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Title

Preservation conditions at new dipwells installed in 2011-12 near the harbour front (MB36, MB37), Bredsgården (MB41, MB42), Enhjørningsgården (FJB3), and at Rosenkrantzgate (MB43) and Lodin Lepps gate (MB44) at Bryggen, Bergen

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Summary

Seven new dipwells were installed in December 2011 (MB36, MB37, MB41, MB42), January (FJB3) and April 2012 (MB43, MB44) to acquire further information about the spatial variability of the preservation conditions of the cultural deposits beneath Bryggen in Bergen. The monitoring was extended both within and outside the central area of Bryggen with the historical buildings from 1702 including an eighth dipwell where no cultural deposits were found (MB40).

Soil samples from the installation of the dipwells and water samples taken one to three months later were analysed by Eurofins. Oxygen consumption of selected soil samples was measured at the National Museum as an indicator for the susceptibility to decay. The results are presented and commented on in this report with special emphasis on the different factors (seawater intrusion/sulphate reduction, groundwater level variation, rainfall or drainage) controlling preservation conditions around the dipwells.

The results for the harbour front have shown that the cultural material found at dipwells MB36 and 37 has a poor to medium state of preservation. The dipwell filters are positioned at the border between the upper modern and very porous deposits and the slightly more compact and organic post-medieval and medieval deposits underneath. Chemical composition of the groundwater shows strong seawater impact with high salinity, alkalinity (due to intensified sulphate reduction) and a higher K and Mg content. On the other hand, high sulphate depletion and the presence of methane indicate that conditions probably are stable for at least some weeks, although very dynamic tidal variation of the groundwater level was observed at MB36 and a strong rainwater impact at MB37. It should be verified if the extreme dynamics at MB37, which contradict the chemical signal in the groundwater, are an installation artefact or not, e.g. by adding a tracer. The temporal effect of these dynamics on water exchange and the supply of oxidants (SO_4, NO_3) cannot be quantified from a single sampling and should be monitored further. A first estimate of the preservation conditions is lousy (PresCon 1) from -1.2 to -1.8 m asl and poor (PresCon 2) down to the drilling depth at -2.8 m asl for MB36 where the S-pool is dominated by pyrite-S indicating that sulphate reduction has taken place to a large extent. For MB37 lousy conditions (PresCon 1) are estimated down to -0.9 m asl, turning to medium (PresCon 3) beneath where sulphate supply may be limited due to more compact layering of the organic-rich material.

The installation of new dipwells in the area east of the SAS hotel has extended the knowledge of preservation conditions in cultural deposits at and above sea level (MB41, 42 at Bredsgården) as well as refined the picture of deep deposits in central Bryggen (FJB3 at Enjørningsgården). At MB41, preservation state (SoPS) and conditions (PresCon) in the deposits located above the minimum water table (ca. 0.5 to 1 m asl) are considered poor (2). A cover of 1 to 1.35 m of stones and sand and gravel-containing layers allows for easy percolation of rainwater down to the cultural deposits. This is clearly documented by the presence of NO_3 in the groundwater of MB41which is located very close to the area affected by both drainage and increased flow of rainwater north-east of the hotel. There is some potential for further degradation in depths above the groundwater minimum where LOI is moderate and reactivity high (ca. 30% LOI and 0.16 to 0.18 mg O_2/g dw/d). But the degree will depend on the exposure time to oxygen and the O_2 availability which might be limited by diffusion and fast consumption in the more compact deposits. Beneath 0.5 m asl preservation state and conditions improve to medium (3). Sulphide and methane in the groundwater indicate the transition to a more reduced and stagnant environment. LOI is 40-50% and higher in depths below sea level and reactivity increases to rates > 0.2 mg O_2/g dw/d. At MB42 a compact fine grained layer at 0.8 – 0.45 m asl with high N content and reactivity (0.37 mg O_2/g dw/d) may protect the underlying deposits against downward transport of oxidants. Reactivity seems to correlate with LOI and also depends on the composition of the organic matter. At FJB3, preservation state changes to good and excellent in depths beneath -2.4 m asl. Here, risk of further degradation is low as most of the cultural deposits are relatively compact and found below sea level and it is unlikely that oxygen is available at all. Accordingly, preservation conditions are estimated as good to excellent (PresCon 4-5) although groundwater chemistry of this deep dipwell could not be included in the evaluation of preservation conditions at FJB3.

