Freeze Coring: Sediment Disturbances / Influence of Freeze Coring on Potential Methane Production Rates in Freshwater Sediment

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Motivation

Field studies over the last decades show that sediment in frehwater impoundments can act as an imporant source of greenhouse gases (GHG) like methane and carbon dioxide (Bastviken et al. 2011). Under anaerobic conditions, enhanced mineralisation of organic matter within the sediment favours methane bubble formation. To investigate the influenceing sediment parameters and relevance of the emissions, the acqisition of undisturbed sediment samples, which retain the *in situ* sedimentological, biological and chemical conditions is required. Over the last decades, various devices for sediment sampling have been developed, each best suited to a particular set of conditions. There is still a lack of a simple, quick and inexpensive coring method for sampling of gas-bearing and water-saturated sediments. Disadvantages of using common tube samplers, such as gravity corers, to sample water-saturated or gas-bearing sediment, include degassing of the bubbles in the sediment column, and/or liquefaction and distortion of the sample. Therefore we developed a novel freeze corer at Cologne University of Applied Science. Complementary, it should be investigated rather freeze coring is suitable to analyze sediment GHG production. Several studies were conducted analyzing the influence of freezing and thawing on greenhouse gases like CO2, N2O and CH4 (Holst et al., 2008; Matzner & Borken, 2008). These studies focus mainly on emissions from soils rather than reservoirs sediments. Potential influencing factors are:

- Changes in microbial community - abundance and composition.
- Changes in soil structure physical disruption of aggregates and cell wall lysis releasing previously inaccessible materials suitable for the methanogensis process.
- Redistribution of water and nutrients in substrate structure.

The objective of this study is to investigate the advantages of freezing coring as an alternative to common coring techniques.

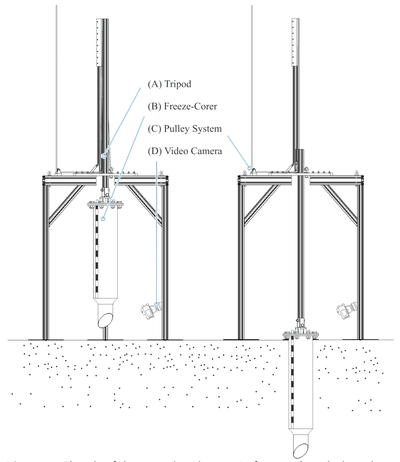

Figure 1. Sketch of the tripod and corer. Left: tripod settled on the sediment. Right: corer position after penetration.

Methods

The new corer freezes the sediment inside a double-walled tube by a strong coolant (mixture of dry-ice and ethanol; temperatur of approx. -70°C), which is added into the space between the corer walls.

Lab and field measurements (Figure 2) were carried out to quantify core distortion (e.g. shortening, smearing and other disturbances of the sediment layer; Figure 4) caused by the freeze corer, especially how freezing affects the gas and the structure within the core. Furthermore, we analyzed the effect of artifical freezing and thawing on methane and carbon dioxide production.

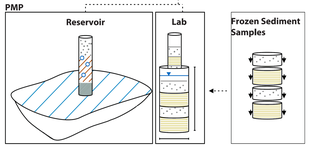

Figure 2. Schematic representation of core processing of lab and field cores.

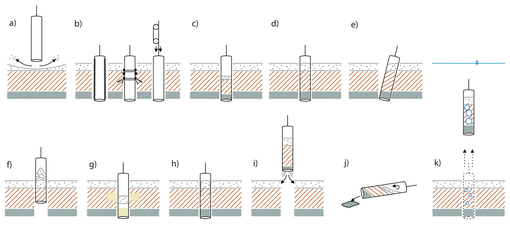

Figure 4. Coring disturbance types: a) shock wave; b) type of penetration (vibra coring, hammering, pulley system); c) shortening; d) bending; e) tilting; f) expansion; g) entry deficit; h) smeaing; i) retrieval; j) handling and k) depressureization.

Methods - Coring Disturbances

Sediment cores were scanned with a X-Ray Dual-Layer Computer-Tomography (CT) Scanner (Philips iQon Spectral CT; Figure 3) for data analysis and 2D-/3D-visualization. The Dual-Layer CT Scans also revealed the atomic number (Zeff) of each voxel of the core. Thresholds were chosen for all cores to allow for a meaningful comparision between the voids, ice and sediment. 3D visualization of sediment gas bubbles were created using MorphoLibJ (ImageJ plugin) and the ImageJ 3D volume viewer.

