Supplement to “Increased petrogenic and biospheric organic carbon burial in sub-Antarctic fjord sediments in response to recent glacier retreat”

Berg, S., Jivcov, S., Kusch, S., Kuhn, G., White, D.A., Bohrmann, G., Melles, M., and Retemeyer, J.

1. Terrigenous organic matter in the catchment of Cumberland Bay

Terrigenous OM in the marine sediments in Little Jason Lagoon and Cumberland Bay derives from terrestrial plants as well as peat and soil deposits in the catchment. In order to characterize the contribution of terrigenous OM we conducted additional investigations in the catchment of Cumberland Bay. These include mapping of the distribution and thickness of peat and soil coverage in the western catchment of Cumberland West Bay. Radiocarbon and lipid biomarker analyses on a peat section (SG062) in the catchment of Little Jason Lagoon were conducted to i) identify $\Delta^{14}$C values for the terrigenous endmember and to ii) support the lipid biomarker interpretation for the quantitative estimates of terrigenous input.

In the catchment of Cumberland Bay vegetation is composed of tussock grass (Parodiochloa flabellata), other grasses (Festuca contracta and Deschampsia antarctica), subshrubs (Acaena spp.), rushes (Juncus spp. and Rostkovia magellanica), and mosses (Greene, 1964). Around Little Jason Lagoon, moraine ridges and debris drapes document past periods of cirque glacier advances in the catchment (Fig. S1, White et al. 2018). At lower altitude, fur and elephant seals and penguins occupy the ground.

1.1 Peat and soils: distribution and thickness

Peat thicknesses in Enten Valley and in the catchment of Little Jason Lagoon (Fig. S1) were found to be a function of elevation, landform stability and landform age. At low altitude (<50 m a.s.l.), relatively flat (presumably non-eroding or depositing) sites, peat thicknesses approach a meter or more on late-glacial landforms (Fig. S1). Maximum thicknesses on mid-Holocene dunes and raised beaches were in the order of 60-120 cm, decreasing to zero for recent dunes and beach sediments. Peat was generally absent above 50 m elevation, even on late-glacial landforms, although thin patches of vegetation on organic soil were present up to 100 m elevation at non-eroding sites. The distribution of peat deposits and soils suggests that the
majority of terrestrial OM that is exported into the fjord is derived from organic-rich deposits at lower altitude.

Figure S1: Satellite image of Enten Valley and the catchment of Little Jason Lagoon. Black lines show moraines (solid = late-glacial, dashed = Holocene) and raised beaches (dotted). Estimated soil and peat thicknesses are shown with dots only, natural sections with peat depths are given in cm.

1.2 Peat profile SG062: Δ¹⁴C values and OM composition

On a late-glacial moraine ridge on the north-eastern shore of Little Jason Lagoon (32 m a.s.l.; 54.189286°S; 36.589241°W), a peat profile was excavated and sampled (Fig. S2). The surface is covered with moss and grass patches and the peat cover on the ridge has a thickness of > 1.0 m (Fig. S1). At the excavated site SG062, the lower part of the profile consists of a stony moraine (1.55 to 1.10 m depth, Fig. S3). Between 1.1 and 1.0 m depth, the onset of organic matter sedimentation is documented by a layer of mixed peaty and siliciclastic (sandy/silty) material. The peat above 1.0 m depth is denser and muddier in the lower part than in the upper 0.6 m. The upper 0.18 m of the profile consist of peat pervaded by roots of grass and moss growing on top. Seal hair and penguin excrements in the top layer reflect the frequent presence of these animals.
TOC content in the three peat samples is >35% and C/N ratios range from 11.6 to 13.2, which is typical for higher land plants (Fig. S3). TOC contents of the underlying siliciclastic sediments are much lower (< 4%) and C/N ratios of 7.2 and 8.7 differ from the peat. Concentrations of high molecular weight fatty acids (C$_{26:0}$, C$_{28:0}$, and C$_{30:0}$) are 10 to 50 times higher in the peat compared to the clayey sand and sandy clay below 1.1 m depth. A $\Delta^{14}$C value of 121‰ for plant remains in the upper 0-18 cm proves the modern origin (bomb-$^{14}$C incorporation) of the peat surface. Seal hair incorporated in this modern sediment shows a depleted $\Delta^{14}$C value (-131±4 ‰, corresponding to 1,060±40 $^{14}$C yr BP), reflecting the marine reservoir age, which is inherent to the marine feeding seals. The $\Delta^{14}$C values of the peat samples become more depleted with depth reflecting an increase in age (Fig. S3, Table S4).
Figure S3: Schematic description of the peat pit SG062. The peat section is underlain by stony moraine material. $\Delta^{14}$C and corresponding conventional $^{14}$C ages ($^{14}$C yr BP) are shown versus depth. Elemental and molecular parameters analysed for samples from five depths are shown to the right: Total organic carbon (TOC), C/N ratio, high molecular weight (HMW) fatty acids ($C_{26:0} + C_{28:0} + C_{30:0}$ homologs) normalized to TOC (mg/g TOC) and fractional abundance of high molecular weight fatty acids.