The two dipwells in the easternmost part of the area, MB43 and MB44, are characterized by a several metres thick cover of porous modern deposits without archaeological interest. At MB43 cultural deposits from 1.9 to 0 m asl are sandy with a low organic content and almost unreactive (0.016 mg O_2/g dw/d). Even if the conditions have to be regarded as lousy (PresCon 1) the risk of further decay is negligible. Below sea level deposits are more organic and reactivity increases rapidly. Good preservation state (SoPS 4) is observed already at -0.3 m asl but reactivity is comparatively low (0.090 mg O_2/g dw/d). It cannot be evaluated if sulphate reduction constitutes a threat because local dynamics are unknown and SO_4 was only present in minor amounts at the time of sampling. From the reduced groundwater chemistry a first estimate of preservation conditions below sea level is medium to good, but the presence of oxygen measured 12 days after sampling indicates a more variable environment and poor preservation conditions (PresCon 2) down to -0.4 m asl. This should be clarified by further measurements and water sampling. From -0.4 to the end of drilling at -1.5 m asl high LOI (28 – 56%) and reactivity (0.18 – 0.33 mg O_2/g dw/d) indicate medium to good preservation conditions (PresCon 3 – 4).

At MB44 the top of the natural sediment (moraine) was reached at 0.2 m asl. All cultural deposits are found above sea level, the filter of the dipwell is positioned at the groundwater table and water chemistry is only weakly reduced. High SO_4 concentrations in groundwater and soil indicate that other processes in the unsaturated zone are a significant source of SO_4. Above groundwater level preservation state was described as indefinable or poor and preservation conditions have to be regarded as lousy (PresCon 1) down to 1.65 m asl. Beneath 1.65 m asl organic content increases to up to 55% LOI and a reactivity of 0.1 to 0.15 mg O_2/g dw/d is found suggesting a high potential for further degradation. A compact gyttja-like soil layer might protect the underlying deposits from rainwater impact and fast decay. Although the loose and semi-compact organic deposits at and below groundwater level are still in good state of preservation (SoPS 4), groundwater chemistry and the only moderate reactivity of 0.1 mg O_2/g dw/d suggests that also these layers beneath 1.25 m asl are at least temporarily threatened by a supply of oxidants from the unsaturated zone. Therefore preservation conditions are estimated as poor to medium (PresCon 2 in the fluctuating zone and 3 below groundwater level).

All these observations show that besides seawater intrusion, infiltration of rainwater, and drainage, soil properties are an important factor controlling the decay of cultural deposits as they affect transport and accessibility of oxidants. Preservation conditions can therefore also be lousy in depths below sea level or even medium to good in the zone of fluctuating groundwater level or the unsaturated zone. In particular, compact fine grained organic-rich layers can act as a trap or barrier for oxidizing agents.

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1. Introduction

The conditions in the archaeological urban deposits underneath the World Heritage Site Bryggen in Bergen have been thoroughly monitored since 2002 by soil and groundwater analysis of an increasing number of dipwells (more than 40) in order to document the state of preservation and the impact of local drainage on decay rates of organic matter. These investigations are supplemented by in situ oxygen, temperature and water content measurements in the unsaturated zone in a test pit at Nordre Bredsgården installed in 2006 and continuous monitoring of temperature and water level/pressure in most of the dipwells. Within the last year, redox sensors have been installed in a depth profile near the test pit and near the sheet piling to follow the effects of mitigation measures. So far results have documented varying preservation conditions depending on the supply of oxidants such as oxygen, nitrate and sulphate to the organic deposits. They range from lousy (PresCon 1) in the drained area with high decay and settling rates to excellent (PresCon 5) in the deeper, anoxic deposits in the central part of Bryggen, where conditions are stagnant and decay rates slow. Details about the latest evaluation of preservation conditions and potential decay rates can be found in some of the latest reports (Matthiesen 2012, Matthiesen and Hollesen 2012, Walpersdorf 2012). Previous monitoring concentrated mostly on the central area of Bryggen and the waterlogged deposits underneath. In December 2011 and January and April 2012 seven new dipwells have been installed aiming to extend the existing network of dipwells, gain further insight into the distribution of cultural deposits beyond the central part of Bryggen and to refine the current image of prevailing preservation conditions including deposits of the unsaturated zone. An eighth dipwell has been installed at Bryggens Museum where no cultural deposits were found.

