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UKOOA Phase II Task 3: Simulated bioturbation of drill cuttings – results from small scale laboratory experiments

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Preface

This report presents the results from a laboratory experiment addressing effects of bioturbation on drill cuttings material. The laboratory work has been carried out at RF/Akvamiljø's facilities in Stavanger.

The sub-task has been carried out as a RF project within UKOOA phase II task 3. In addition to the authors, valuable input in the planning phase was provided by Kjell Birger Øysæd (RF) and Annette Woodham (ERTSL).

THC analyses were carried out by SINTEF, according to the same procedures applied in the SINTEF mesocosm sub-task (Report SINTEF STF66A01139).

Stavanger, 14.01.02

Grethe Kjeilen, project manager

Contents

Executive summary

Bioturbation can influence many of the characteristics of sediments, including their stability, microbial activity and degradation rates of contaminants. This study addresses the effects of mechanical disturbance, resembling bioturbation, on hydrocarbon levels (indicative of degradation and leaching). Drill cuttings from Ekofisk 2/4A, Beryl A and reference sediment were exposed to mechanical disturbance of different rates. The aim of this disturbance was to mimic variable effects of bioturbation rates on cuttings. Redox profiles in the sediment and levels of THC in the surface sediment were the main investigated parameters.

Method used

A total of 9 chambers were filled with 3-4 cm of sediment/cuttings and placed under flow-trough seawater conditions. Each type of sediment was exposed to three levels of mechanical disturbance, no (none), some ("little") or much disturbance, at a depth of 1 cm into the cuttings/sediment.

In the chambers exposed to 'little' and 'much' mechanical bioturbation, a specially designed "rake" was placed approximately 1cm down into the sediment. In the chambers with 'little' disturbance the rake was turned 1/10 of a complete turn five days a week. It then took two weeks to complete one turn. In the chambers with 'much' disturbance the rake was turned twice five days a week. The frequency of stirring was selected to give relatively large differences between the treatments.

Redox measurements (duplicate for each chamber) were made regularly during the 90 day experiment. At the start and end of the experiment samples for analysis of THC content were taken.

Results and discussion

The most distinct differences observed were between the reference material and the two cuttings materials. While most of the redox (Eh) measurements in the reference sediment gave positive values, the cuttings had a more distinct gradient from surface to the bottom, changing from positive to negative. There was also a slightly larger drop in the Ekofisk sediment compared to the Beryl sediment. These differences might be caused by higher degradation rates combined with less water transport (diffusion) through the denser cuttings material, and a higher organic content than in the reference sediment.

It was not possible to see any clear differences of the Eh in the top cm of the sediment in the chambers in relation to the degree of sediment disturbance. Mechanical disturbance (i.e. bioturbation) apparently did not result in more oxygenated surface sediments. The experiment did not reveal any clear changes over time. The gradients in the samples developed rapidly within less than 14 days (12-25 June) and did not change significantly thereafter. The cuttings reached a stable gradient that was not altered by the rotation of the rake.

With regard to THC, on the other hand, there are clear indications that THC levels declined in chambers with stirring compared to the chambers without. The reduction seemed to be restricted to the top cm of the sediment. This depletion of THC might be due to higher degradation in the cutting caused by the mechanical stirring, or loss to the seawater flow, either as direct leaching or by THC being removed associated to particles. The cause of the depletion has not been examined further.

Conclusions

Loss of THC was observed with both Beryl and Ekofisk cuttings when exposed to mechanical disturbance. There were no clear differences in the rate of disturbance (i.a. “little” or “much”). Similar observations were made with redox-levels and gradients, and differences between the cuttings and the reference material were obvious.

List of symbols

RF	RF- Rogaland Research
SINTEF	SINTEF Applied chemistry and SINTEF
AEAT	AEA Technology Environment
ERTSL	ERT (Scotland) Ltd
CP	Cuttings pile
DNV	Det Norske Veritas
UKKOA	UK Offshore Operators Association
OBM	Oil based mud (i.a. well drilled using a OBM)
PBM	Pseudo oil based mud
WBM	Water based mud
THC	Total Hydrocarbon
RPD	Redox potential discontinuity layer

1 Introduction

The UKOOA Task 3 work is comprised of several sub-tasks performed by the project team; RF, SINTEF, ERTSL and AEAT. This report deals with the sub-task: Effects of bioturbation of cuttings, and were performed by RF.

One aim of task 3 was to investigate effects of bioturbation on cuttings pile stability and degradation processes. This study addresses the effects of mechanical disturbance, resembling bioturbation, on THC levels (indicative of degradation and leaching) and redox potential (oxidative status related to potential for biodegradation). *A priori* assumptions suggested that high bioturbation would result in well oxygenated sediments and the highest depletion of THC. Such results could be indicative that bioturbation could enhance degradation processes. Details of the Task 3 project outline is presented in the main report (RF-2001/220).

