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Diatom distribution in southeastern Pacific surface sediments and their relationship to modern environmental variables

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ABSTRACT

The quantitative analysis of diatom assemblages preserved in 52 samples from the Bellingshausen and the Amundsen Seas provides the first comprehensive view on the distribution of diatoms in surface sediments of the eastern and central Pacific sector of the Southern Ocean. On a latitudinal transect along 120°W, diatom valve accumulation rates (AR) reach maximum values ($8–10\times10^8$ valves m^{-2} yr^{-1}) in a zone extending over ca. 900 km between the Antarctic Polar Front and the maximum average winter sea ice extent and exceed those ARs obtained from an eastern transect along 90°W by one order of magnitude. Lowest diatom concentrations ($1–3\times10^6$ valves g^{-1}) were encountered in sediments of the Sea Ice Zone, affected by winter and summer sea ice. The accumulation rate pattern of the most abundant diatom *Fragilariopsis kerguelensis* (>50% abundance in 47 samples) mirrors the pattern of the total diatom valve AR and the biogenic silica (BSi) AR, making *F. kerguelensis* the major contributor to the BSi preserved at the sea floor. Relative abundances of diatom species and species groups were statistically compared with a selection of environmental variables, such as the mean summer sea surface temperature and salinity, mean annual surface nutrient concentration (nitrate, phosphate, silicon), mean annual water column stratification, mixed layer depth in summer, and mean summer and winter sea ice concentrations. Polynomial canonical redundancy analysis (RDA) revealed the biogeographic distribution of diatom species had the strongest relationship with summer sea surface temperature (SSST) out of the nine tested environmental variables. This relationship accounted for 69.6% of the total variance of the diatom distribution, with 29.7% explained by the first gradient (significantly correlated to SSST with $r^2 = 0.941$) and 15.6% explained by the second gradient (correlated to both summer and winter sea ice and silicon concentration). *Azpeitia tabularis, Hemidiscus cuneiformis* and *Roperia tesselata* were associated with warmer water conditions (>4 °C), whereas *Fragilariopsis curta*, *F. separanda*, *F. rhombica* and *Thalassiosira gracilis* were correlated with cold SSST (<1.5 °C). Under the second gradient relationship, *Actinocyclus actinochilus* and *F. curta* were the most important diatoms representative of the diatom distribution in relation to the observed mean summer and winter sea ice concentrations.

Confirming these environmental relationships is crucial for the development of reference data sets used in quantitative estimations of palaeoclimatic and palaeoceanographic conditions with statistical methods. This new data set represents the first modernised treatment of diatom remains from the SE Pacific Ocean and generally supports the use of a circum-polar database for the determination of summer SST, sea ice and potentially biogenic silica distribution of the Southern Ocean back into the Late Quaternary.

1. Introduction

The establishment of quantitative data sets on the diatom species composition preserved in Southern Ocean surface sediments (Zielinski and Gersonde, 1997; Pichon et al., 1998; Armand et al., 2005; Crosta et al., 2005; Romero et al., 2005) has allowed for the development of diatom-based transfer functions, which can be used to quantitatively reconstruct past Southern Ocean surface temperatures and sea ice concentrations (Pichon et al., 1987, 1992a,b, 1998; Zielinski et al., 1998; Crosta et al., 1998a,b) and for the definition of species abundance patterns as a template for the estimation of past sea ice distribution (Gersonde and Zielinski, 2000) and productivity regimes (Abelmann et al., 2006). Most of our understanding of Pleistocene Southern Ocean sea surface temperature (SST) and sea ice conditions at specific time slices and glacial/interglacial variability comes from diatom transfer function-based reconstructions (Crosta et al., 1998a,b, 2004; Zielinski et al., 1998; Bianchi and Gersonde, 2002, 2004; Kunz-Pirrung et al., 2002; Gersonde et al., 2003a,b, 2005; Armand and Leventer, 2003, 2009). Although this approach has essentially met with success, further studies are required to enhance our ability to reconstruct past Southern Ocean surface water conditions. This concerns primarily the extension of the diatom reference data sets into the Pacific sector, as requested by Gersonde et al. (2005), combined with a statistical

