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Sedimentation and sedimentary process in the Indian Ocean

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Abstract

In this paper I shall describe the macroscopic patterns of Quaternary sediment distributions in the deep Indian Ocean in relation to climatology and oceanic circulation and then the calcium carbonate distribution in the Ocean and the sedimentary patterns. This will be followed by a brief discussion about the deep sea drilling project which tells about the spatial and temporal distribution of biosiliceous sediments in the Ocean during the last 45 million years.

Introduction

The Indian Ocean is the third largest of the world's oceanic divisions, covering approximately 20% of the water on the Earth's surface. It is bounded by Asia including India, after which the ocean is named on the north, on the west by Africa, on the east by Australia, and on the south by the Southern Ocean (or, depending on definition, by Antarctica). Being a vast volume it has a very complex distribution of sediments as discussed below.

Theory and analysis

Deep sea sediments of the Indian Ocean

Because of its geographical position, the Indian Ocean contains mostly all known types of recent deep sea sediments. Equatorial and temperate latitudes contain Globigerina ooze, red clay, and radiolarian ooze as well as hemipelagic deposits with coastal affinities such as the blue mud, coral mud etc. Whereas in the sub polar and polar regions, diatom ooze and glacial-marine sediments occur. And all these deposits consist of two type of substances-mineral and organic where the mineral content comes from the adjacent mainland or islands which reach the sediments in these different ways (1) suspended fluvial material, (2) material eroded from the coastline (3) glacial debris from icebergs, or (4) dust from volcanoes and deserts. The organic constituents depend on the animals and plants living in the sea water or on the sea bottom.

In the open ocean the organic material consists almost exclusively of those constituents of the planktonic animal and plant world that have settled to the bottom from the surface waters above. With the distinction as if the calcareous shells of pelagic foraminifera or the siliceous skeletons of radiolarians predominate in the sediment, as in the equatorial and temperate latitudes, we have respectively a Globigerina or radiolarian ooze. If the siliceous fragments of the diatoms prevail, we have the diatom ooze, which occurs principally in Polar Regions. If the organic components are distinctly subordinate to the mineral ones, or are completely lacking, in the open ocean the sediments consist of red clay, but near shore the sediments consist of hemi pelagic deposits, such as blue mud, green mud, or in polar regions, of glacial marine sediments.

Distribution of sediments

The wide deep sea of the tropical and temperate Indian Ocean is occupied mainly by red clay and Globigerina ooze. Red clay occurs mainly at the great depths in true deep-sea basins, whereas Globigerina ooze is found predominantly at relatively less depth, particularly on the deep-sea ridges. Sediments of the west part of the Indian Ocean consist almost completely of Globigerina ooze, except for the red clay area southeast of Madagascar and in the Arabian basin. As the water deepens from the
Central Indian Ridge toward the east basin, the red clay, which occupies almost the entire basin, takes the place of the Globigerina ooze. A small patch of radiolarian ooze lies north of the Kokos Islands within the area of red clay. The local occurrence of Globigerina ooze in the red clay west of the Kokos Islands is caused by an elevation on the sea bottom. In the subpolar region the diatom ooze surrounds the Antarctic continent in a broad belt and takes the place of the Globigerina ooze and red clay. In contrast with the distribution of these three eupelagic sediments, Globigerina ooze, red clay, and diatom ooze, the hemipelagic deposits are conspicuously scarce. For the most part they merely border the coast in a narrow band, but in the Arabian Sea and in the Gulf of Bengal they occupy somewhat larger areas of the sea bottom. Around the south polar continent these hemipelagic deposits consist of glacial marine sediments composed essentially of the debris of icebergs and glaciers on Antarctica.
The distributions of the main deposits of coral sand and coral mud are shown in the first figure afterwards. They are present in relatively large areas only in the region of the Laccadive-Maladive Islands, the Seychelles, the Chagos Islands, Saya da Malha, and on the Nazareth Bank. These two types of sediments are not as extensively distributed around the individual coral reefs as was formerly thought, for Globigerina ooze is found very close to many islands that have coral-reef coasts.

