NUTRIENT CYCLING IN THE OCEANS

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Summary

Nutrients in the oceans are moved about by biological and physical processes. In the euphotic zone in the surface open oceans, nutrients are utilized mainly by phytoplankton and cyanobacteria. Respiration and the decomposition of marine organisms cause nutrients to be released back into the seawater, mostly in the deep waters. As a result, nutrient concentrations are generally low near surface but high in deeper waters, except in polar regions where intensive upwelling brings cold, nutrient-rich seawater back to the surface. Aside from upwelling, physical processes play an important role in moving seawater horizontally and in, therefore, transporting nutrients as well. For instance, ocean currents transport the nutrient-rich Mississippi River water to form the 'death zone' off the delta (see Human Perturbations).

On the shelves there are additional sources of nutrients from rivers, ocean sewage outfalls, groundwater and surface runoff from land. Because of the shallowness of the shelves, wind and tidal mixing as well as vertical mixing caused by winter cooling are able to return the regenerated nutrients from the greater depths back to the euphotic zone. Furthermore, cross-shelf exchanges often transport nutrient-rich subsurface water from offshore to the shelf, while the shelf exports nutrient-poor surface water offshore. However, this nutrient-poor surface water may still be considered nutritious when compared with the nutrient-depleted surface waters in the open oceans.

The major nutrients in the oceans are considered to be nitrogen, phosphorus and silicon. In addition to these, various other elements, referred to as trace elements, are also

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essential for plant growth, including vitamins, iron, copper and zinc. The latter two, however, may become toxic when the concentrations become too high.

1. Introduction

A nutrient element is one which, although sometimes in short supply, is functionally involved in the processes of living organisms. Traditionally, in oceanography the term has been applied almost exclusively to nitrogen, phosphorus and silicon although it is now known that minor elements, such as iron, play an important role, too. The primary processes influencing nutrient concentrations in the sea are the geophysical and geochemical processes which not only control the addition of these elements to seawater but also are responsible for their dispersion and removal. Rock weathering and the decay of organic material, together with waste discharge, are the major sources of most forms of nutrients in the sea, and they are usually carried by terrestrial drainage. Of importance for coastal oceans, though, is that the human input is beginning to be more significant than the input from weathering (see Natural and Anthropogenic Radionuclides; Human Perturbations; and Non Radioactive Ocean Pollution).

Riverine and estuarine systems are linked to regional and large-scale hydrology through interactions among soil water, evaporation and runoff in terrestrial systems. These systems, and more generally the entire global water cycle, control the movement of major nutrients and trace elements over vast distances from the continental land-masses to the continental margins and finally to the world's oceans. River basins are often dense in population and development, and rivers end in and are key features of estuaries and the coastal zone. Therefore, they are the center of consideration of the Land-Ocean Interaction in the Coastal Zone project of IGBP. Because rivers contribute significant quantities of nutrients to coastal oceans, they are linked to fisheries and the Global Ocean Ecosystem Dynamics project, also of IGBP.

The primary biological removal of inorganic nitrogen, phosphorus and silicon from seawater is by phytoplankton. On the shelves, littoral and benthic algae also remove these elements from seawater, but the total amounts involved are relatively small. The primary and other consumers of the marine food web regenerate these elements to soluble form. Bacteria, protozoa and autolysis are involved in these regeneration processes.

Assuming C:N:P ratios of 106:16:1 (the Redfield ratio), remineralization can be represented by the equation:

$$\begin{aligned}&(CH_2O)_{106}(NH_3)_{16}H_3PO_4 + 138O_2 = \\ &106CO_2 + 122H_2O + 16HNO_3 + H_3PO_4\end{aligned} \tag{1}$$

The replenishment of the supply of nutrients in the surface water depends upon the action of the physical processes. The rates of accumulation of inorganic nitrogen, phosphorus and silicon in deep waters are controlled by the biological productivity of the surface layers, by the rates of in situ regeneration, by vertical mixing and eddy

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diffusivity, by lateral movements of the deep water and by diffusion out of the sediments.

Nitrate and phosphate are used to form the soft tissues of organisms and the molar ratio of nitrate to phosphate in ocean water is close to the ratio of 16:1 for organic tissues (the so called Redfield ratio); thus, when all the dissolved nitrate in surface waters has been used up, usually so has almost all the dissolved phosphate. Why nitrate and phosphate should occur in seawater in the same ratio that organisms require them remains unanswered. It is still not known whether organisms evolved to use the 16:1 molar ratio of N:P because it was there, or whether marine organisms themselves established the ratio over time.

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Biographical Sketch

Born in Changhwa, Taiwan, on 22 April 1949, **Prof. Chen-Tung Arthur Chen**, his wife and two daughters are currently residing in Kaohsiung, where he has been Professor at the Institute of Marine Geology and Chemistry since 1986. After receiving his B.Sc. degree in Chemical Engineering from National Taiwan University in 1970, Prof. Chen was awarded his Ph.D. degree in Chemical Oceanography from the University of Miami in 1977. In the same year, he was appointed Assistant Professor in the College of Marine Sciences of Oregon State University, where he was later promoted to Associate Professor in 1981. He served as visiting professor at National Sun Yat-Sen University (NSYSU) in Kaohsiung, Taiwan, and as Chargé de recherche (CNRS), Université Pierre et Marie Curie in Paris during 1984-1985. During this period, he founded the Institute of Marine Geology at NSYSU, and served as its director until 1989 when he was made Dean of the College of Marine Sciences, a position he held until 1992.

Prof. Chen has sat on numerous international committees, including the Scientific Committee on Oceanic Research and the World Ocean Circulation Experiment. He also served as one of the executives of the Scientific Steering Committee of the Joint Global Ocean Flux Study (JGOFS) between 1992-1995. Just prior to that, he had helped to form the Joint JGOFS / LOICZ Marginal Seas Task Team in 1991, and served as its chairman until 1995. Prof. Chen is at present one of the editors of *Oceanography Journal* and associate editor of *Marine Chemistry*. Besides having more than 150 of his own scientific papers published, Professor Chen was awarded the highly-coveted Biowako Prize for Ecology from Japan in 1997.

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