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The ecology of benthic foraminifera across the Frisian Front, southern North Sea

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ABSTRACT

Benthic foraminifera were collected across the Frisian Front, a biologically enriched transition-zone with high organic matter content below a tidal-mixing front in the southern North Sea. On four occasions between 2002 and 2005, box-cores from different hydrographic regimes (i.e. tidally mixed, frontal and stratified) at depths between 30- and 45-m deep were sampled. The results indicate that standing stocks and foraminiferal diversity are higher in the central zone of the Frisian Front than further away from the frontal zone. Most of the abundant species occupy a specific zone relative to the front's central position. *Elphidium excavatum* is abundant at the southern edge of the Frisian Front, where input of labile organic matter is high and physical disturbance (i.e. resuspension of fine-grained material) is relatively frequent. *Ammonia tepida* and *Quinqueloculina* spp. dominate at the front's center where organic carbon input is relatively high. *Hopkinsina pacifica* has its highest abundances at the deepest, northerly boundary of the front, and *Eggerella scabra* dominates the deeper, seasonally stratified Oyster Grounds north of the front. Differences in seasonal distribution patterns were minor compared to spatial patterns. Depth distributions varied between summer (more 'epifaunal' distribution) and winter (vertically more evenly distributed). The latter suggests that the vertical distribution of foraminifera is governed by the arrival of fresh organic matter at the seafloor in spring and summer. A comparison with foraminiferal abundances across the Frisian Front in 1988/1989 reveals that total abundances and distribution of the most abundant species were similar in both data sets, despite a macrobenthic regime shift at the Frisian Front in the early 1990s. The decoupled dynamics of foraminifera and macrofauna suggests that foraminifera reflect reliably the hydrodynamic environment (stratified, frontal, mixed), despite the changed macrofaunal community and its physical and geochemical consequences.

1. Introduction

In many coastal waters, tidal-mixing fronts are found (Pingree and Griffiths, 1978; Simpson et al., 1978). These fronts are the transition-zone between near-coastal waters, which are completely mixed by tidal wave action, and deeper waters that become thermally stratified in spring and summer (Jones et al., 1998; Drinkwater and Loder, 2001; Mavor and Bisagni, 2001). If the tidally mixed waters are rich in suspended matter this will sink down at such fronts when tidal currents drop below a critical velocity along a deepening slope. Enhanced sedimentation results in a frontal deposition zone with high mud content (Creutzberg and Postma, 1979). In the frontal zone, usually a chlorophyll maximum exists, caused by the optimal combination of light and nutrients (Holligan, 1981; Postma, 1988). At the deep boundary of a front, seasonal thermal stratification prevents upward diffusion of nutrients and at the coastal edge, turbidity prevents light penetration, both factors limiting primary production.

In the North Sea two hydrographic fronts separate the Southern Bight from the Oystergrounds: the Frisian Front, off the northern Dutch coast (De Gee et al., 1991), and the Flamborough Front, which is located near the English east coast (Hill et al., 1993; Howarth et al., 1993; Tett et al., 1993). These fronts provide a variety of pelagic and benthic environments within a short bathymetrical range. Benthic studies at the Frisian Front, the zone with increased deposition of silt between the 30- and 40-m isobaths, have shown enhanced biomass and diversity of the macrobenthos compared to locations outside the front (Creutzberg, 1986; Callaway et al., 2002; Dewicke et al., 2002).

Only few studies have included foraminifera in assessing the benthic community structure in the North Sea, despite their high abundances and ecological importance. Studies focusing on foraminifera across hydrodynamic fronts (e.g. Moodley, 1990; Scott et al., 2003) are necessary in order to reliably reconstruct Holocene shelf evolution (Moodley and Van Weering, 1993; Evans et al.,

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2002; Scourse et al., 2002). Another reason to monitor meio-faunal densities and diversity results arises from the intention of the Dutch government to designate the Frisian Front as a protected area. The North Sea in general is heavily trawled and ongoing deterioration of its habitats and declining fish stocks have caused the necessity to restrict fishery in certain areas of the North Sea. The Frisian Front is one of the intended protected locations since it is acknowledged to be an ecologically unique area. Future changes in the benthic faunal diversity, community structure and densities can only be investigated by using base-line field studies that determine faunal abundances shortly before ecological intervention.

Here we present results of benthic foraminiferal abundances across the Frisian Front and discuss their relation to a range of hydrodynamic and environmental conditions. The results are compared to foraminiferal data obtained in 1988/1989 at the same locations to analyze long-term developments in the foraminiferal community composition. The species composition and total abundances of foraminifera may have changed since the macrobenthic species composition has shifted from one dominated by the filter feeding brittle star *Amphiura filiformis* to one dominated by the burrowing shrimps *Callianassa subterranea* and *Upogebia* spp. (Van Nes et al., 2007).