The National Museum of Denmark has been contracted by Riksantikvaren to evaluate possible threats to the cultural layers at these dipwells.

2. Site and methods

The positions of the new and existing dipwells at Bryggen are shown in Figure 1.

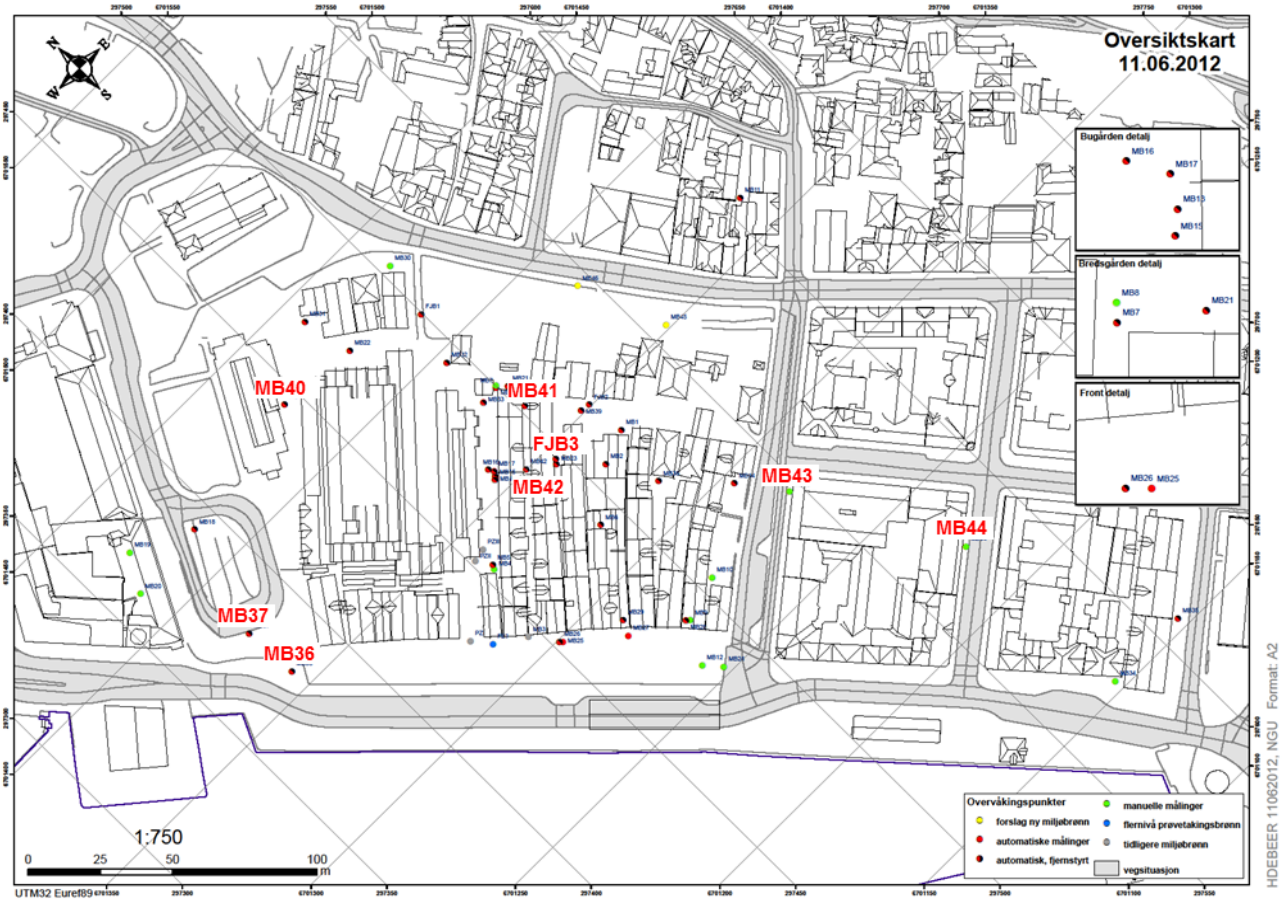


Figure 1: Map of Bryggen, showing the position of MB36 and MB37 at the north-western harbour front, of MB41 and MB42 at Bredsgården, FJB3 at Enhjørningsgården and MB43 at Rosenkrantzgate and MB44 at Lodin Lepps gate and other earlier installed dipwells. Dipwell MB40 inside the sheet piling of the museum where no cultural deposits are found is included for comparison of the groundwater chemistry. Graphics: Hans de Beer, NGU.

Drilling work and installation of the dipwells was done in December 2011 (MB36, MB37, MB40, MB41, MB42), January (FJB3) and April 2012 (MB43, MB44) by Multiconsult and archaeologist Rory Dunlop from the Norwegian Institute for Cultural Heritage Research (NIKU). The soil stratigraphy is described in reports by Dunlop (2011/12), except for MB40 where no cultural deposits were found (Appendix 3). Three soil samples from MB36, MB37, MB41, MB42 and MB44, and four soil samples of MB43 and FJB3 were analysed at Eurofins for pH, dry matter content (i.e. the weight of the dried sample relative to the weight of the wet sample), loss on ignition (i.e. the weight loss when the dried sample is burned), water-soluble chloride and water-soluble sulphate, total phosphor, total nitrogen and total sulphur. Ten samples were collected at the deep drilling at FJB3, and the remaining 6 samples were only analysed for pH, dry matter, LOI, water-soluble chloride and sulphate. Additionally, potassium was determined in the soil from MB43 and MB44 and in four samples at FJB3. One sample from MB36, MB37, MB43, MB44 and FJB3 was also analysed for pyrite. The laboratory reports are attached in Appendix 1. The position of the dipwells along with the level of their water intake is given in Table 1.

