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Biogenic opal in shallow Eurasian shelf sediments in relation to the pelagic Arctic Ocean environment

INTRODUCTION

Due to the permanent ice-coverage, the modern Arctic Ocean is a low-productive environment, which leads in combination with the well-oxygenated deep-water to a low flux and preservation of marine organic matter in the surface sediments (STEIN *et al.*, 1994). SUBBA RAO and PLATT (1984) published primary production rates of 0.004 - 4.9 $gC/m^2/d$ for the marginal areas of the Arctic Ocean with maximum values on the shelves, and in bays and fjords. Exceptionally high rates occur at ice edges and open waters (e.g. polynyas) (SMITH *et al.*, 1985, 1987; HIRCHE *et al.*, 1991). Regional differences in the distribution patterns of various geochemical and/or sedimentological productivity indicators (e.g. biogenic barite, biogenic silica, carbonate, total organic carbon and the related HI-indices and C/N ratios), thus, should appear in the sediment. Accordingly, temporal changes within these parameters will supposedly allow to reconstruct the variability of processes driving marine productivity, e.g. the Arctic pack ice, solar insolation and nutrient supply.
Previous investigations of opaline silica in Arctic Ocean sediments, which supposedly reflects the production of siliceous phytoplankton, concluded that the accumulation of biogenic silica (opal) is negligible (DEMASTER, 1981). LISITZIN (1985) states that the opal accumulation at high latitudes is severely limited by the light factor and the ice cover leading to opal concentrations commonly below 1%. This study, in contrast, reveals significant temporal and spatial variations in opal accumulation and stresses the potential of opal for paleoproductivity reconstructions.

MATERIAL AND METHODS

In the framework of this study, we determined the opal concentrations within surface sediments from the Eurasian shelves and the central Arctic Ocean. A few samples of suspended particulate matter from the central Arctic surface waters were also available. To quantify the opal concentrations, we applied an automated leaching method according to MÜLLER and SCHNEIDER (1993). The opaline material is extracted from the dry and ground bulk sediment by sodiumhydroxide at ca. 85°C for ca. 45 min. The leaching solution is continuously analyzed for dissolved silicon by molybdate-blue spectrophotometry. The DEMASTER (1981) mineral correction was consequently applied.

In order to assure that all biogenic opal is extracted from the samples dominated by terrigeneous components, a 1M NaOH solution was applied. Such strong leaching agent may also cause the dissolution of siliceous sponge spicules as well as clay minerals to a certain degree. Figure 1 shows opal concentrations derived from 1M NaOH leaching versus data from 0.1M NaOH leaching. 0.1M NaOH commonly affects the siliceous sponge spicules to a negligible degree, but is known to effectively dissolve diatoms (SCHLÜTER, 1990). The suspended particulate matter exhibits a reasonable 1:1 correlation, indicating that all biogenic silica extracted originates from siliceous plankton. Opal contributed by clay mineral dissolution can be ruled out since lithogenic components are of minor importance. In contrast to suspended particulate matter, core-top samples significantly deviate from the 1:1 regression line. Since opal contribution from clay mineral dissolution is estimated to range below 1%, the generally higher opal concentrations derived by 1M NaOH leaching must be attributed to the presence of siliceous sponge spicules. From the linear alignment of these samples it is deduced that sponges provide in average ca. 60% silica of the bulk opal signal.

RESULTS AND DISCUSSION

An enhanced surface water productivity, which is due to a strong nutrient supply as is typical in front of river systems and in local upwelling areas, may significantly shape the depositional environment in respect to the conservation of productivity proxies. The major river systems (Lena, Ob, Yenisey) dewatering into the Arctic Ocean annually provide ca. 520-600 km^3 of fresh water (AAGAARD and CARMACK, 1989), and are responsible for the large amounts of suspension load being accumulated on the shelves and the adjacent continental slopes. The estimated high sedimentation rates are an important prerequisite for the accumulation and conservation of large amounts of (marine) organic matter.

