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Middle-Late Miocene Southern Ocean climate development and its implication on Antarctic ice sheet development – Diatom evidence from Atlantic sector ODP Sites

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The Middle to earliest Late Miocene represents a period of rapid expansion of the Antarctic Ice Sheet (Zachos et al., 2001) leading to a global ocean-climate system marked by increased zonality and profound changes in vertical thermal gradients due to the formation of southern source cold deep-waters. This is documented by records of global sea level fluctuations, oxygen and carbon isotopes and estimates of bottom water temperature and may be related to the establishment of the West Antarctic Ice Sheet (WAIS). Holbourn et al (2005) recently proposed that the onset of Antarctic ice-sheet expansion around 14 Ma would be triggered by the co-occurrence of low summer insolation over Antarctica and decline of atmospheric CO_2 levels at this period. The accurate reconstruction of the Miocene ice-ocean evolution is however hampered by remaining discrepancies among available climate records. To augment our knowledge on processes driving Earth´s climate during this period we reconstructed the middle and late Miocene thermal evolution of the Southern Ocean surface waters and relate this with Antarctic cryosphere evolution.

The study was done on sediment cores recovered during ODP Leg 113 on Maud Rise (65˚S, Sites 689, 690) and during ODP Leg 177 on Meteor Rise (46˚S, Site 1092), thus presenting a meridional transect across the Atlantic Southern Ocean. The reconstruction of the surface water thermal evolution was based on the quantitative analysis of diatom assemblages. The age determination and core to core correlation relies on combined bio- and magnetostratigraphic dating (Censarek and Gersonde 2002).

Concurrently with the lowering of sea level and increase of oxygen isotope values starting around 14 Ma, the diatom assemblages from the transect show a gradual change in species composition. The subsequent replacement of taxa that have a broad distribution in the Miocene ocean by taxa that are endemic to the Southern Ocean and their latitudinal distribution on the studied transect is interpreted to indicate a gradual cooling of the Southern Ocean surface water that leads to its thermal isolation around 13 Ma. The latter coincides with a distinct lowering in sea level and stepwise increase in the benthic oxygen isotope record, both indicating a distinct increase in Antarctic ice sheet volume (Haq et al. 1987, Zachos et al. 2001). The cooling trend culminates around 10.8 Ma when diatoms indicate a maximum expansion of the Antarctic cold water sphere extending as far north as the Agulhas Ridge region located in the present northern Subantarctic Zone. The co-occurring drop in sea level (Haq et al., 1987; Betzler et al., 2000) and bottom water temperatures (Billups and Schrag 2002) indicates further expansion of Antarctic continental ice and the massive production of cold bottom water. This is interpreted to reflect the establishment of a broad West Antarctic Ice Sheet and related expanded ice shelf areas in the southern Weddell and Ross Sea embayments. This is folloed by a sudden reestablishment of warmer conditions and weakened Southern Ocean thermal isolation around 10.4 Ma, documented by the occurrence of cosmopolitic diatoms. The observed reversal in climate conditions is accompanied by a rise in sea level and increase in bottom water temperatures. Around 8.5 Ma we observe the first diatoms that may be related to modern sea-ice related species, occurring most abundant at our southern sites, giving hints on the presence of sea ice in the realm of the Weddell Sea. Such sea-ice distribution is only conceivable in the presence of a WAIS and related ice shelf areas.

References: Betzler et al. (2000) Paleoceanography 15, 722-730.; Billups, K. and D. P. Schrag (2002) Paleoceanography, 17(1), 10.1029/3000PA000567.; Censarek, B. and R. Gersonde (2002) Marine Micropaleontology, 45 (3-4), 309-359; Haq, B.U., et al. (1987) Science, 235, 1156-1167; Holbourn, A. et al. (2005) Nature 438, 483-487; Zachos, J. et al.(2001) Science, 292, 686-693.