Dipwell	E-COORD	N-COORD	Soil surface (m asl)	Top of dipwell (m asl)	Water intake – top (m asl)	Water intake – bottom (m asl)
MB36	297379.50	6701357.48	1.20	1.18	-1.80	-2.80
MB37	297378.40	6701377.25	1.45	1.37	-1.40	-2.40
MB40	297441.37	6701423.49	4.00	3.87	0	-2.00
MB41	297502.08	6701366.05	3.50	3.39	1.50	0.50
MB42	297486.80	6701350.10	2.15	2.03	0.60	-0.40
MB43	297553.77	6701281.97	7.10	6.98	0.05	-0.95
MB44	297586.08	6701231.65	6.85	6.70	1.25	0.25
FJB3	297495.84	6701344.54	2.00	2.01	-8.00	-9.00

Table 1: Position and depth of water intake of the new dipwells (data from Multiconsult/NGU/NIKU).

Water sampling from the dipwells by Multiconsult was done at MB36, MB37 and FJB3 on 13th March, at MB40 on 29th, at MB41, MB42, and MB43 on 30th and at MB44 on 31st May 2012. The dipwells were emptied on the day before the actual sampling to ensure that fresh water from the cultural layers was sampled. The samples were filtered in the field (0.45 µm Gelman high capacity in-line filter) and preserved if required, then sent to the laboratory (Eurofins). Oxygen, conductivity and pH were measured in water from the dipwell sampled into a small beaker. This method gives a high risk of oxygen pollution; therefore values below 0.05 mmol O_2/L have been disregarded. Standard laboratory analysis of the groundwater comprised the following parameters: pH, conductivity, alkalinity, salt (sodium, chloride), nutrients (ammonium, nitrate, and phosphate), redox active species (sulphate, nitrate, dissolved iron, dissolved manganese, sulphide, and methane), and other major ions (calcium, magnesium, potassium). This spectrum of pore water components gives a good description of the chemical conditions in the groundwater. The reports from the laboratory are shown in Appendix 2.