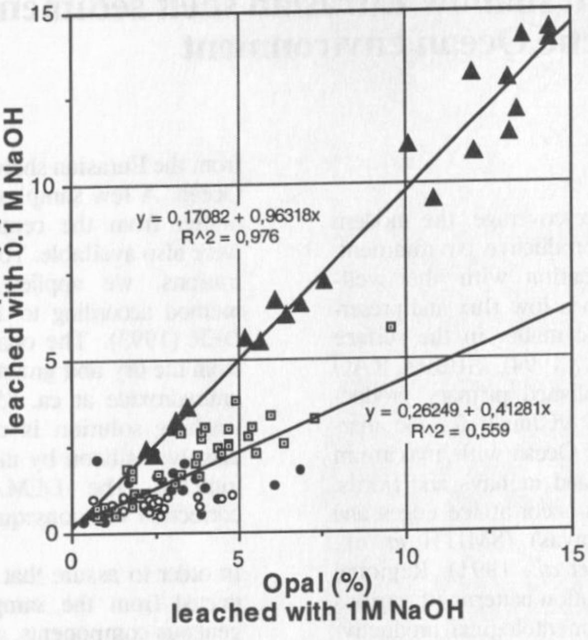

Figure 1. 1M NaOH leaching versus 0.1M NaOH leaching. Triangles represent suspended particulate matter. All others are core-top sediments from Eurasian shelves (see Figures 2 and 3) and the deep central Arctic Ocean.

Laptev Sea

According to PIVOVAROV (in KASSENS and KARPIY, 1994), the influence of freshwater supply to the Laptev Sea via the Lena River is reflected by the distribution pattern of dissolved silica in the surface water layer (ca. 5-10 m water depth). Maximum concentrations of about 1400 µg/l were observed at the eastern side of the Lena river mouth, indicating a predominant outflow to the east (Figure 2). Concentrations gradually decrease with increasing distance from the delta. High chlorophyll-a concentrations (KNICKMEIER and von JUTERZENKA, 1996) point to an enhanced biological activity in the eastern Laptev Sea surface layer, which is definitely reflected in the bottom sediments with enhanced opal concentrations of 3-6% (Figure 2). The diminishing dissolved silica concentrations to the north and to the west result in correspondingly low opal oncentrations in the bottom sediments.

