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Review article

Chronology of Greenland Scotland Ridge overflow: What do we really know?

Gabriele Uenzelmann-Neben*, Jens Gruetzner

Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung, Bremerhaven, Germany

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ABSTRACT

As a sill constricting the exchange of deep water masses between the Nordic Seas and the North Atlantic, which forms an essential part of the Atlantic Meridional Overturning Circulation, the dynamic height of the Greenland Scotland Ridge and thus its overflow have an important influence on global climate. Several DSDP, ODP, and IODP sites have been drilled in the North Atlantic to shed light on the overflow and climate development. Reconstructions of bathymetry and sediment thickness have been put forward as well as calculations of the potential temperature of the conduit feeding the Iceland plume. The available studies have been screened to construct a conceptual model for the evolution of the palaeo-circulation in the North Atlantic and identify possible weaknesses in our knowledge. Details, e.g., timing and location, about the onset of the overflow are unknown, and especially the Paleogene development remains enigmatic. The database for this period is inadequate, and covers only small areas. The discussion centres on the earliest traces of the overflow leading to formation of sediment drifts in the eastern North Atlantic. More data provide a better base to reconstruct variations for the Neogene overflow, but also appears insufficient for in-depth analyses in time and space. Sediment drifts in the Iceland Basin indicate a first Iceland Faroe Ridge overflow for the early Miocene. Denmark Strait overflow appears to have started in mid-Miocene times, but evidence for this still is sparse. Grids of high-resolution seismic reflection data across all sediment drifts and all limbs of the Greenland Scotland Ridge combined with deeper drill sites targeting the complete sedimentary column down to basement are needed to fully understand the chronology of the Greenland Scotland Ridge overflow and its detailed impact on climate.

1. Introduction

The modern and ancient thermohaline circulation (THC) has moved into the focus of research because it is interconnected to climate. In its upper, surface branch THC leads to the transport of heat and freshwater around the globe, compensated by its deep counterpart (Van Aken, 2007). The transformation of warm and saline Atlantic water to cold and less saline water masses at northern high latitudes, e.g., the Nordic Seas overflows, forms an essential part of the Atlantic Ocean's thermohaline circulation (Rudels, 1995; Wunsch, 2002). Dense outflows from the marginal seas form the major sinking legs of the meridional overturning circulation (MOC) with mixing and entrainment of ambient waters setting the properties of NADW, ventilating the North Atlantic, and setting the global ocean density stratification (e.g., Fer et al., 2010; Saunders, 1996; Voet and Quadfasel, 2010). This exchange is constricted by the sills in the Greenland Scotland Ridge (GSR), which separates the Nordic Seas from the North Atlantic (Fig. 1).

Topographic sills are a key factor in exchange flows between ocean basins as they give rise to the hydraulic control of the mass flux in dense overflows (e.g., Hansen and Østerhus, 2007). This also implies their control on the density difference between the semi-enclosed sea and the ocean. The sea surface temperature (SST) gradient (Arctic-Equator) in the modern North Atlantic is ~27 °C, e.g., in the Mid Pliocene Warm Period (MPWP, ~3.3–3.0 Ma) this was only ~18 °C with the high latitudes having been warmer (Dowsett et al., 2009). This gradient reduction was a global phenomenon but strongest in the North Atlantic as has been shown by multiple proxies. Numerical simulations so far have not been able to reproduce the magnitude of SST warming for the North Atlantic (Robinson et al., 2011). In their experiment set in the Pliocene, Robinson et al. (2011) lowered the Iceland Faroe Ridge (the eastern limb of the GSR) by 800 m and produced significant changes in Arctic sea surface temperature (SST), the volume of deep water production, the location of deep water formation, and deep ocean temperature. Combined with increased temperatures typical for the MPWP the Arctic Ocean temperature response due to the change in ocean sill depth produced high latitude warmth and a North Atlantic temperature

* Corresponding author.
E-mail address: gabriele.uenzelmann-neben@awi.de (G. Uenzelmann-Neben).

