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Effect of early Pliocene uplift on late Pliocene cooling in the Arctic–Atlantic gateway

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ABSTRACT

Despite the undisputed role of the Arctic Ocean in the modern and Pliocene climate system, the Arctic has only recently attracted public awareness that ongoing, fundamental change in the Arctic cryosphere could be a response to global warming. Clarification of the Arctic's role in global climate during the Pliocene is, however, largely hampered by equivocal stratigraphic constraints. From a well-dated Pliocene sequence from the Yermak Plateau, off NW Spitsbergen, we present sedimentological and geochemical data indicating that 4 million years ago terrigenous sediment supply and sources changed abruptly in response to a regional tectonic uplift event. We argue that this event together with contemporary uplift and tilting along the northwestern European continental margin preconditioned the landmasses for glacial ice build-up during intensification of the Northern Hemisphere Glaciation (INHG). Our data further suggest that the final deepening/widening of the Arctic–Atlantic gateway, the Fram Strait, between 6.5 and 5 Ma gradually caused increased deep-water mass exchange which, in turn, likely contributed to the intensification of the North Atlantic thermohaline circulation. Coupled to the North Atlantic warm pool as a regional moisture source, declining atmospheric CO_2 levels and other feedback mechanisms during the Pliocene, the regional tectonic activities in the high northern latitudes caused decreased summer ablation and thus allowed the initial build-up of glacial ice both in Scandinavia, and the sub-aerially exposed Svalbard/Barents Sea, culminating in the first large-scale coastline-shelf edge glaciations at ~2.75 Ma ago.

1. Introduction

The influence of the Arctic Ocean on Pliocene global climate reconstructions has remained ambiguous due to a lack of well-dated paleoenvironmental records. Important topics have still not been resolved, amongst them: (1) the Pliocene climate and tectonic history of the Arctic Ocean (e.g. Matthiessen et al., 2009a); (2) the final development of the gateway as the only deep-water connection to the Arctic Ocean via the Fram Strait (Jakobsson et al., 2007); and (3) the influence of the gateway region on changes in Arctic–Atlantic ocean circulation (Sarnthein et al., 2009), uplift/erosion on the adjacent hinterland (Green and Duddy, 2010; Laberg et al., 2012), as well as glacial initiation and its consequences for the petroleum systems in the region (Henriksen et al., 2011).

This lack of knowledge is mainly due to the ambiguous Plio-Pleistocene stratigraphic framework of the Arctic Ocean (Matthiessen et al., 2009a). Although a late Neogene stratigraphy for the central Arctic Ocean has been constructed from the first scientific drill holes (Integrated Ocean Drilling Program (IODP) Expedition 302 ACEX, e.g. Moran et al., 2006; Backman et al., 2008; Frank et al., 2008; Backman and Moran, 2009), insufficient recovery and limited absolute age control do not allow the establishment of a master stratigraphy for the Plio-Pleistocene (Matthiessen et al.,

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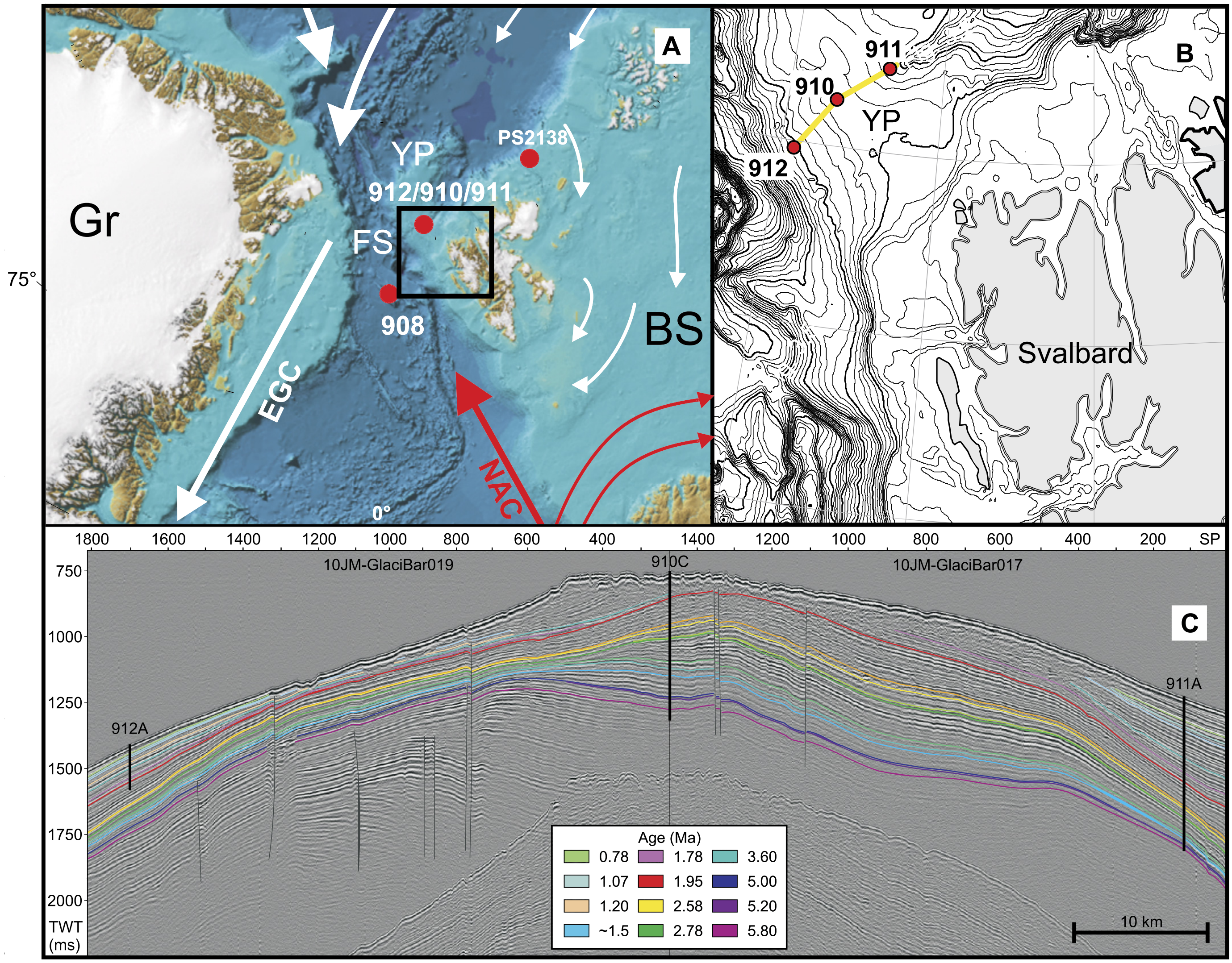