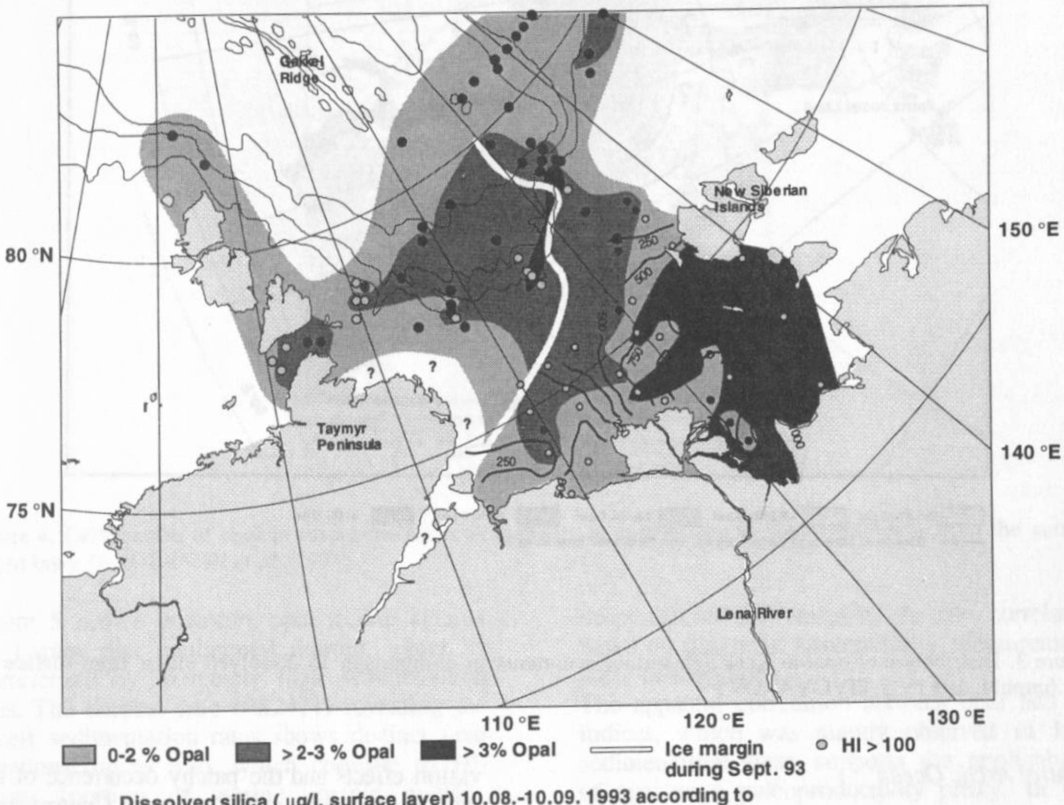

Figure 2. Distribution of opal in Laptev Sea surface sediments in comparison to dissolved silica from surface waters (S. PIVOVAROV in KASSENS and KARPIY. 1994)

A distinct opal maximum of about 3-5% observed on the upper Laptev Sea continental slope in 500-1000 m water depth is directly situated below the summer edge of the pack ice cover, which is relatively stable during summer over years as inferred from satellite imagery. Surface waters overlying these sites showed enhanced chlorophyll-a and phaeopigment concentrations during summer 1993. Nutrients (NO_3, PO_4), in contrast, were significantly depleted (BOETIUS and NÖTHIG, 1996) indicating a plankton bloom at the ice edge. Due to the relatively stable position of the summer ice edge, repeated occurrences of plankton blooms are apparently providing enough biogenic silica to be preserved in the surface sediments (STEIN and NÜRNBERG, 1995)

Kara Sea

The dominant eastward outflow of Yenisey and Ob river waters indicated by the annual average dissolved silica distribution pattern is clearly reflected in the opal concentrations of the seafloor deposits (Figure 3). High opal concentrations of > 5% in the inner river mouths successively decrease to below 1% in the outer Kara Sea regions. In the center St. Anna Trough, maximum opal concentrations in combination with high TOC values and C/N ratios of about 6 (STEIN, 1996) point to an enhanced marine productivity, which is presumably linked to the outflow of nutrient-rich Yenisey and Ob-river water through the St. Anna Trough.

