Quaternary Science Reviews 161 (2017) 30–44

Contents lists available at ScienceDirect

Quaternary Science Reviews

journal homepage: www.elsevier.com/locate/quascirev

Pleistocene iceberg dynamics on the west Svalbard margin: Evidence from bathymetric and sub-bottom profiler data

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A R T I C L E   I N F O

Article history:
Received 15 July 2016
Received in revised form
19 January 2017
Accepted 25 January 2017

Keywords:
Icebergs
Iceberg ploughmarks
Western Svalbard margin
West Spitsbergen Current
Pleistocene

A B S T R A C T

Large icebergs leave evidence of their drift via ploughing of the seabed, thereby providing a geological record of episodes of calving from thick ice sheets. We interpret large-scale curvilinear depressions on the western Svalbard margin as ploughmarks produced by the keels of icebergs that grounded on the seafloor as they drifted through this area. Iceberg ploughmarks were identified at modern water depths between 300 m and 1000 m and in two distinct stratigraphic units. Combining data from sediment cores with seismic stratigraphy from sub-bottom profiler data suggests that the ploughmarks developed in two phases: (1) during Marine Isotope Stage (MIS) 6; and (2) during MIS 2, indicating the presence of large drifting icebergs on the western Svalbard margin during both the Late Saalian and Late Weichselian glaciations. Sediment-core data along the western Svalbard margin indicate a sharp increase in mass-transported sediments dated at 23.7 ± 0.2 ka, consistent with the MIS 2 age of the younger iceberg-ploughed surface. The ploughmarks are oriented in two main directions: SW-NE and S-N. S-N oriented ploughmarks, which shallow to the north, indicate iceberg drift from the south with a SW–NE component marking the zone of splitting of the West Spitsbergen Current (WSC) into the Yermak Slope Current (YSC) and North Spitsbergen Current (NSC). Large MIS 6 and MIS 2 icebergs most likely had an Arctic Ocean source. We suggest that these icebergs probably left the Arctic Ocean southward through Fram Strait and circulated within the Norwegian-Greenland Sea before being transported northwards along the Svalbard margin by the WSC. An additional likely source of icebergs to the western Svalbard margin during MIS 2 was the ice-sheet terminating in the western Barents Sea, from which icebergs drifted northward.

1. Introduction

The Fram Strait (Fig. 1) is the only deep water gateway of the Arctic Ocean and, hence, it plays an important role in global ocean circulation and heat exchange (Schauer et al., 2004). The West Spitsbergen Current (WSC) flows along the western Spitsbergen margin on the eastern edge of the Fram Strait, transporting relatively warm, saline waters to the Arctic Ocean, whereas the East Greenland Current (EGC) discharges cold water of relatively low salinity out of the Arctic Ocean along the Greenland margin at the western edge of the Fram Strait. The western Svalbard margin therefore occupies a key position in understanding the exchange of water and ice between the Arctic Ocean and the North Atlantic during the Quaternary. Geological evidence for iceberg activity provides key insights into the temporal variability of glacier-ice export from the Arctic Ocean to the Norwegian-Greenland Sea. Previous studies have suggested that icebergs were present in Fram Strait for much of the Neogene, but their occurrence shows strong temporal variability (e.g. Andersen et al., 1996; Hevrøy et al., 1996;

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http://dx.doi.org/10.1016/j.quascirev.2017.01.019
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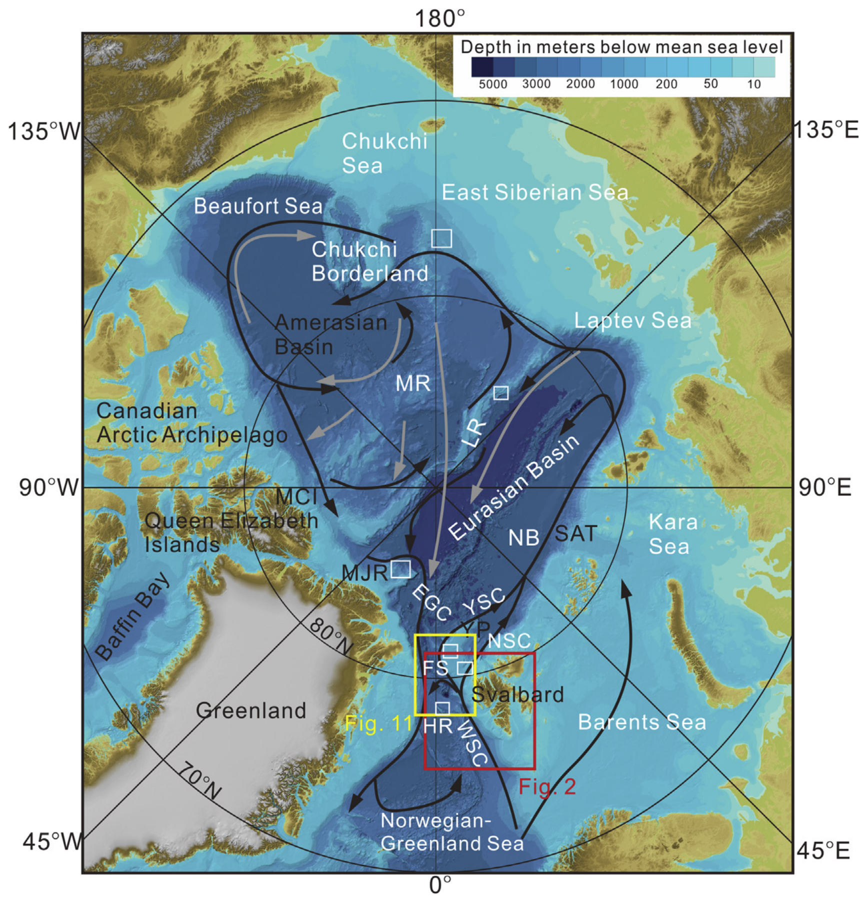