2 Material and methods

2.1 Experimental set-up

Drill cuttings from Ekofisk 2/4A (PBM/WBM), Beryl A (OBM) and reference sediment from the North Sea were exposed to different levels of mechanical disturbance. The mechanical disturbance was introduced by rotating a specially designed “rake” in the sediment. Three treatment levels were applied for each sediment type, namely no (none), some (‘little’) and much stirring of the sediment.

Table 1. Experimental set up.

Sediment / disturbance	None	Little	Much
Beryl 100%, cuttings	1	1	1
Ekofisk 100%, cuttings	1	1	1
Reference	1	1	1

2.1.1 Cuttings and reference material

All three samples (Reference, Beryl and Ekofisk) were collected during the 2000 survey as part of task 1 (Westerlund et al., 2001). The reference sediment was taken from a defined reference location in the North Sea. The Ekofisk 2/4 A and Beryl samples used in the set-up were sub-collected from two box-corer samples each (see Westerlund et al. 2001 for sample identification). The samples represent the top 30 cm of the piles. Prior to the experiment the sediments had been stored refrigerated and dark. The samples were homogenised before they were added to the test chambers. A rotor assembled on a drill was used, and seawater was added to make the mixing efficient (see Figure 1). Judging from visual observations, both cuttings types as sub-sampled from the boxcorers were highly variable with regards to i.e. content of oil, sand, and clay.

Figure 1. Homogenisation of Beryl cuttings (left) before transferring it to the test chambers (right).

2.1.2 Test system

A total of 9 chambers (30 cm in diameter) were placed in two large tanks, partly filled with seawater (see Figure 2). The chambers were filled with 3-4 cm of sediment and placed under flow-trough seawater (temperature ≈10 °C, salinity 34-35 PSU) after the sediment had settled for one day. The seawater was supplied from 70 m depth in the fjord outside RF research station in western Norway. The water flow was kept at a level sufficient to maintain high oxygen levels in the water phase. It was also assured that the water flow was not too high, to avoid disturbing or re-suspension the sediment.

Water was supplied trough a tube placed through a hole in the lid of the chamber. Excess water escaped through a gap between the lid and top of the chamber wall.

Figure 2. Chambers with and without sediments and covers placed in a large tank (12th June). The photo to the right show the rake used.

A mechanical bioturbator, a “rake”, was immersed 1 cm into the sediment. The rake was designed with twisted teeth to ensure that the whole surface of the sediment would be moved, without being stowed into the middle or along the edges. The rake was 29.5 cm long. In the chambers with “little” disturbance, the rake was twisted 1/10 of a turn five days a week. It took two weeks to complete one turn. In the chamber with more sever disturbance (“much”) the rake was turned twice, five days a week. The frequency of stirring was selected to give relatively large differences between the two treatments. The sediment/cuttings were supplied to the chambers and rakes were installed June 12th. During the first week the frequency and length of turning the rakes varied some. This week was used to adjust the depth of the rakes and to allow the surface of the sediments to smooth. The rakes were thereafter turned as planned until the end of the experiment.

2.1.3 Measurements, sampling and analysis

Normally, oxygenated surface seawater has a redox potential of about +400 mV. At anoxic conditions, this may be reduced to –200 mV or even lower.

Redox (duplicate) measurements were made using the microelectrodes; ORP-M1-80-401 (platinum) and REF-M1-402 (Ag|AgCl) (Microelectrodes Inc. USA) at the following depths: 0 mm (in the water just above surface), 2 mm, 5 mm, 7 mm, 10 mm, 15 mm, 20 mm and 30 mm. During measurents, the electrode was lowered into the sediment by lowering an adjustable device measuring the distance with a ruler (Figure 3). The pH electrode was calibrated each day before measurements. The redox electrode was checked against a standard solution. The half-cell potential on the electrode is 205 mV (pers. comm. Microelectrodes Inc) thus the Eh presented in this report are obtained by adding 205 mV to the instrument readings.

Redox measurements were performed the 25th of June (Day 13), 11th of July (Day 42) and at the end of experiment, 28th of August (Day 90). During measurements the chambers were placed on a table (Figure 3), the lid removed, and water down to 1-2 cm above sediment surface was carefully siphoned away. The electrode was then lowered down according to predetermined measuring depths.

In the chambers with no or severe disturbance the locations for redox measurement were chosen randomly, but in the chamber with little disturbance the measurements were performed in both the sector that had just been disturbed and the sector that had not been disturbed for the longest period (5 days or more).