Calcium carbonate distribution

In the tropical and temperate latitudes the areas of red clay and of radiolarian ooze are characterized by low calcium carbonate content (0-30 per cent). Hence the distribution of carbonate in the east part of
The Indian Ocean is portrayed fairly clearly. The few data available indicate that the red clay of the east basin is for the most part carbonate free or poor in carbonate, and only at the boundary with the Globigerina ooze has it a carbonate content of slightly less than 30 per cent. On the other hand, the sediments of the west part of the Macquarie Ridge have a carbonate content of more than 75 per cent. In the south likewise the relationships are fairly clear, for there most of the diatom ooze and the glacial marine sediments are either free of carbonate or they have only slightly more than 10 per cent carbonate. In the west part of the Indian Ocean, on the other hand, areas of red clay are the only ones that with certainty can be shown to be poor in calcium carbonate. In order to indicate roughly the boundaries of the carbonate-rich sediments, it was in this area more than in other areas necessary to take into consideration the submarine topography, which indirectly influences the lime content; for this was the only way to subdivide the deposits. The sediments on the ridge extending from the Crozet Ridge to South Africa in general have a carbonate content of more than 75 per cent, and in some places have as much as 93.9 per cent. The entire Madagascar basin, on the contrary, including areas of red clay, seems to have a lime content of less than 50 per cent. The deposits on the entire Central Indian Ridge contain more than 50 per cent calcium carbonate and in some places contain more than 80 per cent. In the east, this ridge of high carbonate content is separated to a certain extent from the east basin, which is poor in carbonate, by the 30 per cent line, but the boundary on the west is still extremely uncertain, the south part of the Somali basin in general is covered entirely by Globigerina ooze, except for a small area of radiolarian ooze. In view of this and of the depth relations there, it seems as though the average calcium carbonate content of the sediments in the entire Somali basin is less that 50 per cent.

Sedimentation Patterns for the Indian Ocean during the Last 45 Million Years

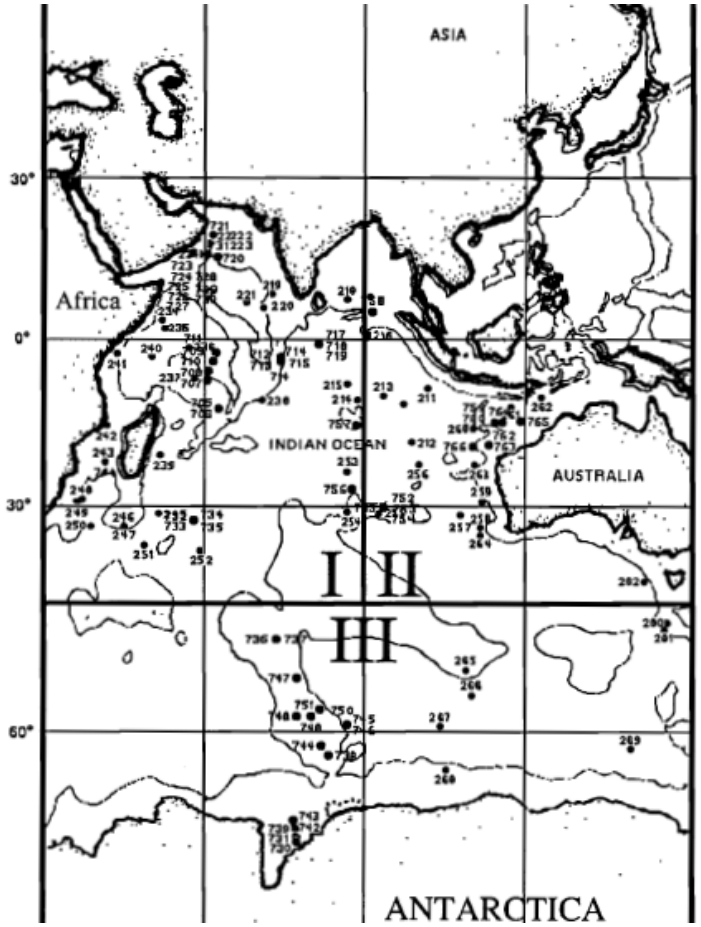
Modern surface circulation of the Indian Ocean consists of three distinct domains that include (i) the monsoon gyre, (ii) the southern hemisphere subtropical gyre and (iii) the Indian Ocean sector of the southern ocean influenced by Antarctic waters and the Circumpolar current. Unique to the Indian Ocean is the monsoonal circulation which is seasonal and which greatly influences upwelling along the coast of Arabia, the Somali Current, and to a lesser extent some parts of the east coast of India. The monsoonal gyre is separated from the southern subtropical gyre by a pronounced hydro chemical front at about 10°S These surface domains are reflected by the distribution of the surface chemical and biological properties, especially by the seasonal sea surface temperatures, phosphate distribution, and primary productivity. Regions of moderate to high phosphate (PO4) contents are associated with the monsoon region and the area of the southern divergence. The monsoon area has PO4 values between 1.0-2.0ug with concentrations dropping to less than 0.4 ug as one goes from the monsoon region across the front at 10°S into the region of the subtropical gyre. The region associated with the Antarctic divergence is rich in PO4 attaining values up to 2.2ug. Clearly this pattern indicates that regions of high productivity characterize the monsoon and Antarctic regions whereas low productivity characterizes the divergence, and to a lesser extent the coastal regions of Oman and India and waters adjacent to Sri Lanka, Burma and Java. The present-day oceanic and climatic conditions in the Indian Ocean are in part reflected in the distribution of modem sediments. Biosiliceous sediments accumulate today beneath regions of high surface water productivity associated with regions of oceanic upwelling This present-day pattern is dynamic and has evolved through geological time in response to global and regional changes in chemical budgets, tectonics, climate, sea-level and changes in the chemical and sediment cycles.

