Biomarkers in upper Holocene Eastern North Sea and Wadden Sea sediments

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Abstract

Total extracts of sediment cores from five different stations in the North Sea and Wadden Sea were analysed for their biomarker composition. Only sediments of the Skagerrak contained significant amounts of marine biomarkers (mainly alkenones), other sites contained predominantly terrestrial biomarkers. Bioturbation in the Skagerrak is, however, far too high to determine sea surface temperature (SST) changes within short time intervals. These results indicate that biomarkers contained in these sediments are not useful to reconstruct climate fluctuations during the upper Holocene. High amounts of α-, β- and ω-hydroxy fatty acids as well as small amounts of α, β-dihydroxy fatty acids were released from the insoluble organic material of the sediments from the Wadden Sea station, indicating a significant input of the eelgrass Zostera marina. This was confirmed by microscopic observations. This is the first time the α,β-dihydroxy fatty acids have been found in a sediment core and they have proven to be potential biomarkers for these seagrass species.

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1. Introduction

The North Sea is an epicontinental sea located on the northwest European passive continental margin and has been the focus of numerous studies. Besides biological and physical research a lot of effort has been put into the reconstruction of the origin of the sedimentary matter. The Norwegian Sea, the Atlantic Ocean and the Baltic Sea are the main sources of suspended sediments supplied to the North Sea. Furthermore, atmospheric input, primary production, rivers and coastal erosion add to the suspended and bed load of the North Sea (McManus and Prandle, 1997). Riverine input is extremely limited (Eisma et al., 1982). Of the organic carbon that is presently deposited in the North Sea about 20% is estimated to be of terrigenous origin, the remainder is supplied by primary production (Beckmann and Liebezeit, 1988) and a small amount by import from the Norwegian Sea (de Haas and van Weering, 1997).

Biological data series collected from the North Sea and Wadden Sea have yielded a wealth of information on the decadal variability within these marine environments during the last few decades (e.g. Kickel et al., 1989; Beukema, 1990; Witbaard and Klein, 1994). However, this timespan is too short to determine long-term variations of the North Sea and Wadden Sea ecosystems. Therefore, it is necessary to derive long-term information from other sources. One of these sources could be the sedimentary archives. Until now no attempt has been made to investigate the biomarker composition of sediment cores from the North Sea area. Changes in ecosystems may be recorded in the sedimentary biomarker record. For example, the sedimentary unsaturated long-chain ketones, biosynthesized by the coccolithophorid (Prymnesiophyta) Emiliania hux-
leyi (Volkman et al., 1980) and Geophryrocapsa oceanica (Volkman et al., 1995) enable the determination of the $^{37}\text{C}$ ratio (e.g. Brassell et al., 1986; Prahl and Wakeham, 1987; Müller et al., 1998) This ratio of C$_{37}$ alkenones with two and three double bounds can be used to reconstruct the sea surface temperatures SSTs. Biomarker distributions may also reflect the biologic input into sediments, giving insight to the composition of the ecosystem(s) in the recent past. Thus, the biomarker information contained in sequences of undisturbed sediments may be used to explore the possible existence of long-term and short-term variations in the North Sea ecosystem over time spans of hundreds or thousands of years. In this paper we report the biomarker composition in sediment cores from five different stations in the North Sea and Wadden Sea and discuss their potential to reconstruct climate fluctuations effecting the North Sea during the upper Holocene. In addition, we assess the contribution of seagrass to the biomarker fingerprints of Wadden Sea sediments.

2. Study area

The depth of the North Sea gradually decreases from approximately 200 m in the northern part to less than 30 m in the south. To the Northeast, in the Skagerrak region, the sea floor steeply slopes down to more than 700 m. In the nutrient-rich waters of the shallow Southern Bight and along the eastern boundary most of the primary production occurs. Counterclockwise currents transport fine-grained suspended material from the Southern Bight along the eastern boundary most of the primary production occurs. Counterclockwise currents transport fine-grained suspended material from the Southern Bight along the eastern boundary of the North Sea towards the Skagerrak (Eisma and Kalf, 1987; Fig. 1). The deep Skagerrak is assumed to be the ultimate sink for organic matter (van Weering et al., 1993). A core was taken at a station (3) where the sedimentation rate is extremely high according to de Haas and van Weering (1997). Other sediment cores were taken at stations along the eastern boundaries of the North Sea; the Norwegian channel, Skagerrak, German Bight and the Wadden Sea. The sediment core from the Wadden Sea was taken in the ‘Vlieter’. The ‘Vlieter’ is an abandoned channel in the Dutch Wadden Sea, which used to be the main drainage channel connecting the former ‘Zuiderzee’ and the western Wadden Sea, before closure of the dike called “Afsluitdijk” in 1932.