The redox electrode took a long time to stabilise at the correct level after having measured high negative values (deepest into the sediment). This is sometimes reflected by the presented data in that measurements of the top section are low due to insufficient stabilising time (an hour could sometimes be needed). Normal oxygenated seawater had a redox around 250 mV and values below this on the surface should be regarded as a result of ‘impatience’ or practicalities. When the electrode was in contact with the sediment it stabilised much faster. Normally, the readings were fairly stable, and after 1-2 minutes the value were noted before measuring the next sediment level.

Figure 3. Chambers on table for redox measurements. The electrode was taped to a rod placed on a rack that could be moved up and down.

Photos were taken to document the experimental observations and for description of the sediments.

One sample for THC analysis was taken from each of the cuttings type after they were mixed (12th June), but before they were introduced to the chambers. At the end of the experiment the top cm were sampled from two different parts of the chambers, these two subsamples were mixed before analysis. At the Beryl A "Much" treatment, an additional sample was taken from the 1-2 cm layer. No samples were taken from the reference sediments.

Analysis of THC was carried out by SINTEF according to the method described by Brakstad and Ramstad (2001).

3 Results and discussion

3.1 General observations

The cuttings samples from the two piles had different characteristics. This was evident from visual observations directly, as the colour, smell and texture varied. The Beryl cuttings had a pale greyish colour and were 'pastier' than the darker Ekofisk material, which had an odour of 'oil'. The reference sediment had a greenish colour and was not pasty.

The reference sediment behaved differently from the cuttings samples. As normal with fine sand/sediment, the particles settled much more rapidly through the water column, and it also settled evenly in the chambers and formed a smooth surface. The cuttings samples had a more jelly-like structure after they were mixed with water and tended to keep its "bulky" appearance with time (Figures 5-6). After the rake had rotated some days it had created grooves in the cuttings, while the surface in the reference sediment smoothened back after the rake was turned (Figure 4).

Even though the sediment colour got darker below the surface, smell of hydrogensulfide or appearance of black sediment, indicative of anoxic conditions, were not observed.

Figure 4. Photographs of Beryl (left) and reference sediment (25 June). Both with treatment "Much". Photo colour slightly manipulated and flash reflex masked. Se grooves in Beryl surface and more smooth surface on reference sediment.

Figure 5. Photos of Ekofisk cuttings ("Little") from top (flash reflex masked) and side of chamber (25 June). Both photos indicate a brighter surface (3-5 mm thick, see arrow) with darker (lower Eh) sediment below. The rake had recently been turned 1/10 and removed (se marks on surface).