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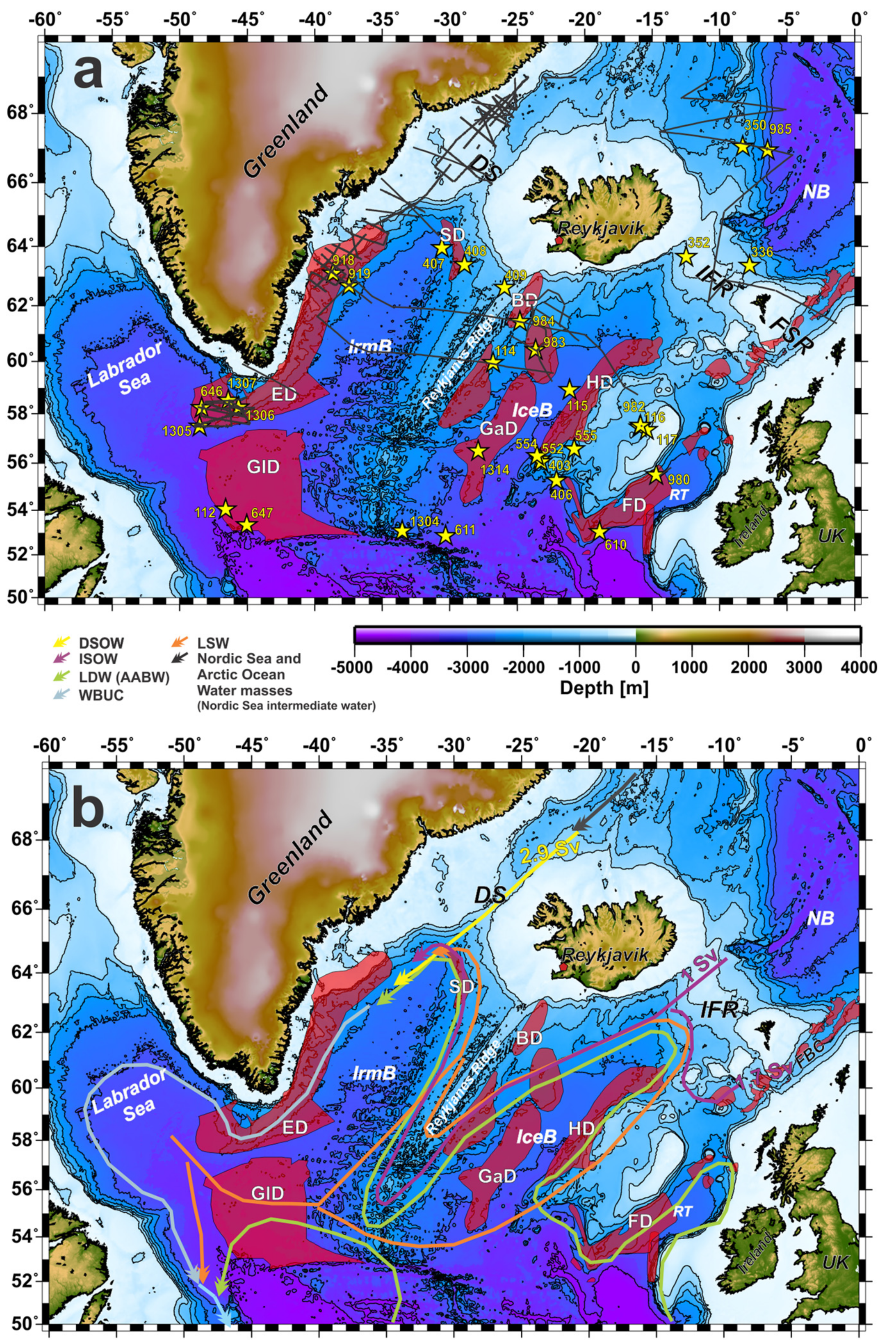

Fig. 1. Bathymetric map of the North Atlantic (Smith and Sandwell, 1997). Red areas show the locations of sediment drifts following Rebesco et al. (2014). a) Location of basins, morphological structures, and DSDP/ODP/IODP sites (yellow stars). Black lines show the location of published multichannel seismic lines. BD = Björn Drift, DS = Denmark Strait, ED = Eirik Drift, FBC = Faroe Bank Channel, FSR = Faroe Scotland Ridge, FD = Feni Drift, GaD = Gardar Drift, GlD = Gloria Drift, HD = Hatton Drift, IFR = Iceland Faroe Ridge, IceB = Iceland Basin, IrmB = Irminger Basin, NB = Norwegian Basin, SD = Snorri Drift. b) Pathways and volume transport of deep water masses modified from Schmitz Jr. (1996) and Hansen and Østerhus (2000). 1 Sv = 10^6 m^3/s. AABW = Antarctic Bottom-water, DSOW = Denmark Strait Overflow Water, ISOW = Iceland Strait Overflow Water, LDW = Lower Deep Water, LSW = Labrador Sea Water, WBUC = Western Boundary Undercurrent.

gradient comparable to proxy data.

Changes in the depth of the GSR have thus implicated changes in strength of deep water export, possibly production, in the Nordic Seas during the Neogene and early Oligocene hence affecting climate (Abelson et al., 2008; Abelson and Erez, 2017; Poore et al., 2006; Stärz et al., 2017; Wright and Miller, 1996). With a shallow sill any deep water production could presumably be sourced from warmer surface waters south of Iceland whereas a deep sill would allow deep water formation only at colder, more northern latitudes (Cramer et al., 2011). δ^{13}C isotopes from the Atlantic, Pacific and Southern Ocean allow the reconstruction of relative changes in Northern Component Water (NCW, precursor of NADW) strength since 12 Ma. They show strong NCW flow during the MPWP and a decrease after the mid-Pliocene (Poore et al., 2006; Wright and Miller, 1996).

During glacial stages with a constant sea-ice cover over the Nordic seas the ocean-atmosphere interaction would be reduced. This would result in reduced vertical mixing and reduced background diffusity under the sea-ice by 1 order (Kim et al., 2015). Production of denser water in water depths > 3000 m pushing the isopycnals over the GSR would follow thus still increasing the MOC in water depths > 3000 m.

Although a large number of geological, geophysical, and oceanographic studies have been carried out in the North Atlantic and several DSDP, ODP, and IODP drill expeditions (Table 1) have produced sediment to analyse and date, onset and variability of the GSR overflow, which is important to understand the development of MOC and NCW export both into the Pacific via the open CAS and into the South Atlantic, are still under debate. This paper reviews the literature to understand the state of our knowledge and identify missing links.

2. Oceanographic background

The inflow of Atlantic waters brings warm and saline water to the