Fig. 1. Bathymetry of the Arctic Ocean (Jakobsson et al., 2012) showing deep iceberg scoured areas and the circulation of surface (grey arrows) and subsurface waters (black arrows). Documented evidence of seafloor erosion by icebergs in previous studies are indicated by white boxes. The boxes mark the locations of Fig. 2 and 11. HR, Hovgaard Ridge; FS, Fram Strait; LR, Lomonosov Ridge; MJR, Morris Jesup Rise; MR, Mendeleev Ridge; NB, Nansen Basin; SAT, St Anna Trough; YP, Yermak Plateau; MCI, M′ Clintock Inlet; EGC, East Greenland Current; WSC, West Spitsbergen Current; NSC, North Spitsbergen Current; YSC, Yermak Slope Current.

Wolf-Welling et al., 1996), which has been recognized as an important factor influencing global oceanic thermohaline circulation (Aagaard and Carmack, 1989; Bischof and Darby, 1997; Broecker, 2010). Isotopic evidence from Ocean Drilling Program (ODP) Site 910 (Fig. 2a) on the southern Yermak Plateau suggests a strong imprint of Arctic freshwater pulses on the Earth's climate system throughout the last 0.8 Ma (Knies et al., 2007). Sediment-core data from Fram Strait reveal that large quantities of icebergs drifted through the straits into the Greenland Sea several times during the late Pleistocene (Darby et al., 2002), with geophysical evidence from the Hovgaard Ridge revealing very deep (>1200 m) iceberg ploughing (Fig. 1; Arndt et al., 2014; Arndt and Forwick, 2016). It has been suggested, therefore, that large amounts of ice (including giant icebergs) were released from ice shelves in the Arctic Ocean and exported southward through Fram Strait during some glacial maxima (Arndt et al., 2014; Arndt and Forwick, 2016).

In this paper, we present new multibeam bathymetry and sub-bottom profiles from the western Svalbard margin. Our study supports the hypothesis that icebergs sourced in the Arctic Ocean drifted southward through the Fram Strait, then drifted into the Norwegian-Greenland Sea and ploughed the seafloor of the adjacent continental margin driven by ocean currents. In addition, icebergs calved from an ice sheet in the western Barents Sea probably drifted northward to plough the Svalbard margin. We discuss the implications of the observed iceberg grounding for the glacial history and past dynamics of the ice sheet and for the reconstructions of ocean currents.

2. Background: palaeoglaciological, geological and oceanographic setting

It is often suggested that Quaternary Arctic ice sheets terminated at the continental shelf edges in the Arctic (Ehlers and Gibbard, 2007; Svendsen et al., 2004). However, studies over the last few decades have demonstrated that glacier ice may have extended northwards into the deep-sea basins of the Arctic Ocean and/or built up from extensive sea-ice cover during some previous glacial periods (Mercer, 1970; Polyak et al., 2001), particularly during the Saalian, when continental ice sheets were larger than during the more recent Weichselian (Jakobsson et al., 2010, 2016; Niessen et al., 2013). Evidence of ice grounding, which has generally been attributed to ice shelves or giant icebergs, has been identified on the seafloor of the Arctic Ocean down to 1280 m present water depth (Vogt et al., 1994; Polyak et al., 2001; Dowdeswell et al., 2010a; Gebhardt et al., 2011; Jakobsson et al., 2008; Niessen et al., 2013; Arndt and Forwick, 2016; Jakobsson et al., 2016). Glacial landforms such as iceberg ploughmarks, produced by the grounding and ploughing action of deep-keeled icebergs (e.g. Woodworth-Lynas et al., 1985), therefore provide important evidence for past glacial activity in the Arctic Ocean. Geological and geophysical studies have shown evidence for iceberg ploughmarks on the central Lomonosov Ridge at water depths of up to >1000 m (Fig. 1) (Polyak et al., 2001; Kristoffersen et al., 2004; Jakobsson et al., 2008, 2016) and at similar water depths in the Chukchi Borderland (Jakobsson et al., 2008), on