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Research paper

Response of marine palynomorphs to Neogene climate cooling in the Iceland Sea (ODP Hole 907A)

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ABSTRACT

The present study on ODP Leg 151 Hole 907A combines a detailed analysis of marine palynomorphs (dinoflagellate cysts, prasinophytes, and acritarchs) and a low-resolution alkenone-based sea-surface temperature (SST) record for the interval between 14.5 and 2.5 Ma, and allows to investigate the relationship between palynomorph assemblages and the paleoenvironmental evolution of the Iceland Sea.

A high marine productivity is indicated in the Middle Miocene, and palynomorphs and SSTs both mirror the subsequent long-term Neogene climate deterioration. The diverse Middle Miocene palynomorph assemblages clearly diminish towards the impoverished assemblages of the Late Pliocene; parallel with a somewhat gradual decrease of SSTs being as high as 20 °C at ~13.5 Ma to around 8 °C at ~3 Ma.

Superimposed, palynomorph assemblages not only reflect Middle to Late Miocene climate variability partly coinciding with the short-lived global Miocene isotope events (Mi-events), but also the initiation of a proto-thermohaline circulation across the Middle Miocene Climate Transition, which led to increased meridionality in the Nordic Seas. Last occurrences of species cluster during three events in the Late Miocene to Early Pliocene and are ascribed to the progressive strengthening and freshening of the proto-East Greenland Current towards modern conditions. A significant high latitude cooling between 6.5 and 6 Ma is depicted by the supraregional "*Decahedrella* event" coeval with lowest Miocene productivity and a SST decline.

In the Early Pliocene, a transient warming is accompanied by surface water stratification and increased productivity that likely reflects a high latitude response to the global biogenic bloom. The succeeding crash in palynomorph accumulation, and a subsequent interval virtually barren of marine palynomorphs may be attributed to enhanced bottom water oxygenation and substantial sea ice cover, and indicates that conditions seriously affecting marine productivity in the Iceland Sea were already established well before the marked expansion of the Greenland Ice Sheet at 3.3 Ma.

1. Introduction

The Neogene is a crucial epoch for the evolution of Earth's climate as it went through the fundamental transition from a relatively warm Early Miocene to the colder conditions at the end of the Pliocene (Zachos et al., 2008). After the Miocene Climate Optimum (MCO, 17–15 Ma), when Earth experienced warmest temperatures since the Middle Eocene (Zachos et al., 2008), global surface and deep ocean temperatures cooled significantly (Wright et al., 1992; Billups and Schrag, 2002; Shevenell et al., 2004; Kuhnert et al., 2009) across the Middle Miocene Climate Transition (MMCT, 14.2–13.7 Ma), and the East Antarctic Ice Sheet experienced major expansion (e.g. Flower and Kennett, 1994; John et al., 2011; Paschier et al., 2011). This transition marked the onset of progressive long-term cooling both on land (Pound et al., 2012) and in sea (Zachos et al., 2008) that ultimately pushed the climate system into the bipolar glaciated mode of today. Superimposed, distinct short-term climate variability has been observed in marine records (Miller et al., 1991; Turco et al., 2001; Andersson and Jansen, 2003; Westerhold et al., 2005; John et al., 2011) and partly attributed to ice sheet growth on Antarctica and/or bottom-water cooling (Mi events sensu Miller et al., 1991). In this context, however, the high northern latitude oceans are of eminent relevance to decipher causes and consequences of the Neogene climate variability (e.g. Thiede et al., 1998) since they influence global climate through feedback mechanisms related to the formation of perennial/seasonal sea ice cover (Miller et al., 2010; Serreze and Barry, 2011), and production of northern-sourced deep-water (Flower and Kennett, 1994; Rahmstorf, 2006).