3. Material and methods

3.1. Core material

Sediment cores were taken during the ‘Dynamo’ cruise (28.05.96–5.06.96) using the RV ‘Pelagia’. Additional sediment cores were taken in the ‘Vlieter’ in June 1997 using the RV ‘Navicula’ (see Fig. 1 and Table 1 for the exact locations of the sample sites). All the cores show somewhat lamination and were stored at 4°C. At least three subsamples were taken from every sediment core from different depths and, if possible different layers, and analysed for their biomarker composition. Additional samples were taken from the core from station 3 from the Skagerrak, to increase the time resolution.

3.2. Extraction and fractionation

The extraction, separation and identification procedures followed are based on those described by Goossens et al. (1989a,b) and are schematically depicted in Fig. 2. Subsamples were taken from the cores at several depths (see Tables 1 and 3) and freeze-dried. The freeze-dried samples were Soxhlet extracted with dichloromethane/methanol (DCM/MeOH, 7.5:1, v/v) for 32 h. In order to remove elemental sulfur, activated (2N HCl) copper curls were added. The fresh seagrass Zostera noltii was dried and ultrasonically extracted with DCM. The extracts obtained were concentrated using rotary evaporation and dried over magnesium sulfate. An aliquot (1–5 mg) of the total extract was derivatized with diazomethane (CH$_2$N$_2$) in diethylether to convert fatty acids into their corresponding methyl esters. Subsequently, very polar compounds were removed by column chromatography over silica gel with ethyl acetate as eluent. The eluate was dried under a stream of nitrogen.
This fraction was dissolved in pyridine and bis(-trimethylsilyl)trifluoroacetamide (BSTFA) was added. This mixture was heated (60°C; 20 min) to convert alcohols into their corresponding trimethylsilyl ethers. The compounds present were analysed by means of gas chromatography (GC) and gas chromatography-mass–spectrometry (GC–MS).

Dried residues after extraction and aliquots of the underivatized extracts were saponified by refluxing with 1N KOH/MeOH (1 h). After cooling the reaction mixtures were neutralised with 2N HCl/MeOH (1:1; v/v) to pH 3.5, centrifuged and transferred to a separation funnel. The residues were washed subsequently with MeOH/H₂O, MeOH and DCM. Each time the supernatants were transferred to the separation funnel. Water was added and the DCM-layers were separated. The MeOH/H₂O layers were washed with DCM (×2). The combined DCM layers were concentrated using rotary evaporation, dried over magnesium sulfate and derivatized as described above.

The dried residues after saponification were also treated with 4N HCl (6 h; 100°C). After cooling the reaction mixture was neutralised with 16N KOH to pH 8.5, freeze-dried and saponified as above. The extracts were washed, separated and derivatized as described above.

Table 1

<table>
<thead>
<tr>
<th>Area</th>
<th>Station</th>
<th>Position</th>
<th>Water depth (m)</th>
<th>Core type¹</th>
<th>Estimated average sedimentation rate (mm year⁻¹)</th>
<th>Core length analysed (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skagerrak</td>
<td>3</td>
<td>58°46.29'N–10°08.58'E</td>
<td>235</td>
<td>p</td>
<td>8–10ᵇ</td>
<td>200</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>57°36.59'N–07°34.79'E</td>
<td>316</td>
<td>p</td>
<td>1–2ᵇ</td>
<td>100</td>
</tr>
<tr>
<td>The “Vlieter”</td>
<td>7-1c</td>
<td>53°01.57'N–05°04.19'E</td>
<td>6.5</td>
<td>b</td>
<td>9–11ᶜ</td>
<td>30</td>
</tr>
<tr>
<td>(Wadden Sea)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Norwegian Channel</td>
<td>14</td>
<td>60°40.72'N–04°35.15'E</td>
<td>358</td>
<td>p</td>
<td>2–4ᵇ</td>
<td>100</td>
</tr>
<tr>
<td>German Bight</td>
<td>17</td>
<td>54°06.35'N–08°06.08'E</td>
<td>22</td>
<td>p</td>
<td></td>
<td>100</td>
</tr>
</tbody>
</table>

² p, piston core; b, box core.  
ᵇ de Haas and van Weering (1997).  
ᶜ Unpublished results.