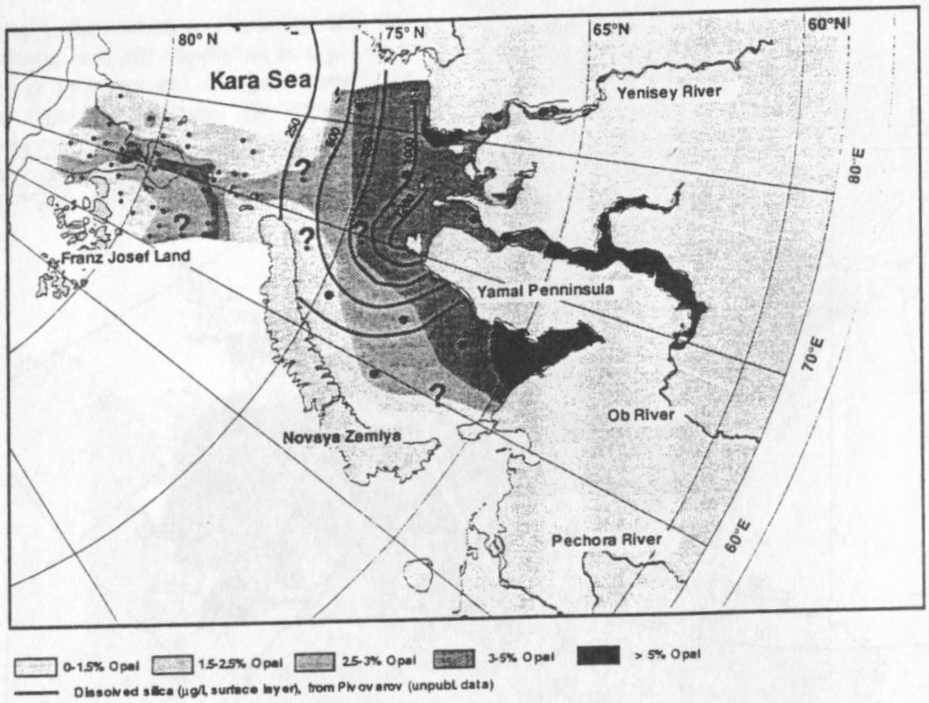

Figure 3. Distribution of opal in Kara Sea surface sediments in comparison to dissolved silica from surface waters (unpubl. data by S. PIVOVAROV)

Central Arctic Ocean

Within suspended particulate matter sampled from below the ship through continuous pumping during the RV "Polarstern" North Pole expedition (ARCTIC'91), opal concentrations range from ca. 2% to > 15% (Figure 4). In the vicinity of Svalbard, opal in suspended material amounts to 2-5%. Within the surface mixed layer, dissolved silica is below 3 µmol/kg at that place (ANDERSON *et al.*, 1994). Opal successively increases northward to ca. 10-15%, as dissolved silica concentrations increase to > 8-10 µmol/kg (ANDERSON *et al.*, 1994). Apparently, opal within suspended particulate matter reflects the distribution pattern of dissolved silica from the surface mixed layer as was described for the shallow shelf sediments.
The opal distribution pattern observed within the water column is not reflected within the deep Central Arctic Ocean surface sediments as it is most likely perturbed by dissolution and preservation effects and the patchy occurrence of benthic siliceous sponges. The entire Central Arctic Ocean commonly shows opal concentrations between 3% and 5%. Maximum opal concentrations (max. 10%) at a few sites within the deep-sea basins and on the slopes of mid-ocean ridges and plateaus are presumably due to the good preservation in high sedimentation areas. Instead, Morris Jesup Rise, Yermak Plateau, the Barents Sea shelf and the Makarov Basin are extremely low in opal, which points to non-preservation due to low accumulation, winnowing and/or erosion. At Yermak Plateau, the low opal concentrations unfortunately mismatch the enhanced levels of other productivity proxies like biogenic barium (NÜRNBERG, 1996), short-chained n-alkanes (SCHUBERT, 1995), high standing stocks of benthic foraminifers (WOLLENBURG, 1995), and enhanced HI-indices (STEIN *et al.*, 1994), though the relatively high sedimentation rates of about 1.9 cm/kyr (STEIN *et al.*, 1994) should favor opal preservation.

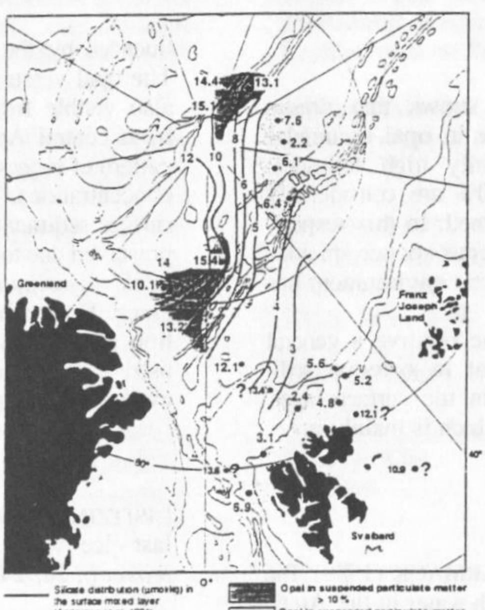

Figure 4. Distribution of opal in suspended particulate matter in comparison to dissolved silica from the surface mixed layer (ANDERSON *et al.*, 1994)

Figure 5 shows downcore opal records accross the Laptev Sea continental margin, which is characterized by extremely high sedimentation rates. The deepest core (PS2471) revealing the lowest sedimentation rates shows distinct opal variations (up to 6%), which correlate to HI-indices (portion of marine organic matter). Though actual numbers are very low, the diatom record indicates that diatoms are present even in the deep Arctic Ocean over the entire core length. The opal records from the shallower cores (PS2474, PS2476) apparently match the deepest record as revealed by the core correlation based on magnetic susceptibility measurements and lithology logs.

