Study 6: 105.
18. Mero JL (1962) Ocean-floor manganese nodules. Economic Geology 57:747–767.
19. Hein JR, Koschinsky A (2003) Deep-ocean ferromanganese crusts and nodules. In: Treatise on Geochemistry 273-291.
20. Banakar VK (2010) Deep-sea ferromanganese deposits and their resource potential for India. J. Indian Inst. Sci 90: 535–541.
21. Baturin GN, Dubinchuk VT (2010) On the composition of ferromanganese nodules of the Indian Ocean. Dokl. Earth Sci 434: 1179–1183.
22. Bedinger G, Bleiwas D (2012) Rare earths, lanthanides, yttrium, and scandium. Min Eng Mag 64: 86–88.
23. Berger VI, Singer DA, Orris GJ (2009) Carbonatites of the world explored deposits of Nb and REE: database and grade and tonnage models. U.S. Geological Survey Open-File Report 09–058.
24. Hein JR (2012) Prospects for rare earth elements from marine minerals. Briefing Paper 02/12, International Seabed Authority 4 pp

25. Hein JR, Petersen S (2013). Chapter 2: Manganese nodules; Chapter 3: ferromanganese crusts. UNEP-GRID-ARENDAL publication. (In print).

26. Hein JR, Yeh HW, Gunn SH, Sliter WV, Benninger LM, et.al. (1993) Two major Cenozoic episodes of phosphogenesis recorded in equatorial Pacific seamount deposits. Pale oceanography 8:293–311

27. Hein JR, Koschinsky A, Bau M, Manheim FT, Kang JK, et.al. (2000) Cobalt-rich ferromanganese crusts in the Pacific. In: Cronan, D.S. (Ed.), Handbook of Marine Mineral Deposits. CRC Press, Boca Raton, Florida, pp. 239–279.

28. Hein JR, Koschinsky A, Halliday AN (2003) Global occurrence of tellurium-rich ferromanganese crusts and a model for the enrichment of tellurium. Geochim. Cosmochim Acta 67: 1117–1127.

29. Koschinskz A, Stascheit A, Bau M, Halbach P (1997) Effects of phosphatization on the geochemical and mineralogical composition of marine ferromanganese crusts. Geochim. Cosmochim. Acta 61: 4079–4094.

30. Koschinsky A, Borowski C, Halbach P (2003) Reactions of the heavy metal cycle to industrial activities in the deep-sea: an ecological assessment. Int. Rev Hydrobiol 88: 102–127.

31. Baker MC, Ramirez-Llodra EZ, Tyler PA, German CR, Boetius A et.al. (2010) Biogeography, Ecology, and Vulnerability of Chemosynthetic Ecosystems in the Deep-sea 139-160.

32. Butterfield DA, Roe KK, Lilley MD, Huber J, Baross JA, Embley RW, et al. (2004) Mixing, reaction and microbial activity in the sub-seafloor revealed by temporal and spatial variation in diffuse flow vents at Axial Volcano," in The Sub-seafloor Biosphere at Mid-Ocean Ridges. Geophysical Monograph Series 144: 269–289.

33. Boschen RE, Rowden AA, Clark MR, Gardner JPA (2013) Mining of deep-sea seafloor massive sulfides: A review of the deposits, their benthic communities, impacts from mining, regulatory frameworks, and management strategies. Ocean & Coastal Management 84: 54–67.

34. Ebbe B, Billett DSM, Brandt A, Ellingsen K, Glover A (2010) Diversity of Abyssal Marine Life, Life in the World's Oceans. 139-160

35. Clark MR, Rowden AA, Schlacher T, Williams A, Consalvey M, et.al. (2010) The Ecology of Seamounts: Structure, Function, and Human Impacts. Ann Rev Mar Sci 2: 253-278.

36. Clark MR, Watling L, Rowden AA, Guinotte JM, Smith CR (2011) A global seamount classification to aid the scientific design of marine protected area networks. Ocean Coast Manag 54: 19-36.

37. Clark M, Kelley C, Baco A, Rowden A (2011) Fauna of Cobalt-Rich Ferromanganese Crust Seamounts. Technical Study. Kingston, Jamaica: International Seabed Authority 17.

38. Consalvey M, Clark MR, Rowden AA, Stocks KI (2010) Life on Seamounts. In: McIntyre, A.D. (Ed.). Life in the World's Oceans: Diversity, Distribution, and Abundance 139-160.

39. Desbruyères D (2006) Composition and Biogeography of Hydrothermal Vent Communities in Western Pacific Back- Arc Basins in Back-Arc Spreading Systems: Geological, Biological, Chemical and Physical Interactions. Geophysical Monograph Series 166: 215-235.