Fig. 2. Extraction and isolation scheme.
3.3. Gas chromatography

GC was performed using a Hewlett Packard 6890 or a Hewlett Packard 5890 instrument, both equipped with on-column injectors. A fused silica capillary column (25 m × 0.32 mm) coated with CP-Sil-5 (film thickness 0.12 μm) using helium as carrier gas. Compounds separated by the HP 6890 were detected by a flame ionisation detector (FID). Compounds separated by the HP 5890 were detected simultaneously by FID and a sulfur-selective flame photometric detector (FPD), using a stream splitter at the end of the column (split ratio FID: FPD = 1:1). The samples were dissolved in ethyl acetate and injected at 70°C. Subsequently, the oven was programmed to 130°C at 20°C/min and then at 4°C/min to 310°C at which it was held for 15 min.

3.4. Gas chromatography–mass spectrometry (GC–MS)

GC–MS was performed using a Hewlett-Packard 5890 gas chromatograph interfaced to a VG Autospec Ultima mass spectrometer operated at 70 eV with a mass range of m/z 50–800 and a cycle time of 1.7 s (resolution 1000). The gas chromatograph was equipped with a fused silica capillary column (25 m × 0.32 mm) coated with CP Sil-5 (film thickness = 0.12 μm). The carrier gas was helium. The samples were on column injected at 70°C and subsequently the oven was programmed to 130°C at 20°C/min and then at 4°C/min to 310°C at which it was held for 10 min. Compounds were identified by comparison of mass spectra and retention times with those reported in literature.

3.5. Microscopy

The microscopic determination of the seagrass parts was performed on a Zeiss Axiophot microscope with 40 × magnification.

4. Results

4.1. General

Cores from the North Sea and Wadden Sea were analysed for their biomarker composition. Because the core of the Wadden Sea revealed a significant input of seagrass the leaf fragments found in the core were analysed microscopically. In order to compare the two species of seagrass present in the Wadden Sea and to verify which one is present in the core, fresh Z. noltii was also analysed chemically. The biomarker composition of Zostera marina was already known (de Leeuw et al., 1995).

4.2. North Sea stations

Analyses of the total extracts (fraction E1; Fig. 2) of samples from sediment cores of the North Sea stations revealed mainly biomarkers of terrestrial origin (Fig. 3 and Table 2). Especially C_{22}–C_{30} alcohols, C_{24}–C_{32} fatty acids (both with an even-over-odd carbon number predominance) and C_{25}–C_{31} n-alkanes (odd-over-even car-

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Relative abundance a of biomarker classes found in the total extracts (fraction E1) of samples from the different sampling stations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Station</td>
</tr>
<tr>
<td>Alcohols</td>
<td></td>
</tr>
<tr>
<td>n-Alkanes</td>
<td></td>
</tr>
<tr>
<td>Alkenones</td>
<td></td>
</tr>
<tr>
<td>Fatty acids</td>
<td>&lt; C_{22}</td>
</tr>
<tr>
<td>Hopanoic acids</td>
<td>C_{32}17α,21β (H)</td>
</tr>
<tr>
<td>Hopanols</td>
<td>C_{32}17β,21β (H)</td>
</tr>
<tr>
<td>ω-Hydroxy fatty acids</td>
<td></td>
</tr>
<tr>
<td>Methyl ketones</td>
<td></td>
</tr>
<tr>
<td>Mid-chain alcohols</td>
<td></td>
</tr>
<tr>
<td>Sterols</td>
<td>5α-cholestan-3β-ol</td>
</tr>
<tr>
<td></td>
<td>desmethyldinosterol</td>
</tr>
<tr>
<td></td>
<td>dinosterol</td>
</tr>
<tr>
<td></td>
<td>5β-sitostanol</td>
</tr>
<tr>
<td></td>
<td>β-sitosterol</td>
</tr>
<tr>
<td>Wax esters</td>
<td></td>
</tr>
</tbody>
</table>

a + + Abundant, + present, +/− trace and − absent.