In order to study the potential for further microbial decay and settling of the organic cultural deposits oxygen consumption of the collected soil samples was measured in the laboratory at the National Museum. Oxygen is the most powerful oxidant of organic matter and the consumption rate is a good indicator for the reactivity of the different materials. Measurements were made on three replicates at in-situ water content and 15°C in a climate chamber as described in Hollesen and Matthiesen (2012). Approximately 1 g sample was transferred to 4.0 ml vials and flushed with atmospheric air before the vials were closed with airtight lids. The oxygen consumption was subsequently determined by measuring the decrease of headspace O_2 concentrations over 20 days by using oxygen optodes (SensorDish Reader from PreSens, www.presens.de). After the measurements were stopped, dry weight was determined by drying the soil samples at 105 ^{o}C. Oxygen consumption rate was calculated as follows:

$$\textit{Oxygen consumption rate (mg/g /d)} = V_{air} \cdot C \cdot (\Delta O_2 / \Delta t) / m \cdot 100 \qquad (1)$$

where V_{air} is the volume of air inside the vial (cm^3), C is the initial concentration of oxygen (mg/cm^3), $\Delta O_2/\Delta t$ is the decrease in oxygen saturation over time (% sat/day – taken from the slope of the curves over 100 to 70% decrease), *m* is the dry weight of the soil sample (g) and 100 (%) is a scale factor. Only the linear gradient from 100 to 70% air saturation was used because with progressing time decreasing oxygen concentration, a build-up of gasses and accumulation of dissolved species in the closed vial might artificially alter microbial reaction rates as reflected in a transition to non-linear oxygen decrease. Reaction rates from laboratory studies need to be combined with oxygen measurements in the field. Duration and degree of exposure to oxygen varies considerably above groundwater level where the soil is not permanently saturated (Matthiesen and Hollesen 2012) but oxygen is absent in permanently saturated layers with a high water holding capacity and in particular in depths below sea level. In this report the oxygen consumption rates are only used as a general indication of the reactivity and vulnerability of the soil.

3. Results

Results will be presented separately for the harbour front (MB36 and MB37, including the groundwater chemistry of MB40 for comparison), the area east of the SAS hotel between sheet piling and the central part of Bryggen (MB41, MB42, FJB3), and an area further to the east separated from central Bryggen by an elevation in terrain (MB43, MB44). The conditions at the new dipwells will be compared to earlier soil and groundwater analyses at other dipwells in the respective areas.

Soil analysis results from Eurofins, preservation category of the different soil strata (SoPS as defined by Dunlop) and oxygen consumption rates are presented graphically in Figure 2.

Results from groundwater analysis are presented in Figure 3. Dissolved species are given as “mmol/L” to allow an easy evaluation of the ion balance in the water and a good overview of their quantitative importance.