40. Fisher C, Rowden A, Clark M, Desbruyères D (2013) Biology Associated with Sea-floor Massive Sulphide Deposits. 1:19-26

41. Galéron J (2012) Environnement profond in Fouquet, Y., and Lacroix, D. (Eds.) Les ressources minerals marine profondes: Etudes prospective à l'horizon 2030. Matière à débattre et decider. Versailles: Edition Quaere, 175.

42. Levin LA, Mendoza GF, Konotchick T, Lee R (2009) Macrobenthos community structure and trophic relationships within active and inactive Pacific hydrothermal sediments. Deep Sea Res 56: 1632–1648.

43. Morato T, Hoyle SD, Allain V, Nicol SJ (2010) Seamounts are hotspots of pelagic biodiversity in the open ocean. Proceedings of the National Academy of Sciences of the United States of America 107: 9707–9711.

44. Rogers AD (2004) The Biology, Ecology and Vulnerability of Seamount Communities. IUCN publication 12.

45. Van Dover CL (2000) The Ecology of Deep-sea Hydrothermal Vents. New Jersey: Princeton University Press 424.

46. Van Dover CL, German CR, Speer KG, Parson LM, Vrijenhoek RC (2002) Evolution and Biogeography of Deep-sea Vent and Seep Invertebrates. Science 295: 1253–1257.

47. Van Dover CL (2011) Mining seafloor massive sulphides and biodiversity: what is at risk?. Indian J. Mar. Sci. 68: 341- 348.

48. Van Dover CL, Arnaud-Haond S, Gianni M, Helmreich S, Huber JA, et.al. (2018) Scientific rationale and international obligations for protection of active hydrothermal vent ecosystems from deep-sea mining. J.MarPol 90, 20-28.

49. Bashir M, Kiosidou E, Wolgamot H, Zhang W, Wilson PA, et.al. (2012) A Concept for Seabed Rare Earth Mining in the Eastern South Pacific. The LRET Collegium Series: Seabed Exploitation 1: 138.

50. Egorov L, Elosta H, Kudla N L, Shan S, Wilson P A. et.al., (2012) Sustainable Seabed Mining Guidelines and a new concept for Atlantis II Deep. The LRET Collegium Series: Seabed Exploitation 4: 190.

51. Hein JR (2012) Prospects for Rare Earth Elements from Marine Minerals. International Seabed Authority, Kingston, Jamaica, Briefing Paper (May): 2–5.

52. Hwang HS, Kim HA, Lee SH, Yun JW (2009) Anti-obesity and antidiabetic effects of deep-sea water on ob/ob mice. Mar Biotechnol 11:531–539.

53. Katsuda SI, Yasukawa T, Nakagawa K, Miyake M, Yamasaki M, et al. (2008) Deep-sea water improves cardiovascular hemodynamics in kurosawa and kusanagi-hypercholesterolemic (KHC) rabbits. Bio Pharm Bull 31:38–44.

54. Fu ZY, Yang FL, Hsu HW, Lu YF (2012) Drinking deep-seawater decreases serum total and low-density lipoprotein-cholesterol in hypercholesterolemia subjects J Med Food 15:541.

55. Hsu CL, Chang YY, Chiu CH, Yang KT, Wang Y, et. al. Cardiovascular protection of deep-seawater drinking water in high-fat/cholesterol fed hamsters. Food Chem 127:1146-1152.

56. Sheu MJ, Chou PY, Lin WH, Pan CH, Chien YC, et.al. (2013) Deep-sea water modulates blood pressure and exhibits hypolipidemic effects via the AMPK-ACC pathway: An in Vivo Study. Mar Drugs 11:2183–2202.

57. Ueshima S, Fukao H, Okada K, Matsuo O (2003) Suppression of the release of type-1 plasminogen activator inhibitor from human vascular endothelial cells by Hawaii deep-sea water. Pathophysiology 9: 103–109.

58. Takahashi MM, Huang P (2012) Novel renewable natural resource of Deep Ocean Watr (DOW) and their current and future practical applications. *Kuroshio Science* 6:101–113.

59. Michelle M, Beerman KA (2007) *Nutritional Sciences: From Fundamentals to Food*. 7th. Peter Marshall. The major minerals and water 517–525.

60. Ouchi Y, Tabata RE, Stergiopoulos K, Sato F, Hattori A, et.al. (1990) Effect of dietary magnesium on development of atherosclerosis in cholesterol-fed rabbits. Arteriosclerosis 10: 732-737.

61. Faryadi Q (2012) The magnificent effect of magnesium to human health: a critical review. *Int J. Applied Sci. Technol* 2:118–126.

62. . Kimura M, Takeda R, Takeda T, Imanishi M, Tail H, (2001) et.al. Effect cholesterol level in plasma of rats by drinking high magnesium water made from deep-sea water 1965–1966.

63. Yoshioka S, Hamada A, Cui T, Yokota J (2003) et.al. Pharmacological activity of deep-sea water: examination of hyperlipemia prevention and medical treatment effect. Biol. Pharm. Bul. 26 :1552–1559.