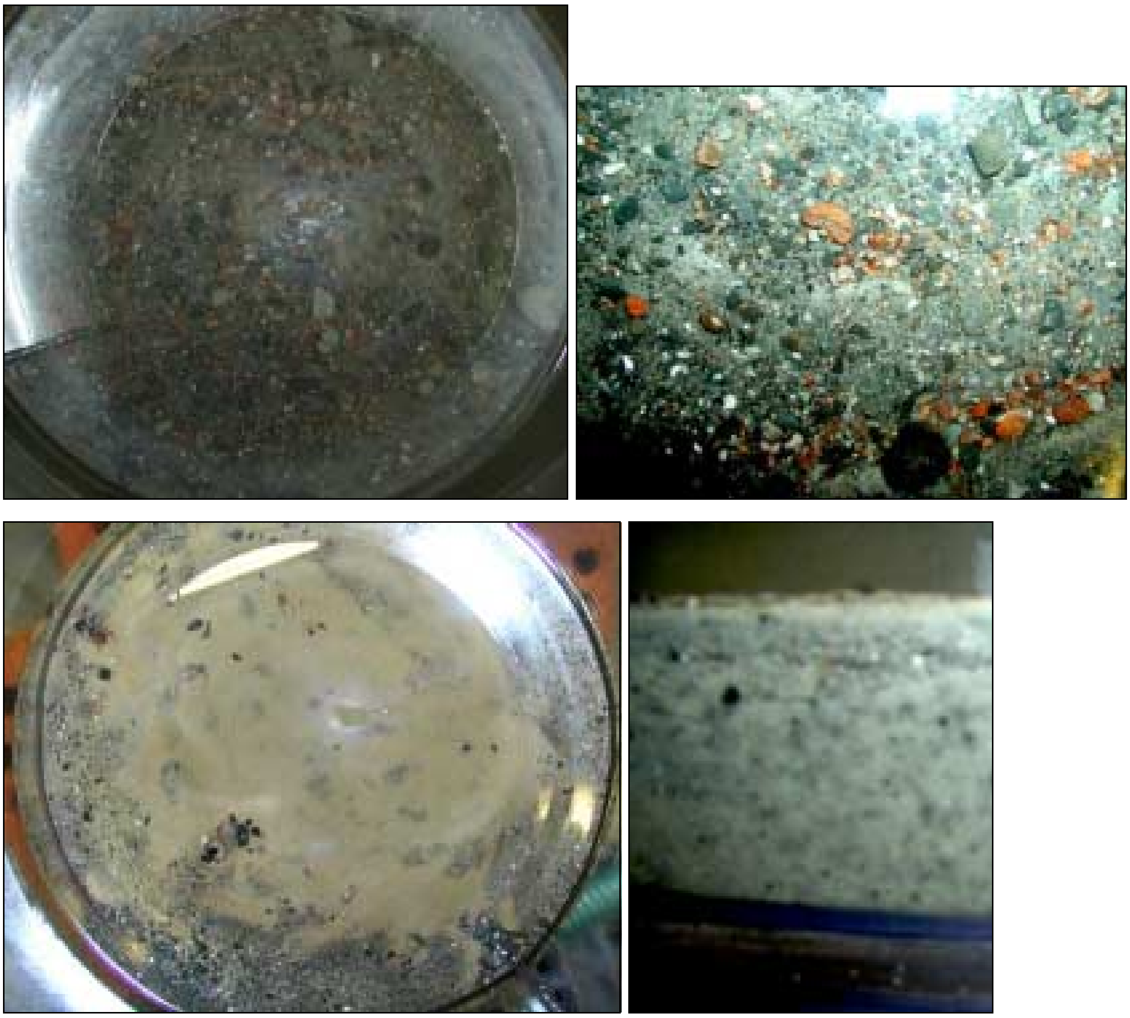

Figure 6. Top: Photographs of Beryl cuttings ("Much disturbance") viewed from top of chamber at the end of the experiment 28th August (flash reflex masked) and close-up (upper right, colour and contrast modified). Below: Beryl cuttings ("No disturbance") viewed from top of chamber (flash reflex masked) and from side (28 August). Note the difference in top layer, with more coarse particles on top in the 'much' treatment, and smaller particles in the top layer of the 'none' chamber (no disturbance). Side view (below, right) indicates darker spots in the sediment.

3.2 Redox measurements

Some aspects of Eh measurements were discussed in Chapter 2.1.3. The results are presented in Figures 7-9 and the numbers are also included in Appendix 1. The shift in the redox gradients, more than the exact numbers measured, describes the impacts of disturbance best. The most distinct differences seen were between the reference material and the cuttings. While most of the readings in the reference sediment were positive and did not change significantly with depth (although the lowest values were measured at 30 mm), the cuttings sediments developed a much clearer gradient from surface to the bottom (Figures 7-9). This was possibly a result of more restricted water transportation (diffusion) through the 'denser' cuttings material, and also higher organic content than in the reference sediment. Metabolism of organic material normally consumes oxygen. This fact may partly explain the lower oxygen depletion (judging from higher redox levels) in the reference material which had a low organic load. Also, Ekofisk cuttings tend to have slightly lower Eh values than Beryl. This corresponds to the fact that the organic content of Beryl is lower than in Ekofisk (Westerlund et al., 2001), but other reasons for the difference is possible.

No clear RPD (Redox Potential Discontinuity layer) developed in the reference sediment. However, at the end of the test period the Eh tended to drop below 15 mm.

It is possible that the experiment duration (90 days) was insufficient for the low organic content reference sediment to develop a stable redox gradient. It is also possible that the particle fractions of the reference material were course enough to ensure sufficient oxygen transport to prevent a RDP layer from developing in the top 3 cm. In the sub-task focusing on recolonisation (RF 2001/218) a steeper redox gradient developed between 2 and 10-15 mm in the same reference sediment. These differences indicate that the (experimental) conditions have a major influence on the development of RPD layers. In natural sediments the vertical distribution of RPD layers will also change with sediment composition and oxygen supply. As examples, Schanning et al. (1997) measured a gradual decrease in redox between 4-8 cm in the Oslofjord, and a much more distinct gradient around 2 cm in the Porsangerfjord.

Measurements of oxygen and sulfide levels around Beryl A in October 1999 (Shimmield et al. 2000) indicated that oxygen was depleted a few (2-4) mm below surface and sulfide was detected 10 to 15 mm below surface. The measurements were made *in situ* at 65, 165 and 300 m from the apex of the cuttings pile. The RPD layer was closest to surface at the station nearest to the platform and no vertical mixing were suggested in this sediment. Compared to those results, our experimental cuttings/sediments never developed such low oxygen content or sulphide production. The time factor may be the explanation.