<table>
<thead>
<tr>
<th>Table 3</th>
<th>Core depth and U_{37}^{a} values of samples from sediment station 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core depth (cm)</td>
<td>U_{37}^{a}</td>
</tr>
<tr>
<td>25–27</td>
<td>0.58</td>
</tr>
<tr>
<td>27–28</td>
<td>0.59</td>
</tr>
<tr>
<td>28–29</td>
<td>0.57</td>
</tr>
<tr>
<td>29–30</td>
<td>0.58</td>
</tr>
<tr>
<td>30–31</td>
<td>0.58</td>
</tr>
<tr>
<td>31–32</td>
<td>0.59</td>
</tr>
<tr>
<td>32–33</td>
<td>0.59</td>
</tr>
<tr>
<td>33–34</td>
<td>0.58</td>
</tr>
<tr>
<td>34–35</td>
<td>0.59</td>
</tr>
<tr>
<td>50–52</td>
<td>0.58</td>
</tr>
<tr>
<td>75–77</td>
<td>0.59</td>
</tr>
<tr>
<td>110–111</td>
<td>0.58</td>
</tr>
<tr>
<td>189–190</td>
<td>0.59</td>
</tr>
</tbody>
</table>

a U_{37}^{a} = [C_{37:2}]/[C_{37:2} + C_{37:3}].
Fig. 3. Gas chromatograms of the total extracts (fraction E1; Fig. 2) from (a) Skagerrak (station 3), (b) Skagerrak (station 5), (c) Norwegian Channel (station 14) and (d) German Bight (station 17). Numbers indicate carbon chain length and IS = internal standard.
bon number predominance) were found. Also present, but in a significant lower amount, was a complex mixture of sterols (predominantly: β-sitosterol, 5β-sitostanol, dinosterol, desmethyldinosterol and 5α-cholestan-3β-ol) and hopanols [mainly 17β,21β(H)-bishomohopan-32-ol].

Analyses of samples from the sediment core from station 3 of the Skagerrak revealed also high amounts of di- and tri-unsaturated C_{37–C_{39}} long-chain alkenones. The analyses of different sections of the sediment core 3 showed no significant change in $U_{37}^{C}$ as shown in Table 3.

Fig. 4. Gas chromatograms of (A) the total extract, fraction E1, (B) the residue hydrolysed under base conditions, fraction E3, and (C) the residue hydrolysed under acid conditions, fraction E4, of sediments from the Wadden Sea station. Numbers indicate carbon chain length. i, iso branched, ai, anteiso branched and n, normal β-hydroxy fatty acid.
4.3. Wadden Sea station

Like all sediments investigated from the North Sea stations, the total extract (fraction E1) of samples from sediments core of the Wadden Sea station revealed predominantly terrestrial biomarkers (Fig. 4a). In contrast, significant amounts of ω-hydroxy fatty acids were also found (Table 2). High amounts of C₁₆–C₂₈ ω-hydroxy fatty acids were released from the residues by base hydrolysis (fraction E3; Fig. 4b). High amounts of C₂₂–C₂₇ α- and C₁₂–C₂₀ β-hydroxy fatty acids as well as trace amounts of C₂₂–C₂₄ α,β-dihydroxy fatty acids were released from the residues by acid hydrolysis (fraction E4; Fig. 4c). Since the mass spectra of the β-hydroxy fatty acids do not contain sufficient information to distinguish iso (i)-, anteiso (ai)-branched or normal (n)-hydroxy fatty acids, these assignments are based upon relative retention times in analogy to the identification of hydroxy fatty acids by Boon et al. (1977).

Further investigation of the sediments from the Wadden Sea station revealed a significant amount of 2-methylmercaptobenzthiazole (MTBT) and N-methylmercaptobenzthiazole (NMTBT) as shown in Fig. 5.