The timing of the onset of glaciations in the Northern Hemisphere is still debated but ice-rafted debris (IRD) has been recorded as early as the Middle Eocene in the Arctic Ocean (Stickley et al., 2009) and the Greenland Sea (Eldrett et al., 2007; Tripati et al., 2008). Although it has been speculated that a Neogene Greenland Ice Sheet has existed since at least 18 Ma (Thiede et al., 2011), published records suggest that

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small scale glaciations large enough to reach sea-level might have occurred on Greenland not before the early to middle Late Miocene (Schaeffer and Spiegler, 1986; Wolf and Thiede, 1991; Fronval and Jansen, 1996; Wolf-Welling et al., 1996; Helland and Holmes, 1997; Winkler et al., 2002). In contrast, ice sheets probably developed in the northern Barents Sea and on Scandinavia already in the Middle Miocene (Fronval and Jansen, 1996; Knies and Gaina, 2008).

The formation of glacial ice on the circum-Arctic continents might have been linked to the fundamental reorganization of the circulation in the Nordic Seas. The opening of Fram Strait and the subsidence of the Greenland–Scotland Ridge (GSR) have led to an enhanced exchange of water masses between the Arctic Ocean and the North Atlantic via the Nordic Seas (Bohrmann et al., 1990; Wright and Miller, 1996; Poore et al., 2006; Jakobsson et al., 2007; Knies and Gaina, 2008). Jakobsson et al. (2007) assumed that Fram Strait reached sufficient width (40–50 km; present-day width 400 km) to efficiently ventilate the Arctic Ocean at ~17.5 Ma, and began to open at greater depth by ~14 Ma, which is supported by benthic foraminiferal evidence from the Lomonosov Ridge and Fram Strait (Kaminski et al., 2006; Kaminski, 2007). Simultaneously, a prominent shift from biosiliceous to calcareous-rich sediments in the Norwegian Sea (Bohrmann et al., 1990; Cortese et al., 2004) was likely coupled to the subsidence of the Greenland–Scotland Ridge, which consequently modulated exchange of North Atlantic and Arctic water masses. Reduced fluxes in Northern Component Water (NCW) have been correlated with uplifts of the GSR and vice versa (Wright and Miller, 1996; Poore et al., 2006; Abelson et al., 2008), and Bohrmann et al. (1990) related periodic changes in biogenic carbonate and opal accumulation in the Norwegian Sea to variable exchange of surface waters between the Nordic Seas and the North Atlantic. The initiation of a proto-East Greenland Current (EGC) may have coincided with the establishment of a modern-like ice drift pattern through Fram Strait at around 14 Ma (Knies and Gaina, 2008), but Wei (1998) suggest an onset around 12 Ma based on calcareous nannofossils from the Irminger Basin. An even younger onset at around 10.5 Ma is proposed by Wolf-Welling et al. (1996) based on changes in bulk accumulation rates in the Fram Strait. The modern EGC was probably first established during the intensification of Northern Hemisphere glaciations with the thermal isolation of Greenland due to the final closure of the Isthmus of Panama and the opening of Bering Strait at the Pliocene–Quaternary transition (Sarnthein et al., 2009).

However, to date, most information is derived from a few Neogene sections located along the path of the inflowing North Atlantic waters in the Norwegian Sea (Fig. 1) while the Neogene paleoceanography of the Greenland and Iceland seas is almost unknown due to the discontinuous occurrence of calcareous microfossils in these sediments (e.g. Fronval and Jansen, 1996). Here we present a comparatively high-resolution record of organic-walled microfossils (e.g. dinoflagellate cysts = dinocysts, prasinophytes, acritarchs) from the almost continuous middle Miocene to upper Pliocene sequence of ODP Hole 907A in the Iceland Sea, an area close to the growing Greenland and Iceland ice sheets, which experienced the effects of sea ice cover, migrating wind fronts and ocean currents. The pristine paleomagnetic record of Hole 907A provides the unique opportunity for detailed investigations on the response of palynomorph assemblages to the MMCT and subsequent long-term cooling, and thus to derive complementary information on the Neogene of the Nordic Seas cold-water domain. Palynomorph-based interpretations have been supplemented with a low-resolution alkenone SST record that provides new constraints on the thermal evolution of the Iceland Sea.