Effect of disturbance

It was not possible to see any clear effect in the top cm in the chambers with the same cuttings type, but different levels of disturbance. The assumption that the mechanical disturbance (i.e. bioturbation) would result in more oxygenated surface sediments was apparently incorrect. In fact, the Eh levels measured in the disturbed chambers were sometimes lower than in the undisturbed chambers, or remained at the same level. A possible explanation for this is that the stirring probably causes more microbial activity (increased metabolic processes) in the sediment and thereby higher oxygen consumption and the experiment periode was not long enough to create the expected differences.

Difference between duplicate readings

There are several factors that influence the redox readings. Firstly the accuracy of the readings themselves may be in the order of 25-40 mV. Additionally, the cuttings in the chambers clearly had a heterogeneous composition, as has also been observed in the other task 3 sub-tasks (of which the reolonisation experiment (RF-2001/218) is most comparable). This can explain the rather large differences between readings in the two parallels. Another indication of that is seen in the lower variability in the reference sediment measurements compared to the cuttings. Schanning (1994) calculated a standard deviation of 33 mV in his degradation experiment. This is likely in agreement with the readings in our experiment. In the “Little” disturbance it was not possible to see any pattern in the difference between the two positions measured, one being recently disturbed while the other was left undisturbed for 5 days. Assuming that the recently stirred sediment would be more oxic than the part that had not been disturbed for 5 days was not confirmed in the measurements.

Changes with time

The experiment did not reveal any obvious changes with time. The gradients in the samples developed rapidly within less than 14 days (from 12 to 25 June) and thereafter changed little or randomly. The cuttings seemed to reach a stable gradient that was not altered by the rotation of the rake. Only in the reference sediment with no disturbance were there indications of reduced redox from the first to the last measurement. Similar observations were made in the related task 3 sub-task on colonisation and macrofaunal activity (Report RF 2001/218).