The $^{14}$C age of 3,680±40 $^{14}$C yr BP at 0.60-0.76 m depth provides a minimum age for the onset of peat formation at this site. It also provides an estimate for the minimum $\Delta^{14}$C value of terrestrial organic matter that is deposited in the fjord: assuming that the terrestrial OC released by erosion on land mainly derives from the peat deposits (which are very organic rich compared to the debris covering most of the catchment), we use the mean $\Delta^{14}$C value of the three peat samples (-154‰) as an estimate for the “pre-aged” terrigenous endmember. The underlying sediments contain OC as well, however, the relatively low TOC content and relatively low high molecular weight fatty acid concentrations likely have a negligible effect on the $\Delta^{14}$C signal and FA composition exported into the marine sediments.
1.3 Composition of organic carbon in Cumberland Bay and Little Jason Lagoon

Table S1 ACL (Average Chain Lengths) calculated for fatty acids (FA) with C\textsubscript{14:0} to C\textsubscript{30:0} carbon atoms [ACL = \(\sum(C_n \times n) / \sum C_n\), with \(n\) = even-numbered chain lengths and \(C_n\) = abundance of the specific homolog in the sample], CPI (Carbon Preference Index, after Marzi et al. 1993) giving the even-over-odd predominance of fatty acids with chain lengths from C\textsubscript{14:0} to C\textsubscript{30:0} \([\text{CPI} = ((C_{14:0}+C_{16:0}+...+C_{28:0}) + (C_{16:0}+C_{18:0}+...+C_{30:0}))/ (2*(C_{15:0}+C_{17:0}+...+C_{29:0}))].\) high molecular weight (HMW) FA = C\textsubscript{26:0}+C\textsubscript{28:0}+C\textsubscript{30:0}; low molecular weight (LMW) FA = C\textsubscript{14:0}+C\textsubscript{16:0}+C\textsubscript{18:0}; brGDGT= IIIa+IIIa'+IIa+IIa'+Ia (analogous to the calculation of the BIT index; Hopmans et al., 2004)

| core      | Depth (cm) | TOC % | TOC/ N | HMM FA (µg/g TOC) | LMW FA (µg/g TOC) | ACL | CPI | brGDGT (ng/g TOC) | Cren (ng/g TOC) |
|-----------|------------|-------|--------|-------------------|-------------------|-----|-----|------------------|----------------|
| 258-3     | 0-2        | 0.41  | 40.7   | 579               | 2016              | 19.9| 7.8 | 2338.0           | 46700.6        |
| 259-1     | 0-2        | 0.58  | 53.6   | 350               | 2136              | 18.7| 8.1 | 364.7            | 9027.4         |
| 260-1     | 0-2        | 0.40  | 41.8   | 322               | 2942              | 17.9| 8.8 | 593.2            | 8242.4         |
| 262-1     | 0-2        | 0.60  | 5.0    | 357               | 1993              | 18.7| 7.6 | 416.6            | 11742.6        |
| 280-2     | 0-2        | 0.81  | 6.8    | 105               | 648               | 18.5| 6.2 | 312.5            | 9271.7         |
| 283-1     | 1-2        | 0.45  | 7.1    | 30                | 300               | 18.1| 5.3 | 11.7             | 11.0           |
| 284-1     | 5-7        | 0.65  | 7.9    | 34                | 390               | 17.7| 9.2 | 33.6             | 644.5          |
| Co1302    | 0-2        | 2.82  | 6.6    | 927               | 6381              | 17.9| 7.1 | 6499.2           | 202.9          |
| Co1303    | 0-2        | 2.99  | 7.5    | 841               | 9170              | 17.1| 7.4 | 6438.2           | 427.2          |
| Co1304    | 0-2        | 2.82  | 6.5    | 1060              | 5571              | 18.4| 5.0 | 2027.8           | 147.1          |
| Co1305    | 0-2        | 3.03  | 6.3    | 569               | 4943              | 17.5| 10.1| 312.6            | 54.2           |
| SG 062    | 0-18       | 39.50 | 11.9   | 2255              | 2030              | 22.1| 10.3| 159061.4         | 812.9          |
| SG 062    | 30-45      | 44.59 | 13.2   | 3062              | 2854              | 22.1| 9.0 | 139910.1         | 1362.3         |
| SG 062    | 60-76      | 37.49 | 11.6   | 3629              | 2100              | 23.5| 6.7 | 31147.4          | 167.2          |
| SG 062    | 110-135    | 3.33  | 8.7    | 75                | 68                | 22.5| 6.4 | 1600.5           | 54.5           |
| SG 062    | 135-155    | 1.24  | 7.2    | 235               | 107               | 24.0| 6.4 | 1667.2           | 57.2           |
2. Results of mixing models and endmember values for $\Delta^{14}$C

