1 Particle Flux in the Ocean: Introduction

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1.1 BACKGROUND

For more than a decade the SCOPE/UNEP Carbon Unit at the Hamburg University has initiated and coordinated projects on global carbon cycle. The three projects conducted by the Unit are: *Carbon and Mineral Transport in Major World Rivers*, *Carbon and Nutrient Cycling in Lakes and Estuaries* and *Particle Flux in the Ocean*. A large number of scientists from developing, threshold and developed countries actively participated in the projects. Within the framework of these projects ten international workshops were organized by the Unit in: Hamburg, Germany (1982); Assuit, Egypt (1983); Caracas, Venezuela (1984), Tianjin, People's Republic of China (1985); Fairbanks, USA (1986), Texel, The Netherlands (1987), Irkutsk, Russia (1988), Istanbul, Turkey (1989), Goa, India (1991) and Hamburg, Germany (1993). These workshops provided a state of the art assessment in the respective fields and formulated future research needs. The proceedings of these workshops have been published in a series of special monographs from the Hamburg Carbon Unit. *SCOPE Report 42: Biogeochemistry of Major World Rivers* provides a summary of information collected within the framework of the first two projects mentioned above.

The present volume is an outcome of the final workshop on *Particle Flux in the Ocean*, which was held in Hamburg, Germany in September 1993. Scientists from several countries, including Argentina, Brazil, Chile, the People's Republic of China, France, Germany, India, Japan, Romania, Russia, Turkey, Ukraine and the USA, participated in the Workshop to review progress made in the field. The following is a brief introduction to the role of particle flux in the marine carbon cycle.

Particle Flux in the Ocean.
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1.2 PARTICLE FLUX AND THE MARINE CARBON CYCLE

The production of biogenic particles in the upper ocean and their fractional removal to the deep sea determines the distribution of the biogeochemical elements in seawater. The rain of particles from the sea surface is the source of sediments accumulating at the ocean floor and fuels benthic life in the deep sea. Their fractional decay and remineralization as they sink through the water column controls - together with water circulation - the balances of oxygen, nutrients and other trace constituents. The settling particles carry with them indicators of biogeochemical processes at the ocean surface whose distribution in sediments can hence be used to reconstruct palaeoenvironmental conditions.

With regard to the global carbon cycle, particle flux in the ocean is one mechanism for the transfer of carbon derived from atmospheric CO_2 to the deep sea. The two relevant biological processes in this context ("the biological pump") are the formation of organic matter during photosynthesis (organic carbon pump) and the formation of carbonate during calcification (carbonate pump) (Heinze et al., 1991). These processes affect the surface ocean CO_2-balance in different ways. Photosynthesis consumes CO_2, calcification releases CO_2 (it is the dissolution of carbonate by CO_2 that effectively takes up CO_2 in the long run). Thus, changes in the initial production ratio of calcium carbonate to organic carbon can be expected to effect changes in atmospheric CO_2 (Berger and Keir, 1984). This ratio is controlled by the upper ocean community structure; e.g., the relative abundances of diatoms and coccolithophorids, which are the major respresentatives of primary producers in the ocean.

The efficiency of the marine biological pump does not depend on the gross uptake of atmospheric CO_2 via the formation of organic matter in the upper ocean (much of the organic matter is quickly mineralized back to CO_2 within the surface layers, which exchange gas with the atmosphere) but on the net export to the ocean's interior which is isolated from the atmosphere. It is only this fraction of organic matter that ultimately removes CO_2 from the atmosphere.

The importance of organic matter degradation within the water column in the modern ocean is also evident from a comparison of the carbon inputs at the ocean surface (Figure 1.1) with the amount of organic carbon being buried in the underlying sediments (Figure 1.2). The ocean's water volume and its carbon input at the surface are grouped according to depth intervals in Figure 1.1.