Figure 3. Sediment cores in CT Scanner.

Methods - Potential CH4 and CO2 Production

To test the influence of freezing (-70°C) and thawing on the potential methane and carbon dioxide production, sediment incubations were performed (Figure 5):

- Depth profiles: Sediment cores were subdivided in slices of 4 cm.
- Freeze core incubation at 15°C and 20°C.
- Gravity core incubation at 20°C.
- Sediment processed under oxygen free conditions and stored in glass vials flushed with nitrogen.
- Measurement of headspace CH4 and CO2 concentration.

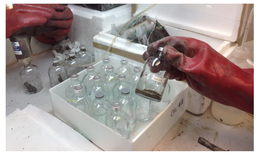

Figure 5. Laboratory sediment incubation.

Results - Field Cores

The total volumetric gas content of gravity (GC), frozen gravity (GCfrozen) and freeze cores (FC) showed no correlation (Table 1). Bubble size distribution and total gas content was generally consistent for all gravity cores, but the pattern between the other coring techniques differed significantly. The bubbles in the gravity cores of Urft Reservoir were much larger compared to the frozen gravity and freeze cores (Figure 6 and 7).

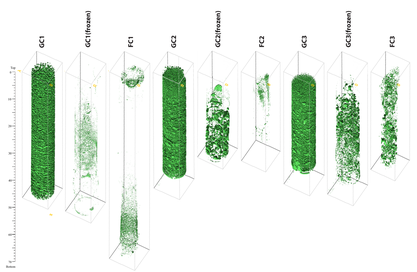

Figure 6. 3D bubble visualization of Urft Reservoir cores.

Table 1. Comparision of the total volumetric gas content. Differences in gas content between the frozen gravity and freeze core im comparision to the gravity core is noted in brackets.

Core ID			Gas content (mm3)		
GC1	/ GC1frozen /	FC1	127,872	4,842 (26)	6,486 (20)
GC2	/ GC2frozen /	FC2	166,996	25,746 (6)	1,422 (117)
GC3	/ GC3frozen /	FC3	68,402	26,666 (3)	26,802 (3)

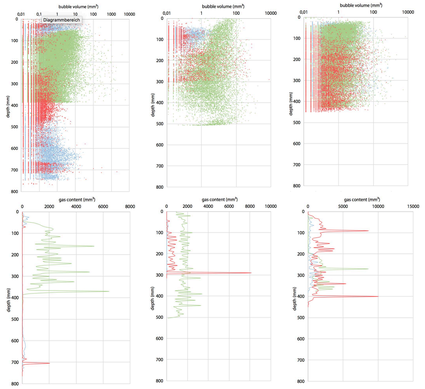

Figure 7. Void and gas content distribution of gravity (green lines/dots), frozen gravity (red lines/dots) and freeze core (blue lines/dots).

Results - Coring Disturbances

Our laboratory tests with artificially laminated sediment gives an indication of the mechanism and origin of the coring disturbances. The results reveal four major disturbance types (Figure 8):

(1) Bending: a slow penetration velocity, stiff sediment and a low water content increase the bending.

(2) Smearing: the higher the water and organic content, the higher the risk of smearing. Gravity cores are more often affected by smearing than freeze cores.

(3) Expansion: layer deformation due to the expansion of water by freezing. Only occurs in freeze cores.

(4) Shortening: the higher the water and organic content is, the greater is the shortening (liquefaction). Gravity cores exhibit more shortening than freeze cores (23% increase).

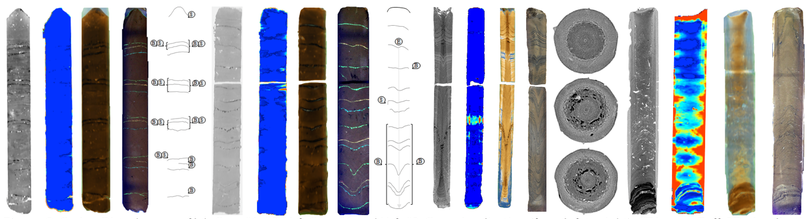

Figure 8. Coring Disturbances of lab Core #1, #2, Urft Core #1 and Urft #3. Core visualization (from left to right): CT image, Zeff, 3D-visualization, core image and digitized sediment layer (B = bending, S = smearing and E = expansion).

