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Preparing for ANTARÉS; Flux of biogenic silica in the SouthernOceon: Water column and sediments

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Abstract: Oceanic biogeochemical cycles exert an important control on atmospheric CO_2 concentrations. To understand past changes associated with climatic events and predict future atmospheric CO_2 levels, the role of the Southern Ocean needs to be specifically addressed. Because most the primary production occurring in the Southern Ocean is driven by diatoms, the marine cycle of silicon plays a key role in understanding the dynamics of the biological pump. The purpose of this presentation is twofold. It consists first in reviewing the current questions on the oceanic processes controlling the dynamics of silica in water masses and in surficial sediments of the Southern Ocean and, second in presenting the multidisciplinary approach undertaken by the French oceanographic community: ANTARES, in the framework of the Southern-JGOFS international program.

1. Introduction

In the Southern Ocean, primary productivity is mainly controlled by diatom species and the deep-sea sediments are the main repository of siliceous biogenic debris. This ocean plays, consequently, a major role in the global biogeochemical cycle of silicon whose dynamics, in this region of the globe, is still poorly understood. The quantification of biogenic fluxes of silica in the water column and at the sediment water interface are of prior importance to assess oceanic budgets for Si. Moreover, the dynamics of the biogeochemical transformations of silicon, in this environment, exert a direct control over the distributions and the biogeochemical cycles of C, N, S, P, and trace oligo-elements.

The South circumpolar marine province is at the confluence of the 3 major oceans: Atlantic, Indian, and Pacific, It is bounded on the north by the subtropical fronts and on the south by the Antarctic continent. The Southern Ocean has been divided into four different oceanographic regions which surrounds the Antarctic Continent. They are, from the North toward the Antarctic continent, the Polar Front (PFZ), the permanently Open Ocean Zone (POOZ), the Seasonal Ice zone (SIZ) and the Coastai Continental Shelf Zone (CCSZ). These zones are more or less corresponding geographically to concentric rings surrounding the Antarctic continent.

This ocean represents 19% of the surface of the world ocean and the circulation of the water masses is dominated by Antarctic Circumpolar Current (ACC) which has a net transport flow of 130 Sv. The heat flux across this current contributed to the formation of cold bottom waters for the entire globe. This ocean is the place of deep upwellings, seasonal sea ice formations, and low salinity waters. The cloud cover is importamt and the ecological ecosystem is under the influence of a strong seasonal forcing.

This short presentation emphasizes the role

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of the advection of water masses and the climatic forcing exerted over the Southern Ocean ecosystem. Remote sensing data have demonstrated that the Southern Ocean is a region of the world where a large level of mesoscale variability exists. The important seasonal and atmospheric forcing imposed upon the Antarctic ecosystem play certainly an important role in determining its ecological dynamics and its internal machinery. Because this ocean is still mysterious by numerous aspects and because it is though that it has played in the past an important role in the earth biogeochemical dynamics, it represents an important marine area to study.

The biological pump in the Southern Ocean is primarily under the control of the diatom population. In order to understand the importance that this ocean might have on a global scale it is consequently important to focus the study of biogeochemical processes around the cycle of silica. The following section presents some of the basic informations which are relevant in defining the French contribution to Southern-JGOFS.

2. Fluxes of biogenic silica and C_{org} in the Southern Ocean

The primary productivity of the Southern Oceanic Waters has been the focus of numerous research reports. Most of this productivity seems to occur at ocean boundaries and in frontal zones. Recently studies particularly addressed the paradigm of the existence of very low primary produtivity zones where the concentration of nutrients were never exhausted. The potential explanations of these observations are nourishing passionate debates. The main hypothesis are light inhibition, temperature influence on growth rates, strong turbulences in the upper mixed layer, important grazing activity, and/or oligo-element limitation (Fe, hypothesis, …). The determination of the factors that control primary production when nutrients are not limiting is one of the most important scientific goal of the Southern-JGOFS program.

Although the Antarctic Ocean produces less than 5% of the global primary production of the world ocean, its production of biogenic cilica corresponds to about 20% of the entire ocean (TRÉGUER and BENNEKON; 1991), (Fig.1). The mean biogenic ratio between biogenic silica ($SiO_{2(B)}$) and organic carbon (C_{org}) in the Southern ocean diatoms is:

$$0.19 \leqq \frac{SiO_{2(B)}}{C_{ORG}} \leqq 0.65$$

In comparison, the same rame ratio for the mean oceanic diatoms is approximately 0.13. Diatoms, which are living in Antarctic regions, are consequently concentrating, on the average, more biogenic silica.