Deep Sea Drilling Project

Scientific drilling during Deep Sea Drilling Project Legs 22-28 and Ocean Drilling Program Legs 115-122 has provided a database from over 100 sites in the Indian Ocean. Analysis of the sediment from these sites allows determination of the spatial and temporal distribution of biosiliceous sediments in the Indian Ocean during the last 45 million years. For the purposes of this study the Indian Ocean has been divided into 3 quadrants. Quadrant 1, representing the northwest Indian Ocean, consists of the region from 90°E to 30°E and north of 40"S.Quadrant 2, representing the northeast Indian Ocean consists of the interval from 90°E to 150°E and north of 40"S. Quadrant 3 represents the Indian Ocean south of 40'S. DSDP and ODP sites within these quadrants are shown in the figure below. Quadrant I contains over 60 sites most of which are located in the area influenced by seasonal monsoons, along the Ninety east, Central Indian, or Chagos-Laccadive ridges, or positioned in the Madagascar region. Quadrant 2 contains 30 sites concentrated in two areas including the western and northwestern margin of Australia and Broken Ridge.

Quadrant 3 in the southern Indian Ocean contains 23 sites of which all but 7 are located on a north-south transect from the Kerguelen Plateau to Prydz Bay, east Antarctica. The somewhat patchy spatial arrangement of the sites in the Indian Ocean allows limited insight into the spatial and temporal distribution of biosiliceous sediments and the response of productivity and sedimentation to changing oceanographic, tectonic and climatic conditions. In the northwest Indian Ocean (Quadrant I. Figure below) few sites represent a near continuous stratigraphic record. This in part reflects spot wring procedures used during early DSDP cruises, the occurrence of stratigraphic breaks, or unsuccessful recovery of the sedimentary sequence. Stratigraphic sequences containing consistent diatoms occur in the Oman Margin-Arabian Sea-Owen Ridge areas the Mascarene Plateau region and the Central Indian and Chagos-Laccadives ridges. From a temporal perspective these stratigraphic intervals enriched with diatoms are generally restricted to two time intervals, the Paleogene (30-42 Ma) and the late Neogene- Quaternary (0-1 1 Ma). Paleogene sediments containing diatoms occur at some sites. Upper Neogene-Quaternary sediments containing diatoms are numerous (see Figure below). The dataset for the northeastern Indian Ocean (Quadrant 2) consists of 8 having a documented occurrence of diatoms for the last 45 million years. These are located in proximity to the Wharton Basin and Java Trench, on the northern end of the Ninetyeast Ridge, northwest Australia and the Java Sea. With the exception of poorly preserved diatoms in the Eocene-Oligocene interval at DSDP Sites some sites and the upper Oligocenemiddle Miocene interval at ODP Site 758, diatoms are restricted to sediments of late Neogene- Quaternary age (0-8 Ma.The one exception occurs from sites positioned on the continental margin of Prydz Bay, east