2. Material and methods

ODP Hole 907A is located on the eastern Iceland Plateau (69°14.989′ N, 12°41.894′ W; 2035.7 m water depth; Fig. 1), and was drilled in an undisturbed hemipelagic sequence that mainly consists of unlithified silty clays and clayey silts (Shipboard Scientific Party, 1995). Based on the revised magnetostratigraphy (Channell et al., 1999), which has been adjusted to the latest astronomically-tuned Neogene timescale (ATNTS) 2004 (Lourens et al., 2005), a total of 120 samples spanning the early Middle Miocene to Pliocene (Samples 23H-CC, 10–12 cm to 6H-3, 82–84 cm), has been selected at ~100 kyr resolution. The stratigraphic occurrence of a selected number of dinocyst and acritarch species is discussed by Schreck et al. (2012).

2.1. Palynological methods

Subsamples (~15 cm^3) were processed using standard palynological techniques (e.g. Wood et al., 1996), including acid treatment (HCl [10%], HF [38–40%]), but without oxidation or alkali treatments. 2 *Lycopodium clavatum* tablets (Batch no. 124961, X = 12,542, s = ±416 per tablet) were added to each sample during the HCl treatment to calculate palynomorph concentrations (Stockmarr, 1977). The residue was sieved over a 6 μm polyester mesh to ensure that small palynomorphs

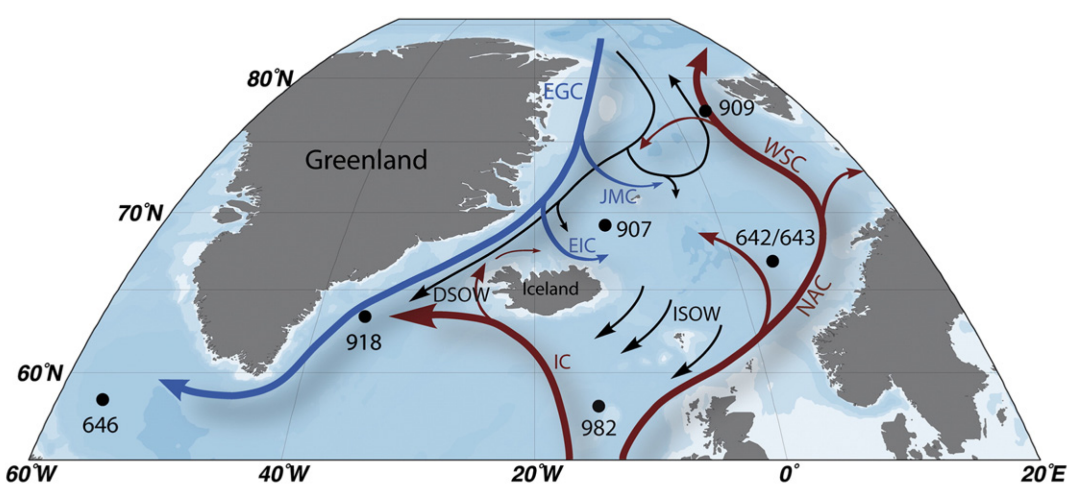

Fig. 1. Schematic present-day ocean circulation in the Nordic Seas, and location of ODP Leg 151 Site 907, as well as sites discussed in the text (black dots). Blue arrows refer to Arctic Ocean derived cold surface waters: EGC = East Greenland Current, JMC = Jan Mayen Current, EIC = East Iceland Current. Red arrows indicate Atlantic Ocean derived warm surface water: WSC = West Spitzbergen Current, NAC = Norwegian Atlantic Current, IC = Irminger Current. Black arrows show pathways of deep/bottom water: DSOW = Denmark Strait Overflow Water; ISOW = Iceland Scotland Overflow Water (modified from Blindheim and Østerhus, 2005).