Fig. 1. (A) Physiogeography in the Atlantic–Arctic gateway region and location of investigated Ocean Drilling Program (ODP) sites and reference core PS2138. Red arrows: North Atlantic Current (NAC); white arrows: Transpolar Drift and East Greenland Current (EGC). YP: Yermak Plateau; BS: Barents Sea; FS: Fram Strait. (B) Inset map showing (from west) the location of ODP sites 912, 910, and 911 and the 2D high-resolution single-channel seismic lines 10JM-GlaciBar19 and 10JM-GlaciBar17. (C) Composite seismic profile crossing ODP Holes 912A, 910C and 911A on the Yermak Plateau. Seismic amplitudes with color coded reflectors dated by age fix-points from the three ODP Holes as discussed by Mattingsdal et al. (2013) and detailed in Supplementary Table S1.

2009b; O'Regan et al., 2010; März et al., 2010). More promising are the ODP sites from the marginal Arctic Ocean, i.e. the Atlantic–Arctic gateway region (ODP Leg 151) (Myhre et al., 1995) (Fig. 1). Here, in contrast to the central Arctic Ocean, carbonate bearing sequences permit establishment of a relatively continuous stable oxygen isotope ($\delta^{18}O$) and foraminiferal stratigraphy, which still are the prerequisite for any subsequent application of chronological approaches (Knies et al., 2007). Moreover, the region is characterized by dynamic coupling between the northernmost branch of the North Atlantic Current and the Arctic Ocean allowing inferences on changes of external forcing factors (tectonic activity, freshwater supply) that may have influenced water mass characteristics, circulation and sea ice cover (e.g. Sarnthein et al., 2009; Lunt et al., 2012).

A new stratigraphic framework for the Arctic gateway region over the last 6 Ma has recently been established, using available material from ODP Leg 151 (Sites 910, 911 and 912) and new high-resolution seismic data (Mattingsdal et al., 2013) (Fig. 1). According to this new stratigraphic model, sites 910 and 911 have recovered complete marine Pliocene sequences allowing new inferences and in-situ testing of the proposed early-mid Pliocene Arctic warming (e.g. Robinson et al., 2011; Ballantyne et al., 2010), the final opening of the Atlantic–Arctic gateway (e.g. Kristoffersen, 1990; Engen et al., 2008), and the onset and intensification of the Northern Hemisphere Glaciation (INHG) between ∼3.6 and 2.7 Ma (Mudelsee and Raymo, 2005).

In this paper, we focus on the Pliocene epoch (∼5.332–2.588 Ma) (Gradstein et al., 2012) and discuss onset and intensification of the Northern Hemisphere glaciations, as well as regional tectonic constraints in the gateway region during its final opening, from a consistent Pliocene stratigraphic framework of Hole 910C and 911A (Fig. 1). New stable isotope and multi-proxy data are discussed with previously published results from the Fram Strait (ODP Site 908) (Matthiessen et al., 2009a; Winkler et al., 2002; Wolf-Welling et al., 1996), the southwestern Barents Sea (Ryseth et al., 2003), and the NW European margin (Stoker et al., 2002, 2005; Dahlgren et al., 2005; Eidvin et al., 2007). We provide stratigraphic evidence that passive margin uplifts during the late Miocene/early Pliocene preconditioned the landscape adjacent to a warm Pliocene North Atlantic Ocean for continental ice sheet growth around 4 Ma. The new results support the hypothesis put forward in previous studies (Ruddiman and Kutzbach, 1989;