The fluxes of biogenic silica from the euphotic zone to the sea floor have been investigated in relatively few places using sediment traps (WEFER *et al.*, 1982; NORIKI and TSUNOGAI, 1986; DUMBAR *et al.*, 1991; and others). The large majority of sediment trap deployments have been performed near the continent and very little information exists on the fluxes of biogenic silica in open waters. These experiments have shown that there exists, as expected, a strong seasonal signal. The major vehicle of the biogenic silica rain to the sea floor seems to be fecal pellets in nearshore environments. This organic packaging of the diatoms frustules might reduce drastically the dissolution of diatoms frustules in the water column since they will be preserved during their descent to the sea floor.

Studies of Silica fluxes in the Southern Ocean have proposed that 2/3 of the biogenic silica production was undergoing dissolution in the water column prior to reaching the sea floor (NELSON and GORDON, 1982). If one considers that this is valid for the entire Southern Ocean, in numerous region the flux of accumulation of biogenic silica sediments can not ne explained only by the small primary productivity observed in surface waters. In some environments the sedimentary flux is even larger than the measured primary production

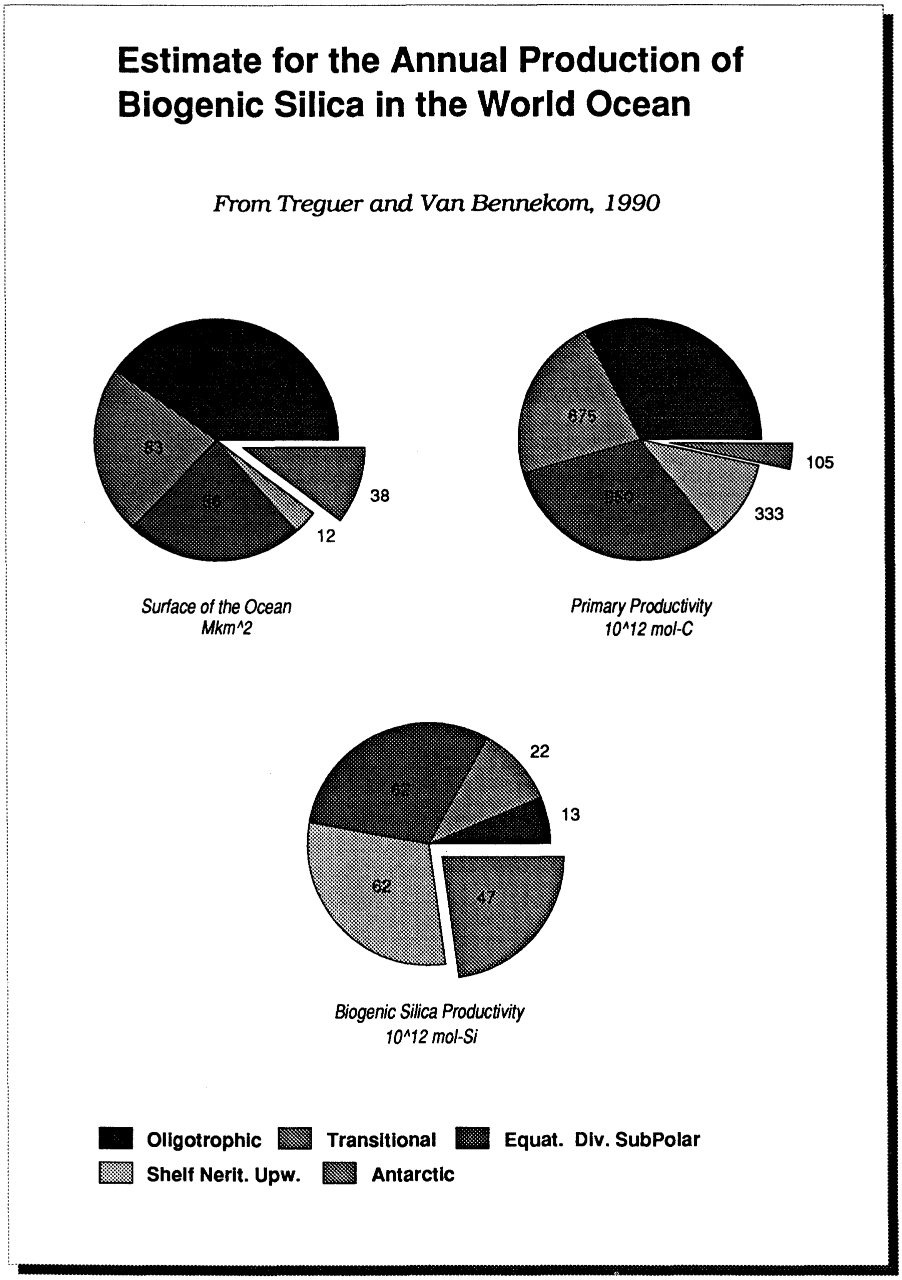

Fig. 1. The annual production of biogenic silica in the Antarctic Ocean compared to the superficies of the different oceans and their annual primary production.

of surface waters.