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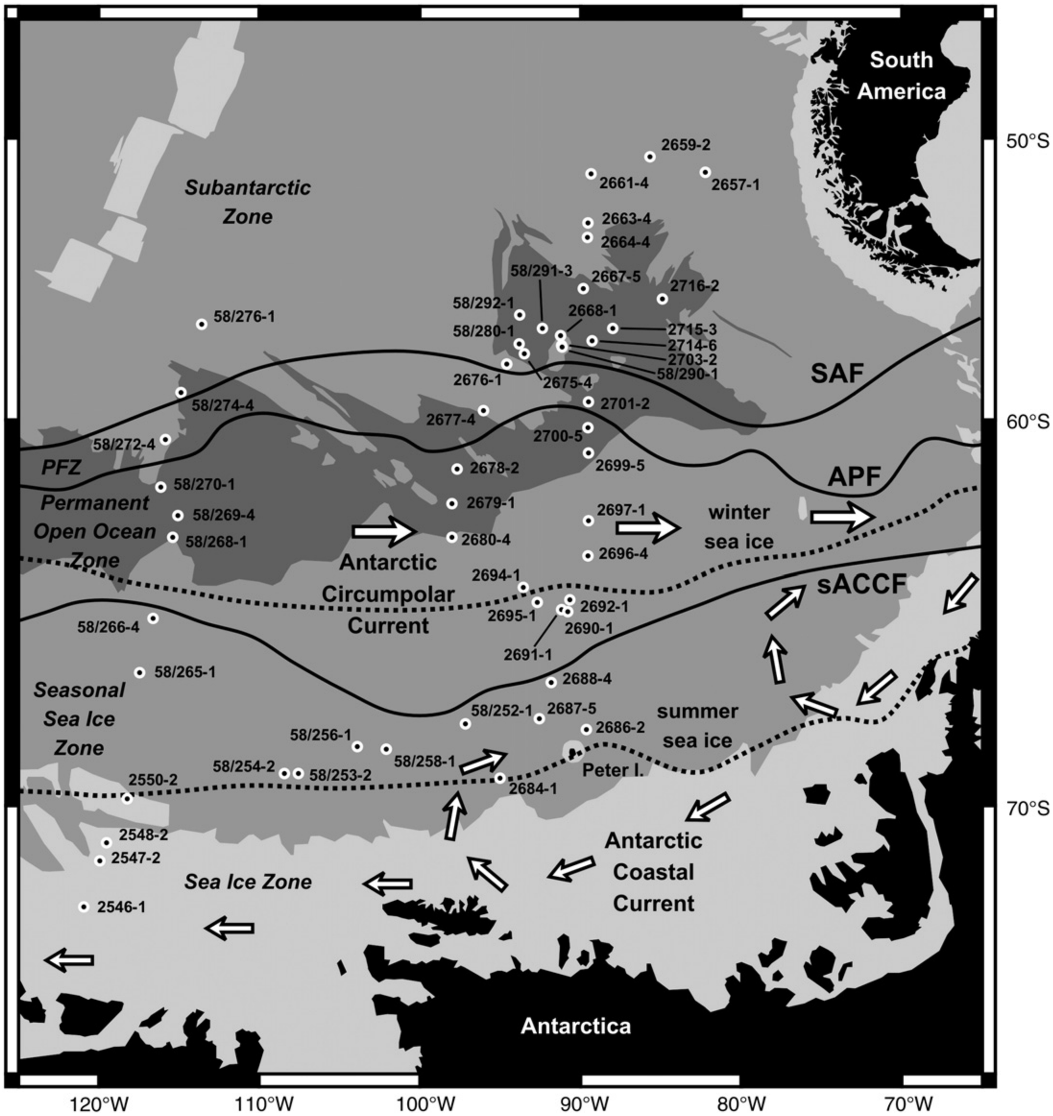

Fig. 1. Present-day surface oceanography in the Pacific sector of the Southern Ocean with the positions of the oceanic fronts (after Orsi et al., 1995; SAF: Subantarctic Front; APF: Antarctic Polar Front; PFZ: Polar Front Zone; sACCF: Southern ACC Front), the main sea surface currents (arrows; after Read et al., 1995; Nechaev et al., 1997; Smith et al., 1999), summer and winter sea ice extent (dashed lines; after Schweitzer, 1995), the bathymetry of the observed area (light grey: < 3000 m, medium grey: 3000–5000 m, dark grey: > 5000 m; taken from GEBCO: the General Bathymetric Chart of the Oceans) and the 52 sample positions.

verification of the relationship between environmental variables and the distribution of diatoms in modern sediments.

Although the Pacific sector of the Southern Ocean is the largest of the Southern Ocean sectors, modern studies of the distribution of diatoms preserved in the sedimentary record relevant to this Pacific sector have been restricted to coastal environments and basins along the Antarctic Peninsula (Crosta et al., 1997; Zielinski and Gersonde, 1997), the Amundsen Sea shelf (Kellogg and Kellogg, 1987) and the Ross Sea (Cunningham and Leventer, 1998) rather than venturing into the Antarctic Circumpolar Current (ACC). South Pacific open-ocean assemblages have been presented by Kozlova (1966) and Donahue (1973) and recently from a limited number of sites by Armand et al. (2005), Crosta et al. (2005) and Romero et al. (2005). In contrast, detailed studies of diatoms from South Pacific surface waters have been undertaken (e.g. Frenguelli and Orlando, 1958; Kozlova, 1966; Hargraves, 1968; Hasle, 1969; Fenner et al., 1976; Hasle, 1976; Burckle et al., 1987; Savidge et al., 1995; de Baar et al., 1999). In the absence of a reference data set for this area, palaeoenvironmental reconstructions based on diatom transfer functions rest on the assumption and earlier dispersal observations (e.g. Discovery reports by Hart, 1934; Hendey, 1937; Baker, 1954) that diatom distributions are circumpolar in character, that is, that the distribution of the Atlantic and Indian sectors can be extrapolated to the Pacific sector of the Southern Ocean. By confirming that the general zonal pattern of diatom distribution continues through the Pacific sector, palaeoceanographers could confidently support the pooling and application of reference data sets across the Southern Ocean for statistical analysis of core data from all sectors.

Here we present a comprehensive documentation of the diatom species distribution in the central and eastern Pacific sector of the Southern Ocean. We examined 52 surface sediment samples collected from two transects around 120°W and 90°W between the central ACC and the Antarctic near-shore coast (minimum water depths of about 2000 m) (Fig. 1). Considering that the sea-floor diatom assemblage compositions

Fig. 2. Environmental and physical variables characterising the (sub)surface water layer of the working area. Environmental variables are the mean sea surface summer temperature (TEMP; panel a) and the mean annual sea surface salinity (SAL; panel b), the mean annual dissolved nitrate concentration (NO_3; panel c), the mean annual dissolved phosphate concentration (PO_4; panel d) and the mean annual dissolved silicon concentration (Si; panel e). Physical variables include the summer mixed layer depth (MLD; panel f) and the mean annual stratification of the upper water column between 0 and 75 m expressed as Brunt–Väisälä-frequencies (N; panel g), the mean winter sea ice concentration (WSIC; panel h) and the mean summer sea ice concentration (SSIC; panel i).