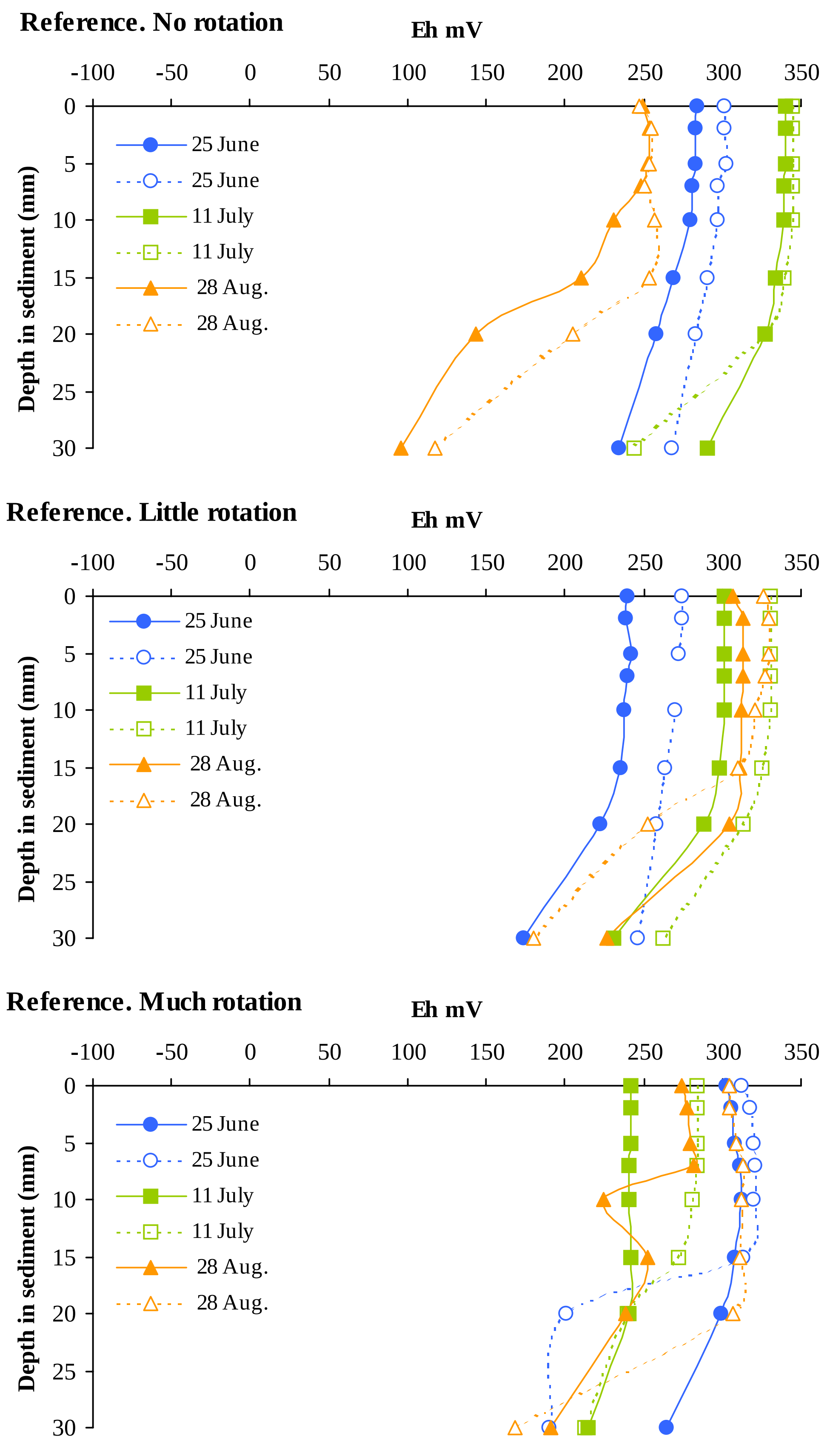

Figure 7. Redox measurements (duplicate) in reference sediment at three dates with three levels of mechanical bioturbation (disturbance). Note: lines between data points are smoothened and do not represent measurements.