Table S2 Contribution of petrogenic (%petro), marine (%marine) and terrigenous (%terr) organic matter in surface sediments of Cumberland Bay and Little Jason Lagoon calculated using mixing models based on i) fatty acid and ii) GDGT ratios. $\Delta^{14}$C values for the respective endmembers of petrogenic, marine and terrigenous OM are given in Table S3.

| core  | fatty acid ratio | GDGT ratio |
|-------|------------------|-------------|
|       | %petro | %marine | %terr | %petro | %marine | %terr |
| 258-3 | 80.7±1.7 | 30.5±1.4 | 8.8±0.4 | 60.1±1.2 | 37.9±1.2 | 2.0±0.1 |
| 259-1 | 42.9±2.1 | 49.7±1.8 | 8.2±0.3 | 41.6±1.7 | 56.1±1.7 | 2.3±0.1 |
| 260-1 | 67.8±1.0 | 29.0±0.9 | 3.2±0.1 | 67.7±1.0 | 30.0±0.9 | 2.3±0.1 |
| 262-1 | 36.5±2.3 | 53.9±2.0 | 9.6±0.4 | 35.7±1.9 | 62.4±1.9 | 1.9±0.1 |
| 260-2 | 14.4±3.0 | 73.6±2.6 | 11.9±0.4 | 13.5±2.5 | 83.9±2.6 | 2.6±0.1 |
| 283-1 | 73.2±3.5 | 24.3±3.2 | 2.5±0.3 | 74.3±1.6 | 12.3±0.8 | 13.4±0.8 |
| 284-1 | 28.6±2.1 | 65.6±2.1 | 5.7±0.2 | 28.4±2.1 | 68.0±2.0 | 3.6±0.1 |
| Co1302 | 4.4±3.3 | 83.5±2.9 | 12.1±0.4 | 10.1±13.6 | 2.7±0.4 | 87.2±13.2 |
| Co1303 | 4.2±3.0 | 87.8±2.8 | 8.1±0.3 | 10.1±13.2 | 5.4±0.8 | 84.5±12.4 |
| Co1304 | 5.3±3.5 | 79.6±3.0 | 15.1±0.6 | 10.5±13.1 | 6.2±0.9 | 83.3±12.1 |
| Co1305 | 4.9±3.1 | 85.3±2.8 | 9.8±0.3 | 10.2±12.0 | 13.7±1.8 | 76.1±10.2 |

Table S3 $\Delta^{14}$C endmember values used for mixing model. (Cumberland West Bay=CWB, Cumberland East Bay=CEB)

| Endmember | $\Delta^{14}$C [%] | Archive | Reference |
|-----------|-------------------|---------|-----------|
| petrogenic | -1000  | $^{14}$C-free | this study |
| min. terrestrial | -154 | Peat deposit in the terr. catchment of CWB | this study |
| max. terrestrial | 121 | Peat deposit in the terr. catchment of CWB | this study |
| min. marine | -133 | Benthic foraminifers in surface sediment from the shelf | Graham et al. 2017 |
| max. marine | -85  | C$_{16:0}$ fatty acids in surface sediment in CWB | Berg et al. 2020 |

3. Calculation of mass accumulation rates and burial rates

We use organic carbon content (%OC) and the mean content of petrogenic organic carbon (%OC$_{petro}$) and terrestrial organic carbon (%OC$_{terr}$), respectively, derived from mixing models, to calculate mass accumulation rates (MAR) for OC, OC$_{petro}$ and OC$_{terr}$ for each coring location in the fjord and in Little Jason Lagoon using

\[
\text{MAR}_{OC} = SR \times DBD \times f_{OC}
\]

\[
\text{MAR}_{OC_{petro}} = SR \times DBD \times f_{OC} \times f_{OC_{petro}}
\]

\[
\text{MAR}_{OC_{terr}} = SR \times DBD \times f_{OC} \times f_{OC_{terr}}
\]
we calculate To estimate the burial of p
2017). For the determination of mass accumulation rates
fraction petrogenic in organic carbon, \( f_{\text{OCpetro}} \) = fraction terrigenous in organic carbon.
(SR = sedimentation rate, DBD = dry bulk density, \( f_{\text{OC}} \) = fraction organic carbon, \( f_{\text{OCpetro}} \) =

For the calculation of MAR a mean DBD value was determined from the uppermost lithological unit of each core, likely most representative of present-day sedimentation.

To estimate the burial of petrogenic (\( f_{\text{OCpetro}} \)) and terrigenous (\( f_{\text{OCterr}} \)) OM in Cumberland Bay we calculated the total OM burial as \( \text{MAR}_{\text{OCpetro}} \times \text{fjord area} \). The spatial extent of Cumberland West Bay, Cumberland East Bay and Little Jason Lagoon was extracted from
Google Earth™ using the glacier extent in 1958 and 2017, respectively (from https://sggis.gov.gs/).

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