2. Methods

2.1. Area description

At the transitional zone between the Southern Bight water (depth 25 m) and the Oyster Grounds (50 m) the maximum tidal current velocity drops below a critical value, resulting in increased deposition of mud (particles <63 μm) and organic carbon at the sea bed. This biologically enriched benthic zone between the 30- and 40-m isobaths is called the Frisian Front and is located approximately between 53°30′ N, 4°00′ E and 54°00′ N, 5°00′ E (Creutzberg, 1986; De Gee et al., 1991). On a north–south transect along the 4°30′ E meridian, the frontal zone extends from 53°37′ N to 53°55′ N, with the highest mud content between the latitudes 53°42′ N and 53°46′ N, where water depths are between 37 and 40 m (Fig. 1). In the late 1990s mud percentages of >20% were found between 53°42′ N and 53°48′ N. South of the Frisian Front, the sediments consist of fine sands with almost no mud and towards the deeper Oyster Grounds that are characterized by spring and summer stratification the mud content gradually decreases.

The hydrographic Frisian Front stretches out to the east, parallel to the Dutch and German northern coastline and to the west, where it joins the Flamborough Head Front at approximately 0°40′ E. An along-front jet flows eastwards, just south of the Frisian Front (Lwiza et al., 1991). During stratification of the water north of the Frisian Front, a colder surface layer can be distinguished just south of the stratified area. This phenomenon is ascribed to small, circular cross-frontal currents, which transfer deep and colder waters of the stratified area up to the surface (Van Haren and Joordens, 1990). Studies on chlorophyll-*a* (Chl-*a*) content in cross-sections of the Frisian Front revealed that the Chl-*a* profiles are not consistent through space and time. Chl-*a* maxima exist regularly in summer near the sediment–water interface at the south side of the benthic front (Van Haren and Joordens, 1990) and occasionally, a weaker optimum just north of the front is observed.

Across the Frisian Front, regular seasonal patterns in surface sea water temperature have been recorded, ranging from 7 °C in January and February to an average of 17 °C in July and August (Jones et al., 1998). Bottom water temperatures usually display smaller differences between winter and summer. Seasonality in surface salinity is less apparent with a difference of 0.25–0.50 between summer and winter. The annual average surface salinity is 34 with a difference <1 between surface and bottom values (Howarth et al., 1993).

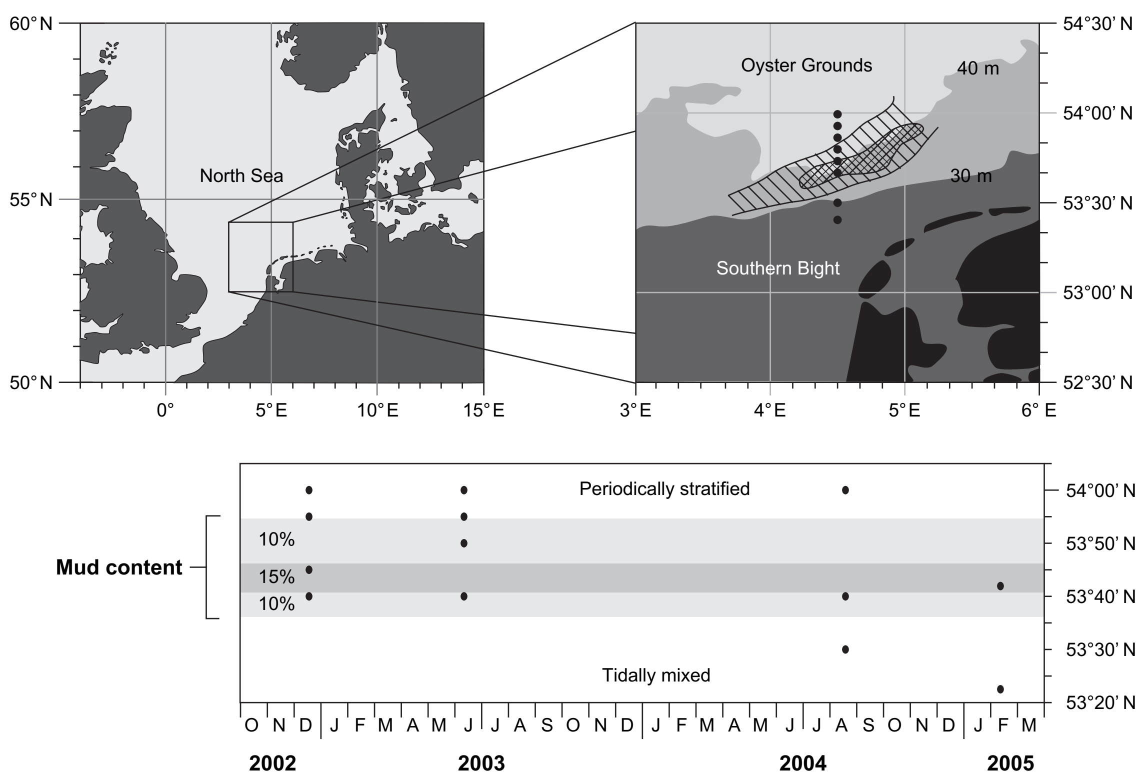

Fig. 1. The Southern North Sea, the location of the enriched benthic zone in the Frisian Front (single hatched area) with the highest mud content (cross-hatched area), the sampling stations and the sampling scheme.