Antarctica, which either contain sporadic diatoms or are barren of diatoms.Within quadrant 3 diatoms are generally prevalent in sediments of Oligocene or younger age.



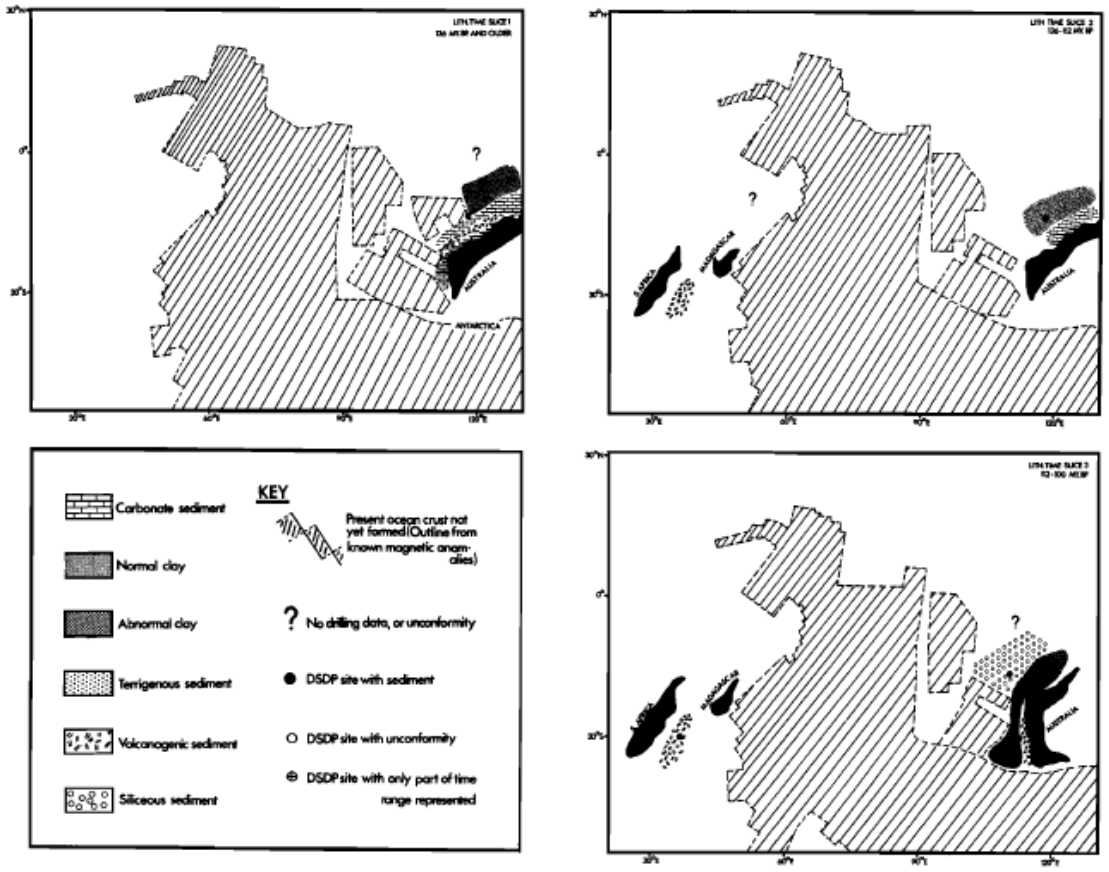
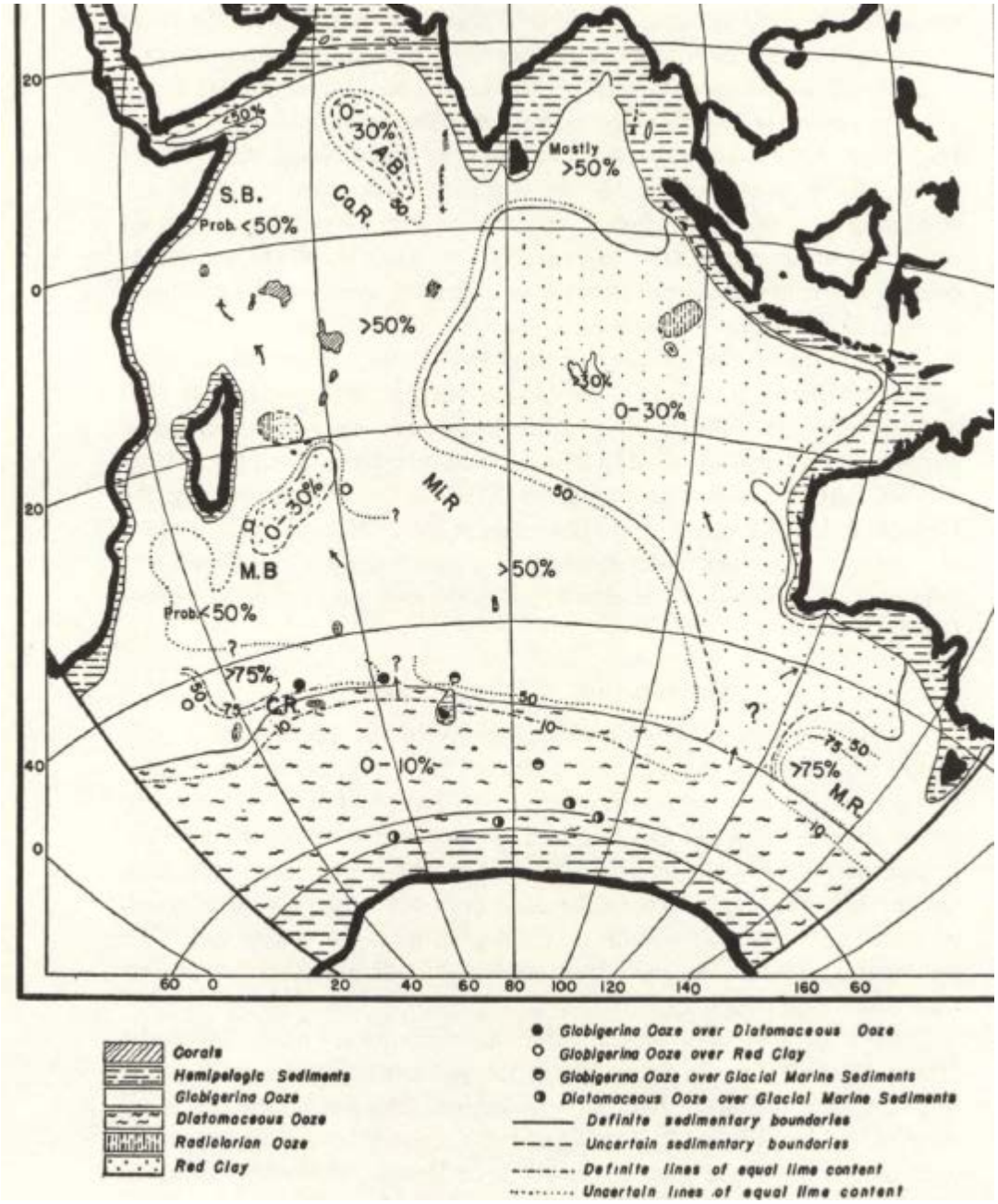


Fig. 5. Present distribution of sediments in the Indian Ocean. Top left: sediments 136 m.y. old and older; top right: 136 - 112 m.y.b.p; bottom right: 112-100 m.y.b.p.



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