Consequently little is known on the recycling of silica in the open waters of the Southern Ocean. The dissolution experiments of biogenic silica performed during cruises do not always agreee with the estimates of biosilica primary productivity and the inventory of the sediment. The explanation might reside in large transport and accumulation of sediments localized in deeper basins. Ultimately the quantification of the silica cycle should help understanding the transfer of biogenic compounds in this environment and therefore the importance of the CO_2 cycle in the Southern Ocean for the world ocean.

3. Water-sediment interface, recycling and burial

The sediments of the Southern Ocean are the repository of approximately two thirds of the total biogenic silica accumulation in marine sediments. This accumulation produces biogenic silica rich sediments which are distributed in the shape of an open ring surrounding the Antarctic continent. (DEMASTER, 1981; LEDFORD-HOFFMAN *et al.*, 1986).

The dissolution of biogenic silica debris buried in the surficial sediments generates an important flux of dissolved silica from the sea floor to the overlying bottom waters. The gradients of concentration of dissolved silica present in the interstitial waters, close to the sediment water interface, are very important. In the region of high silica accumulation the formation of silica oozes is observed. The concentration of dissolved silica increases in less than 2 cm below the sediment water interface from 100 μ moles. l^{-1} in the overlying waters to 750 μ moles. l^{-1} (GAILLARD *et al.*, 1992). Almost in all the cores, at deeper depth, diatoms frustules are well preserved whereas the concentration of dissolved silica does not reach equilibrium values with amorphous silica. Consequently it appears that the dissolution of the skeletons of the various diatom species is inhibited when buried in the sediments. The mechanism by which these frustules are protected from dissolution by a protective coating is still unknown, but it is possible to devise a theoretical model accounting for this phenomenon (Fig.2). In some benthic locations, when a geochemical mass balance is performed on the sediment, one finds that a biogenic silica rain greater than the average observed biosilica production of the surface waters is required to account for distribution of concentrations in both the

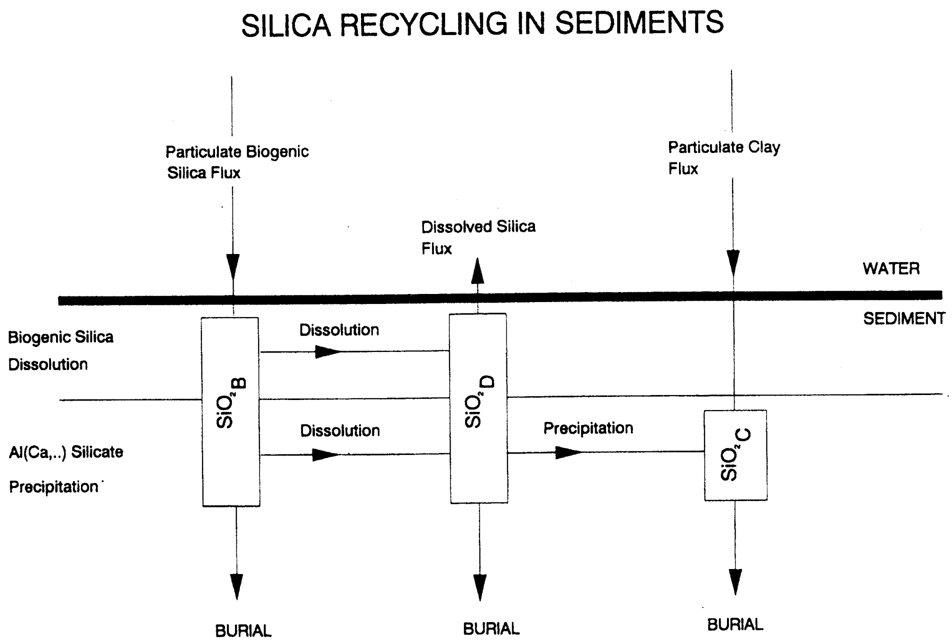

Fig. 2. A schematic diagram of the recycling and burial of biogenic silica in surficial sediments.

pore waters and the sediments.