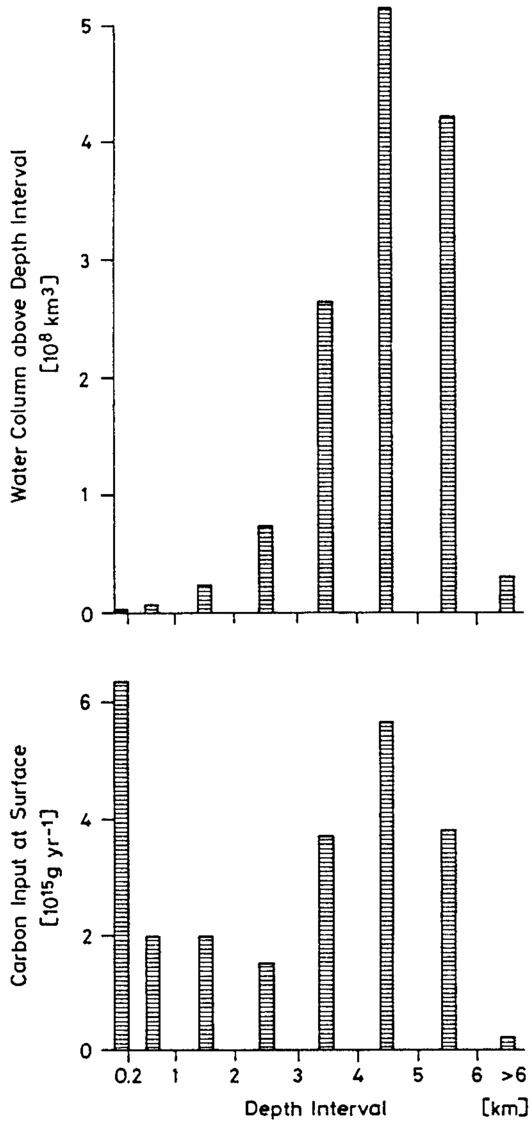

Figure 1.1 Water volume distribution above the various depth intervals in the modern ocean (top) and their respective carbon inputs at the surface (bottom) (after Deuser, 1979).

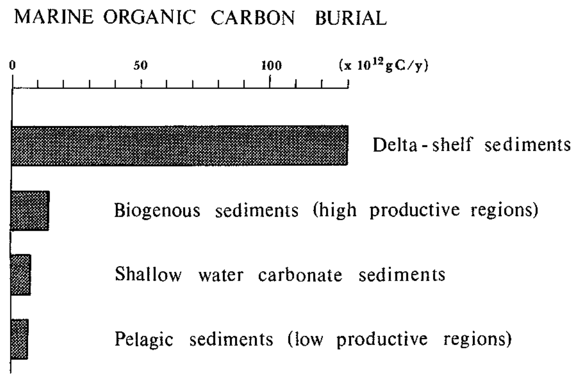

Figure 1.2 Distribution of organic carbon burial in the modern ocean according to sediment types (after Berner, 1982). Total burial rates 157 x 10^{12} g y^{-1} of which 85% occurs in deltaic and shelf sediments. Note that biogenic sediments underlying highly productive areas contribute less than 10%.

It is of note that the shallow regions (< 200 m) with their relatively small volumes of water receive comparatively large amount of carbon input at the surface. Also, oceanic regions with water depths > 3000 m obtain significant quantities of carbon input at the surface. Surprisingly, in modern marine sediments, 83% of the annual carbon burial (total burial 157 x 10^{12} g y^{-1}) occurs in deltaic-shelf sediments (Figure 1.2), and no more than 4% is buried in the deep-sea sediments. Apparently, organic matter recycling within the water column is a major process in the open ocean environment, effectively limiting the quantity of carbon being fixed in deep-sea sediments. The similar quantities of refractory organic carbon brought by the rivers to the sea (e.g., Ittekkot, 1988) and of organic carbon buried in modern marine sediments annually also suggest that the bulk of carbon fixed during marine photosynthesis is recycled within the water column, leaving very little for burial in sediments. The vertical distribution of this recycled carbon flux determines how much of the photosynthetically fixed CO_2 remains in exchange with the atmosphere on a given time scale, in a given water circulation regime. It is on this aspect of the global carbon cycle that particle flux studies provide invaluable information.