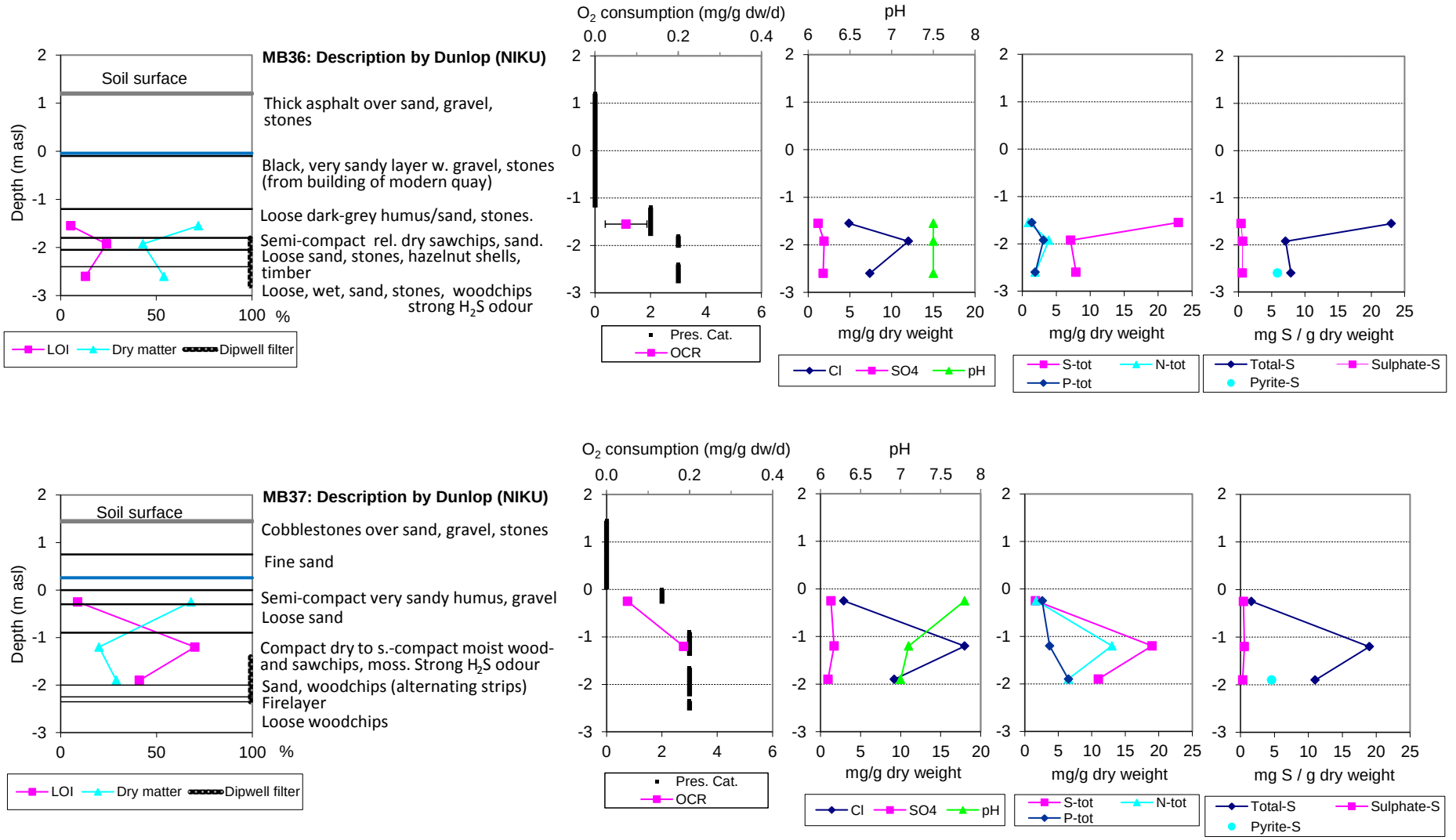