4.4. Seagrass

Microscopic observations of leaf fragments found in the sediments of the Wadden Sea station revealed a significant amount of the eelgrass Z. marina (Fig. 6), which chemical composition is reported by de Leeuw et al. (1995). The chemical analysis of the other potential species, Z. noltii, revealed a similar fatty acid distribution patterns in all fractions. Besides the C₁₆ saturated fatty acid a significant contribution comes from the unsaturated C₁₈ fatty acid. The α-hydroxy fatty acids are released after acid treatment (fraction E4; Fig. 7). The β-hydroxy fatty acids are absent or virtually absent in all fractions of the living seagrass. The ω-hydroxy fatty acids are only encountered in fraction E2. Only traces of C₂₂–C₂₄ α,β-dihydroxy fatty acids were found in fraction E4.

If the quantities of fatty acids and hydroxy fatty acids in fresh Z. noltii are compared with those in fresh Z. marina, analysed by de Leeuw et al. (1995), only fraction E4 reveals any significant differences (Fig. 7). The Z. marina E4 fraction contains a significant amount of

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Fig. 5. Partial gas chromatogram from total extract E1 of sediment from the Wadden Sea station with (a) a flame ionisation detector and (b) a sulfur-selective flame photometric detector. *2-methylmercaptobenzthiazole (MTBT); **N-methylmercaptobenzthiazole (NMTBT).

Fig. 6. Photomicrographs of leaves from (a) Z. marina found in sediment core of the Wadden Sea station (b) fresh Z. marina and (c) fresh Z. noltii.
β-hydroxy fatty acids and α,β-dihydroxy fatty acids but only traces were found in *Z. noltii*. Furthermore, the contribution of unsaturated fatty acids, especially the unsaturated C18 fatty acid, is relatively higher in the *Z. noltii* than in the *Z. marina*.

5. Discussion

5.1. All stations

In total extracts (fraction E1) of all the sediments terrestrial biomarkers dominate. This is most likely due to the oxic conditions experienced by the organic material during frequently occurring transport through resuspension and sedimentation in the North Sea. This process likely leads to an enrichment of the more refractory terrestrial biomarkers relative to the more labile marine biomarkers (Haddad et al., 1992; Harvey, 1994; Santos et al., 1994; Canuel and Martens, 1996; Colombo et al., 1997; Budge and Parrish, 1998). Our samples contain significant though lower amounts of marine sterols (i.e. dinosterol and desmethyldinosterol) and hopanols. This indicates a contribution of dinoflagellate algae (Shimizu et al., 1976; Boon et al., 1979; Withers, 1983) and bacteria (Rohmer et al., 1992; Yunker et al., 1995), respectively. These biomarkers may provide some palaeo-environmental information. However, the bioturbation, the long residence time in the basin, the transport through the North Sea, sedimentation and erosion must have caused considerable disturbance of the record. This and the relative small amounts of the biomarkers found, makes them less useful for palaeo-environmental reconstruction.

5.2. Skagerrak (station 3)

Only the sediments from the Skagerrak (station 3) revealed a significant amount of unsaturated C_{37}–C_{39} long-chain alkenones, probably derived from blooms of *Emiliania huxleyi* in the area (Buitenhuis et al., 1996). The long-chain alkenones are only found in this area probably due to the extremely high sedimentation rates in combination with the depth. Analyses of different sections in the sediment core showed an average SST of 11–12°C without any change in temperature variation, indicating no apparent short- and long-term variation in SST. Dauwe et al. (1998) recently reported the presence of fauna up to 20 cm depth in the sediment causing a lot of disturbance and mixing in the Skagerrak. This will make it impossible to determine $U_{37}^3$ and SST changes within a short period of time (yearly to decennial). The absence of long-term variations (decennial to centennial) in SST can be caused by the fact that there are no SST changes over a longer period of time or they are too small to be noticed.

5.3. Wadden Sea station

The high amounts of ω-hydroxy fatty acids, in fractions E1 and E3, and α- and β-hydroxy fatty acids, in fraction E4, indicates a high input of seagrass in the sediment of the ‘Vlieter’. The composition of the hydroxy fatty acids is similar to that reported by de Leeuw et al. (1995) in decomposing eelgrass *Z. marina*. The relative small amounts of α,β-dihydroxy fatty acids, found in fraction E4, is worthy of note since α,β-dihydroxy fatty acids have only been encountered in *Z. marina* and *Z. muelleri*. Hence they may be highly specific...
biomarkers for these seagrasses as proposed by de Leeuw et al. (1995). Fresh Z. noltii, the other seagrass present in the Wadden Sea (Philippart, 1994), also contains traces of $\alpha$, $\beta$-dihydroxy fatty acids in fraction E4. This makes it chemically impossible to distinguish Z. marina from Z. noltii. The leaf fragments found in the sediment core of the Wadden Sea station were microscopically analysed (Fig. 6) and when compared with leaves from fresh Z. marina and Z. noltii, the presence of Z. marina was confirmed. This makes the presence of remnants of Z. noltii in the sediment core less likely.