Vertical particle flux in the ocean is mediated by biological processes occuring in the upper ocean (Figure 1.3). Thus, aeolian and riverine particles entering the oceans are rapidly removed from the upper ocean together with biogenic particles produced *in situ* (e.g., Honjo, 1982; Deuser et al., 1983). Biological processes mediate in the formation of large particle aggregates such as fecal pellets, macroaggregates and marine snow which subsequently act as vehicles for particle

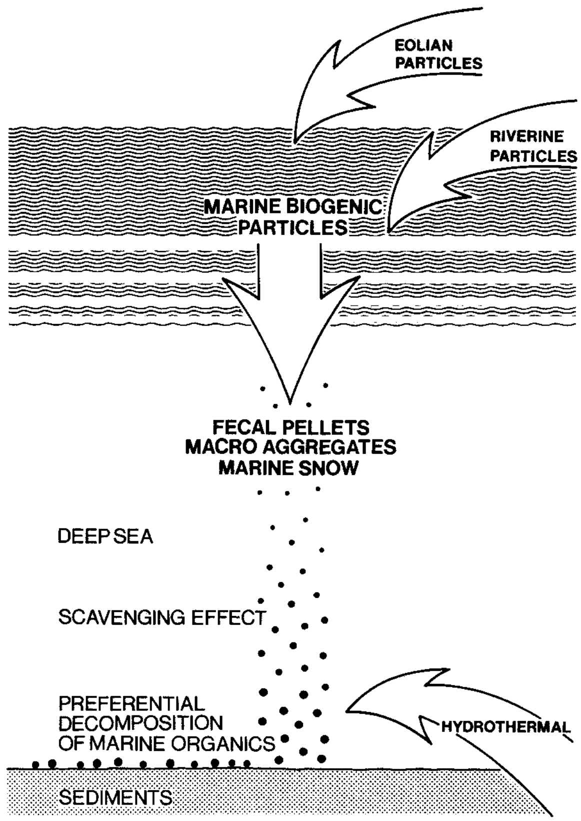

Figure 1.3 A scheme of parti cle sources and vertical transport in the ocean (from Ittekkot and Haake, 1990).

transport. During descent through the water column and at the seafloor the metabolizable fraction becomes decomposed leaving the refractory fraction to accumulate in sediments alongwith biogenic hard parts.

The present volume contains a series of review articles and case studies on these and other aspects of particle flux in the ocean contributed by scientists actively involved in research in the field. They cover results from particle flux experiments using time-series sediment traps in the Nordic Seas, the Northern and Equatorial Atlantic, the Southern Ocean, the Mediterranean, the Black Sea, the Arabian Sea, the Bay of Bengal, the South China Sea and the Pacific Ocean. They include results from some of the longest running ocean particle flux studies in the world. Included in the report is also a contribution on particle flux in Lake Baikal, the largest fresh water lake in the world. Large lakes and oceans have many traits in common, and also the controlling factors of vertical particle flux are similar. These contributions show the considerable effort being put in by groups of scientists in various countries on ocean particle studies and we hope that they will add significantly to our understanding of processes controlling material cycling in the ocean.

1.3 ACKNOWLEDGMENTS

The transfer of know-how and the training of young scientists from developing countries have been landmarks of the three projects undertaken by the Carbon Unit in Hamburg over the last decade. Through its activities the Unit has been able to establish an international network which has served to catalyze research in the field of biogeochemistry. Interested groups in developing countries were provided with information and the necessary training to initiate national programs in the field. The United Nation's Environment Programme (UNEP) and SCOPE have jointly encouraged and generously supported these activities throughout the years and we express our sincere gratitude to both organizations. We gratefully acknowledge the support by the national SCOPE Committees, universities and research organizations in the various countries. Dr. E. Duursma provided a review of the manuscript on behalf of SCOPE. The comments and suggestions by Dr. J. Thornton on behalf of UNEP helped considerably in improving the manuscript. We thank Mrs. Veronique Plocq-Fichelet and her team at the SCOPE Secretariat, Paris, who have been a constant source of encouragement and help throughout the years.

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