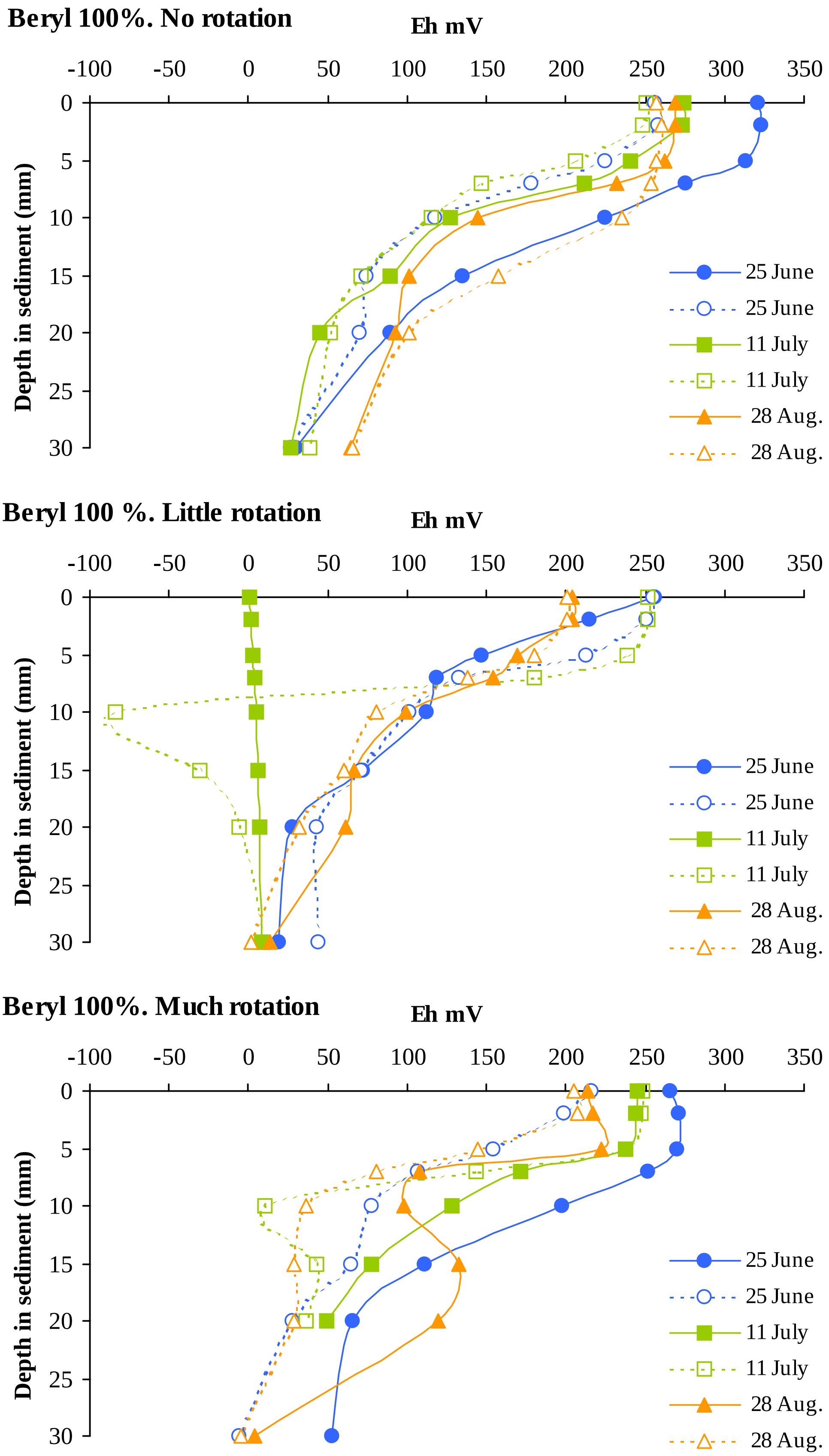

Figure 8. Redox measurements (duplicate) in Beryl cuttings at three dates with three levels of mechanical bioturbation (disturbance). Note: lines between data points are smoothened and do not represent measurements.

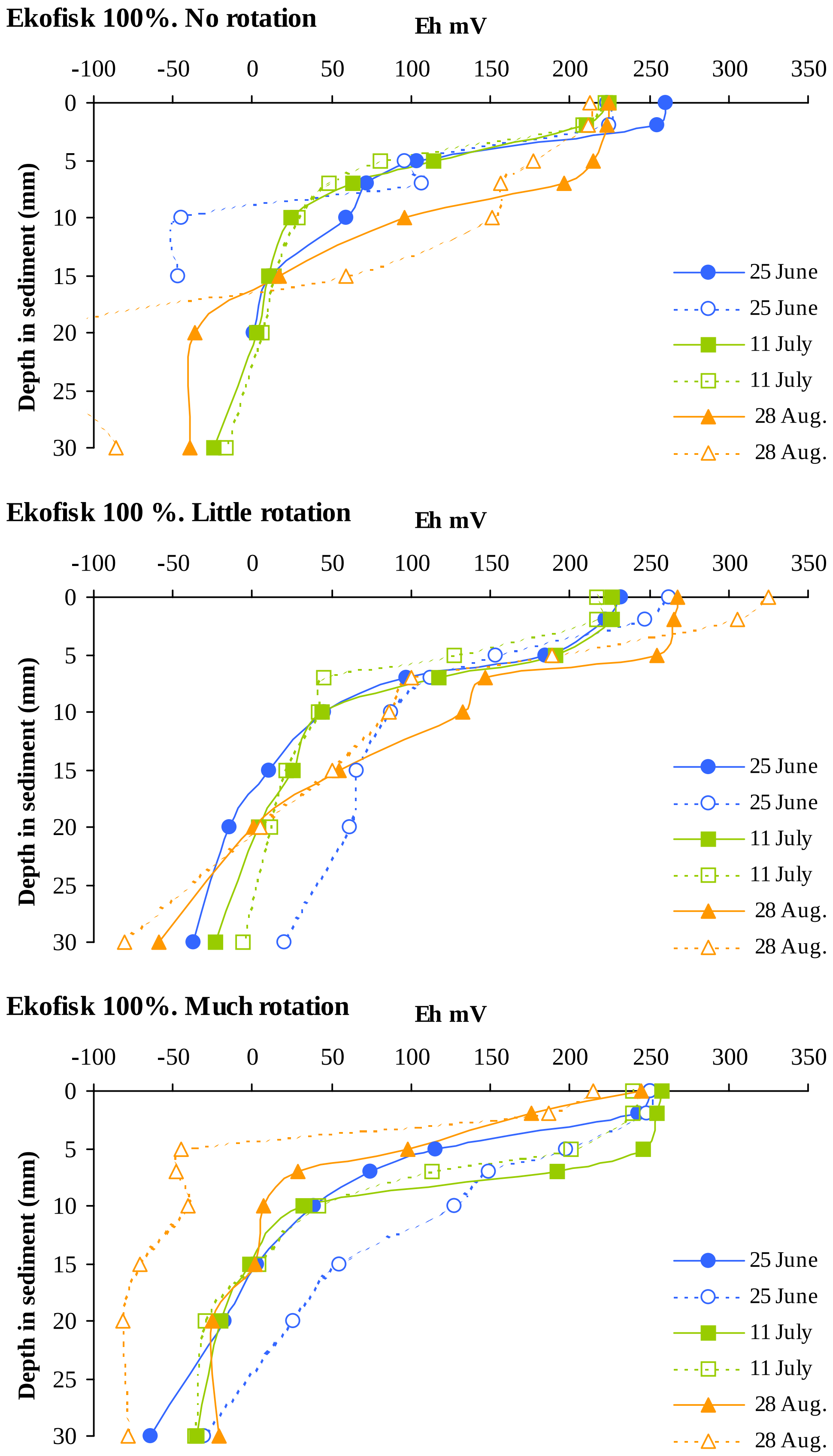

Figure 9. Redox measurements (duplicate) in Ekofisk cuttings at three dates with three levels of mechanical bioturbation (disturbance). Note: lines between data points are smoothened and do not represent measurements.