Results - Freezing of Bubbles

The effects of freezing on gas bubbles (void structure) were assessed by comparing CT scans of mechanically undisturbed frozen and unfrozen cores under laboratory conditions. Freezing-induced gas reduction was generally consistent over depth for all clay cores, whereas gas profiles for silt and sand were statistically unidentifiable. The results have shown that freezing caused a volume contraction of gas bubles and increased the amount of small bubbles, but the distribution of bubbles remained unchanged (Figure 9).

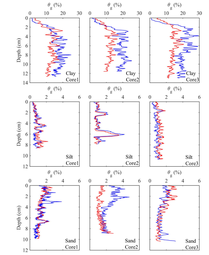

Figure 9. Depth profiles of volumetric gas content in the sediment cores (clay, silt and sand) before (blue lines) and after (red lines) freezing.

Results - PMP

The results of the sediment incubation tests are shown in Figure 10. The blue lines refer to gravity core data analyses and the red lines to freeze core results. The methane production rates vary between different sampling sites. There is a tendency of higher production rates at the sediment-water-interface than in deeper layers. Based on the results so far, no clear trend is observed. In some cases the CH4 and CO2 production rates of the freeze cores are higher than the gravity cores. In other cases it is the other way round. In some tests the production rates converge with increasing depth. Freeze cores show a positive correlation between the organic matter content and the methane production rate (Figure 10: second row - right site).

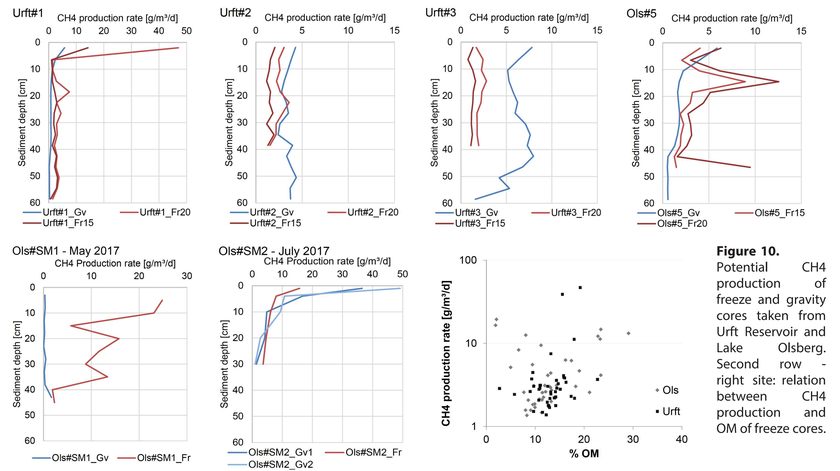

Figure 10. Potential CH4 production of freeze and gravity cores taken from Urft Reservoir and Lake Olsberg. Second row - right site: relation between CH4 production and OM of freeze cores.

Conclusion

- The new freeze corer proved its applicability as an inexpensive and easy way to obtain sediment cores to determine the characteristics and bubble distribution of *in situ* sediments.
- Freezing caused a volume contraction of gas bubbles and can increase the amount of small bubbles, but the distribution of bubbles remained.
- Coring disturbances of the freeze corer can be identified and quantified more easily in comparision to gravity corer.
- Both, the gravity and freeze corer showed different types and quantities of coring disturbances, caused by:
  - Friction between the corer and the sediment,
  - Freezing Process / Expansion of water,
  - Loss of sediment due to liquefaction,
  - Expansion and movement of gas bubbles due to the reduction of hydrostatic pressure.
- Vertical displacement and mixing due to coring disturbances could affect PMP by changing the composition of sliced layers.
- Freeze coring does not inhibit CH4 and CO2 production in sediment.
- Freezing and thawing appear to influence CH4 and CO2 production, but the extent and direction of the effect remains unclear.
- Further research is needed regarding the influence of spatial heterogeneity, sediment composition, freezing duration and microbial community composition.

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References

Bastviken, D., Tranvik, L., Downing, J., Crill, P., Enrich-Prast, A. 2011. Freshwater Methane Emissions Offset the Continental Carbon Sink. Science. 331. 50

Matzner, E. and Borken, W. 2008. Do freeze-thaw events enhance C and N losses from soils of different ecosystems? A review. European Journal of Soil Science. 59. 274-284

Holst, J., Liu, C., Yao, Z., Brüggemann, N., Zheng, X., Giese, M. and Butterbach-Bahl K. 2008. Fluxes of nitrous oxide, methane and carbon dioxide during freezing-thawing cycles in an Inner Mongolian steppe. Plant Soil. 308. 105-117.

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