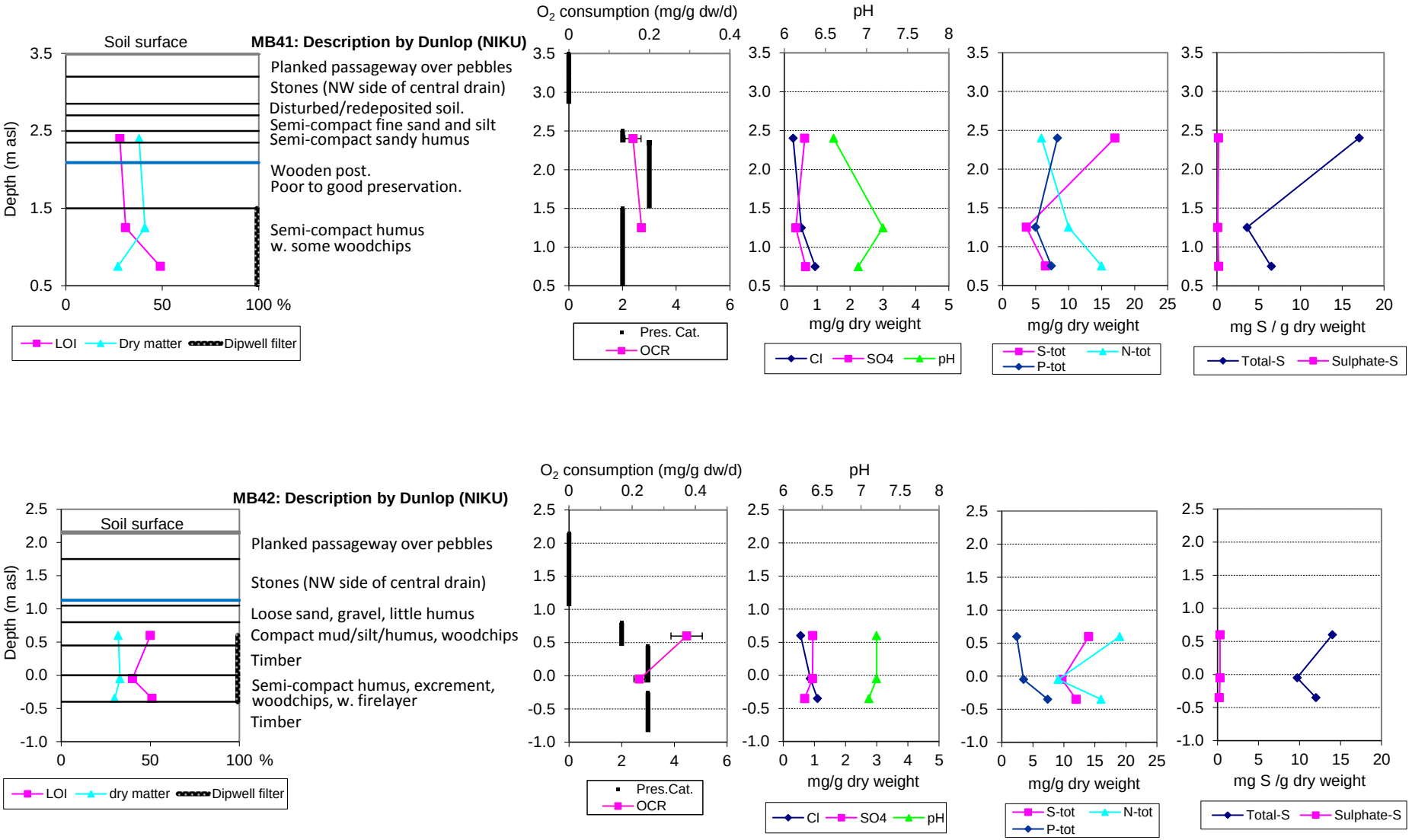