3.3 THC levels

The THC levels measured are presented in Figure 10. The results are presented in more detail in Appendix 2. From other task 3 sub-tasks, it is apparent that relatively large variations are seen in THC measurements of the same cuttings samples (see data in RF-report 2001/217 and further discussion in RF 2001/220). Based on these observations, it was expected to observe a similar high variation also in this study. It was therefore decided to not put much emphasise on THC measurements, as the anticipated variability could possibly mask any real effect that bioturbation were likely to have on THC levels in cuttings.

The results presented in Figure 10 indicate that there has been an effect of the turbation. Less THC is found in chambers with ‘little’ and ‘much’ rake rotation than in chambers with no disturbance both for Ekofisk and Beryl. The THC analyses from the Beryl “much” treatment, sampled from two layers, indicate that the reduction is mainly restricted to the top cm, in which the cuttings were disturbed.

The indicated loss of THC may be due to depletion/leaching from the sediment, losses as THC on particles led away with the seawater, or by increased biodegradation of THC indirectly caused by the mechanical stirring as oxygen rich seawater and nutrients have been mixed into the sediment.

The THC level measured in the Beryl cuttings sampled at T0 apparently is not representative for the cutting samples introduced to the chambers. No apparent explanation for this can be given. There is no indication that the analytical protocols have not been followed. It must therefore be assumed that the sub-sample analysed has not been representative (see also discussions in other task 3 sub-tasks).

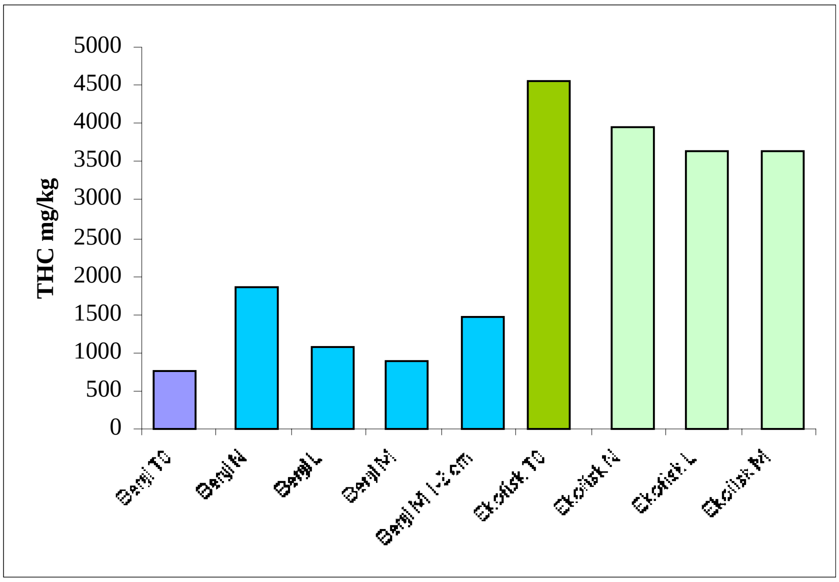

Figure 10. THC levels in the Beryl and Ekofisk cuttings at the start 12th June (T0) and at the end of experiment in August. Three treatments: No, Little and Much disturbance. See text for comments on Beryl T0 THC levels.

4 Conclusions

The most distinct differences seen were between the reference material and the cuttings. While most of the Eh measurements in the reference sediment were positive, the cuttings had a more distinct gradient from surface to the bottom, changing from positive to negative. There is also a slightly larger drop in the Ekofisk sediment compared to the Beryl sediment. These differences might be caused by higher degradation rates combined with less water transport (diffusion) through the denser cuttings material and a higher organic content than in the reference sediment.

It's not possible to see any clear difference of the Eh in the top cm of the sediment in the chambers in relation to the degree of sediment disturbance. Mechanical disturbance (i.e. bioturbation) does not result in better oxygenated surface sediment. The experiment did not reveal any clear changes over time. The gradients in the samples developed rapidly within less than 14 days (12-25 June) and did not change significantly thereafter. The sediments reached a stable gradient that was not altered by the rotation of the rake.

With regard to THC, on the other hand, there are clear indications that THC levels declined in chambers with stirring compared to the chambers without. The reduction seems to be restricted to the top cm of the sediment. This depletion of THC might be due to a higher degradation in the cuttings, caused by the mechanical stirring, or due to loss to the seawater flow, either as direct leaching or by the THC being removed associated to particles.

5 References

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Appendix

Appendix 1. Figures from Eh measurements

Appendix 2. Figures from THC analysis