De Leeuw et al. (1995) also analysed decomposing Z. marina, about 12.5 years old. These fractions were compared with the same fractions from the sediment core of the Wadden Sea station. Especially fraction E4 gave a completely different picture. In this fraction of the sediment from the Wadden Sea station the $\alpha$-hydroxy fatty acids are relatively low and the $\alpha$, $\beta$-dihydroxy fatty acids are only present in trace amounts. The presence of a significant input of $\beta$-hydroxy fatty acids indicates the presence of bacterial biomass, because iso- and anteiso-$\beta$-hydroxy fatty acids occur as amide-bound moieties of lipopolysaccharides in gram-negative bacteria (Goossens et al., 1986). This could explain that not only the Z. marina contributed to this fraction but there was also a significant contribution of fatty acids and $\beta$-hydroxy fatty acids coming from bacteria. It must also be considered that the sediments of the Wadden Sea station analysed covered the last 25 years but the Z. marina present is probably much older material (as will be explained below) and therefore the $\alpha$, $\beta$-dihydroxy fatty acids and the $\alpha$-fatty acids can be more biodegraded.

Until the early 1930s, the Z. marina was present in large quantities in the Wadden Sea (Oudemans et al., 1870; van Goor, 1919; van Eerde, 1942; de Jonge and Ruiter, 1996). After the epidemic that struck the North Atlantic population of seagrass in the early thirties, the Atlantic population of seagrass in the Wadden Sea resulted in a lot of erosion. Glim et al. (1987) for instance reported an increased flow in the ‘Doove Balg’, a channel near the ‘Vlieter’ causing a lot of erosion near the ‘Meerwaard’, a large old Z. marina bed.

The high amounts of terrestrial biomarkers and the high input of eelgrass in the sediments suggest that the ‘Vlieter’ is one of the major depositional sites of the Wadden Sea ecosystem. This is further supported by the input of 2-methylmercaptobenzothiazole and N-methylmercaptobenzothiazole (Fig. 5). Benzothiazoles have gained widespread application in industrial processes. They are well-known vulcanisation accelerators (Fiehn et al., 1994) in the rubber industry, manufacture of rubber tyres, and can be found in street runoff (Spies et al., 1987). MBTB is an impurity that appears to be environmentally stable. NMBTB is not a well-known impurity but may be formed by a methyl shift of MBTB during the vulcanisation process. Where these compounds originate from is not clear. It is possible they come from the ‘Afsluitdijk’ on which a highway is present. Another possibility is that they are originating from somewhere else and through transport (rainwater, rivers, etc.) end up in the ‘Vlieter’. The appearance of these compounds in the sediment in combination with the high sedimentation rates makes it more likely that the ‘Vlieter’ is a major depositional site of the Wadden Sea ecosystem.

6. Conclusions

1. Except for the Skagerrak, where alkenones are present, the North Sea sediments contain predominantly terrestrial biomarkers.
2. Bioturbation in the Skagerrak is far too high to determine SST within a short period of time (yearly to decennial) and the changes in averaged SST (over approximately the last 200 years) seem to be too small to be noticed.
3. The sediments from these stations are thus not useful to reconstruct climate fluctuations during the upper Holocene.
4. High amounts of $\alpha$, $\beta$- and $\omega$-hydroxy fatty acids and traces of $\alpha$, $\beta$-dihydroxy fatty acids indicate a significant input of the eelgrass Z. marina in the Wadden Sea site. This is the first time that these $\alpha$, $\beta$-dihydroxy fatty acids are found in a sediment core and that they have proven to be potential biomarkers for these classes of eelgrass.
5. The ‘Vlieter’ is a major depositional site of the Wadden Sea system.

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