The apparent correlation between opal and HI-indices, which was mainly observed in high sedimentation areas, supports the applicability of opal as a paleoproductivity proxy. In low sedimentation areas (ridges and plateaus), however, reworking, dissolution effects and the bad preservation of opal and marine organic matter prevents the usage of opal for paleoreconstructions.

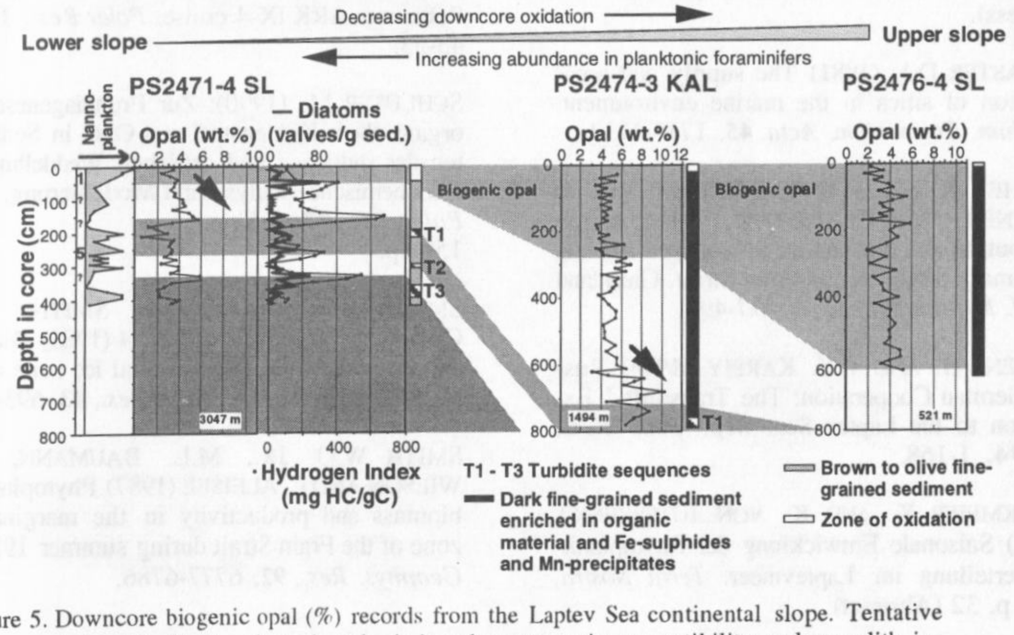

Figure 5. Downcore biogenic opal (%) records from the Laptev Sea continental slope. Tentative core correlation (shading) and stratigraphy is based on magnetic susceptibility and coccolith investigations, respectively (NÜRNBERG *et al.*, 1995). HI-indices match the opal variations.

CONCLUSIONS

In conclusion, our study shows that drastic temporal and spatial changes in opal accumulation appear even in extremly high latitudes. Concentrations of up to 10% are considerably higher than previously assumed. In this respect, the presence of benthic siliceous sponge spicules widely distributed in the Arctic environment has to be considered.
On the Eurasian shelves we observe a general correspondence between opal in core-top sediments and dissolved silica in the surface layer, the distribution pattern of which is mainly influenced by the large Siberian river outflows. The opal versus dissolved silica relationship is also visible from suspended particulate matter from central Arctic surface waters revealing a pattern of successively northward increasing opal concentrations. Within the deep central Arctic surface sediments, however, such pattern is not preserved due to regionally varying accumulation rates, dissolution effects and reworking processes. Downcore records from high sedimentation areas stress the potential of opal of being used as a paleoproxy for marine productivity even at ice-covered Arctic regions.

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