In order to interpret more quantitatively the historical record preserved in the sediments it is necessary to obtain more information on the nature of the early diagenetic processes involved in the preservation, recycling, and transformation of bigenic silica in the Southern Ocean sediments. At the same time the paleoceanographic studies of the distribution of the diffrernt diatoms species and their different dissolution characteristics will prove to be very valuable for reconstructing past climate.

The last point to mention is the little information that one possesses on the burial and degradation of organic matter, the distribution and the diversity of the benthic fauna, and the metabolic activity of the organisms at the sea floor. All these aspects are important in assessing the role of the benthic environment in the cycle of the chemical elements. The Southern Ocean is a region of the globe where large volumes of bottom waters are formed and consequently all these benthic processes affect their chemical composition and are important to consider.

4. ANTARES 1 Cruise

The program ANTARES is the Frech contribution to Southern-JGOFS. This program is organized by Dr. P. TRÉGUER. The first cruise is presently in its planning stage and should take place during the month of March and April 1993. Its principal goal is the study of the benthic environment along a transect following 55°E. This expedition will survey this route by providing sea floor information, using conventional techniques such as bathymetry, acoustic properties of the sediments, and on board determination of the sedimentology of surficial sediments and piston cores. With the help of these geophysical and sedimentological informations three study zones will be defined. These study sites have to be characterized by a constant pelagic sedimentation in order to extend the present knowledge of oceanic processes to the historical record. These 3 zones will be situated at the northern and southern limits of the POOZ, and in a region of the SIZ accessible by ship during austral summers. After the survey and the precise choice of the locations, the sampling of the benthic environment will focus on the surficial sediments and deep waters physics and chemistry. It is expected to obtain at each site a frame of box cores for biological and geochemical studies, surficial sediments using a multitube corer, and deep sediment cores for paleoceanographic studies. A benthic chamber, operating as a free vehicle, will be launched at each site for determining benthic fluxes of O_2 and dissolved silica. Deep water sampling using a rosette and CTD will be performed in order to determine the chemical composition of the water column. Before leaving the site, sediment trap arrays, consisting of 3 traps and 3 current meters, (which can be detected in case of an unexpected release by a satellite detection device: ARGOS buoy), will be moored. The last aspect of this expedition is the study and the characterization of the circulation of Oceanic Waters in order to understand the transfer of material of material within the water column. On the 55°E route back to port, several XBTs and hydrocasts will be performed on a mesh following a precise timing. The next cruises of the ANTARES program will principally focus on upper ocean processes with a continuous hydrological survey.

Along with the teams devoted to the mooring of sediment trap arrays and hydrological studies the participants of this cruise are for the most part involved in benthic studies. These studies will encompass the fields of biology, geochemistry, and microbiology. The different aspects that will be developed during the cruise are the following:

- Benthic populations:
  Survey of Species, Numbering, Biomass
- Sedimentology (Recent Sediments):
  Find recent depostis, determine sedimentology on board the ship. Benthic photogra-

phy, Acoustic Information.

•Sediment Geochemistry:

+Bulk Sediment Analysis: C_{org}, Opal, $CaCO_3$, Metals, …

+Sedimentation Rates Estimation: Using Radioisotopes

+Pore Water Chemistry: O_2, Nutrients, Metals, SiO_2, Electron Accerptors.

+Experimental Kinetic Studies of $Si_{(B)}$ Dissolution/Precipitation

+Organic Geochemistry: Lipids as Tracers.

•Sediment Microbiology:

+ETS, O_2, Sediment Oxygen Demand.

+Bacterial activity: using ^{14}C and ^{35}S-SO_4

•Benthic Fluxes:

+Benthic Chamber Experiments:

Determination of O_2 benthic demand.

Fluxes of Dissolved Silica to the Overlying Waters.

The scientists involved in the study of the circulation of deep oceanic waters and their chemical/physical characterizations will particularly concentrate on the following aspects:

•Antarctic Circumpolar Current

+Baroclinic Flux from the Polar Front to the Antarctic Continent.

•Isotopic Composition of Water Masses

+ ^{18}O and ^{13}C tracers.

•Water Column Chemistry

+Dissolved Silica Variations

+Iron and Nd chemistries.

Finally the paleoceanography team will address two issues. The first issue will focus on the definition of past hydrological conditions using the isotopic records of ^{18}O and ^{13}C of the sediments, and the second on the long term sedimentary record. This last aspect will particularly look at past planktonic assemblages in the sediments and assess the variations of the biogenic silica flux and biogenic carbonate flux over the last glaciations periods.

ANTARES 1 Participants:

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