Figure 2a: Description and soil analyses of drillings MB36 and MB37. The blue horizontal line marks the groundwater level measured on 13/3/2012. Pres.Cat is the preservation category evaluated by Dunlop on a scale from 1 (lousy) to 5 (excellent), 0 indicates that no sample was taken. The reactivity of the soil samples was measured as oxygen consumption rate (OCR) at 15 ℃ and in situ water content. Rates are given relative to the dry weight, error bars are 1 standard deviation of 3 replicates. LOI is the loss on ignition; Cl and SO_4 is water extractable chloride and sulphate. S-tot, N-tot, P-tot is total amount of sulphur, nitrogen, and phosphor. Pyrite-S is calculated from pyrite-Fe, which is measured as iron extracted in boiling HNO_3 (after removal of non-pyritic iron). Sulphate-S is the water soluble fraction (calculated from SO_4).


MB41: Description by Dunlop (NIKU)
Soil surface
Planked passageway over pebbles
Stones (NW side of central drain)
Disturbed/redeposited soil.
Semi-compact fine sand and silt
Semi-compact sandy humus
Wooden post.
Poor to good preservation.
Semi-compact humus
w. some woodchips
Depth (m asl)
LOI
Dry matter
Dipwell filter
O2 consumption (mg/g dw/d)
Pres. Cat.
OCR
pH
Cl
SO4
mg/g dry weight
S-tot
N-tot
P-tot
Total-S
Sulphate-S
mg S / g dry weight
MB42: Description by Dunlop (NIKU)
Soil surface
Planked passageway over pebbles
Stones (NW side of central drain)
Loose sand, gravel, little humus
Compact mud/silt/humus, woodchips
Timber
Semi-compact humus, excrement,
woodchips, w. firelayer
Timber
Depth (m asl)
LOI
dry matter
Dipwell filter
O2 consumption (mg/g dw/d)
Pres.Cat.
OCR
pH
Cl
SO4
mg/g dry weight
S-tot
N-tot
P-tot
Total-S
Sulphate-S
mg S /g dry weight

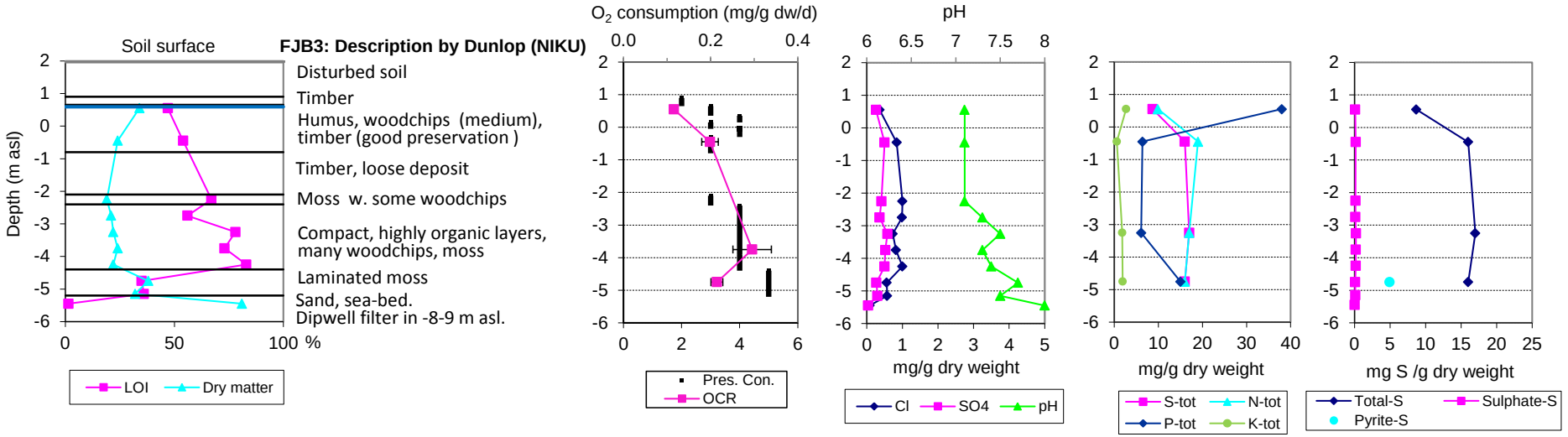


Figure 2b: Description and soil analyses of drillings MB41, MB42 and FJB3. The blue horizontal line marks the groundwater level measured on 28/3 (MB41, 42) and 13/3/2012 (FJB3). Pres.Cat is the preservation category evaluated by Dunlop on a scale from 1 (lousy) to 5 (excellent); 0 indicates that no sample was taken. The reactivity of the soil samples was measured as oxygen consumption rate (OCR) at 15 ℃ and in situ water content. Rates are given relative to the dry weight, error bars are 1 standard deviation of 3 replicates. LOI is the loss on ignition; Cl and SO_4 is water extractable chloride and sulphate. S-tot, N-tot, P-tot and K-tot is total amount of sulphur, nitrogen, phosphor and potassium after total digestion of the sample. Pyrite-S is calculated from pyrite-Fe, which is measured as iron extracted in boiling HNO_3 (after removal of non-pyritic iron). Sulphate-S is the water soluble fraction (calculated from SO_4).

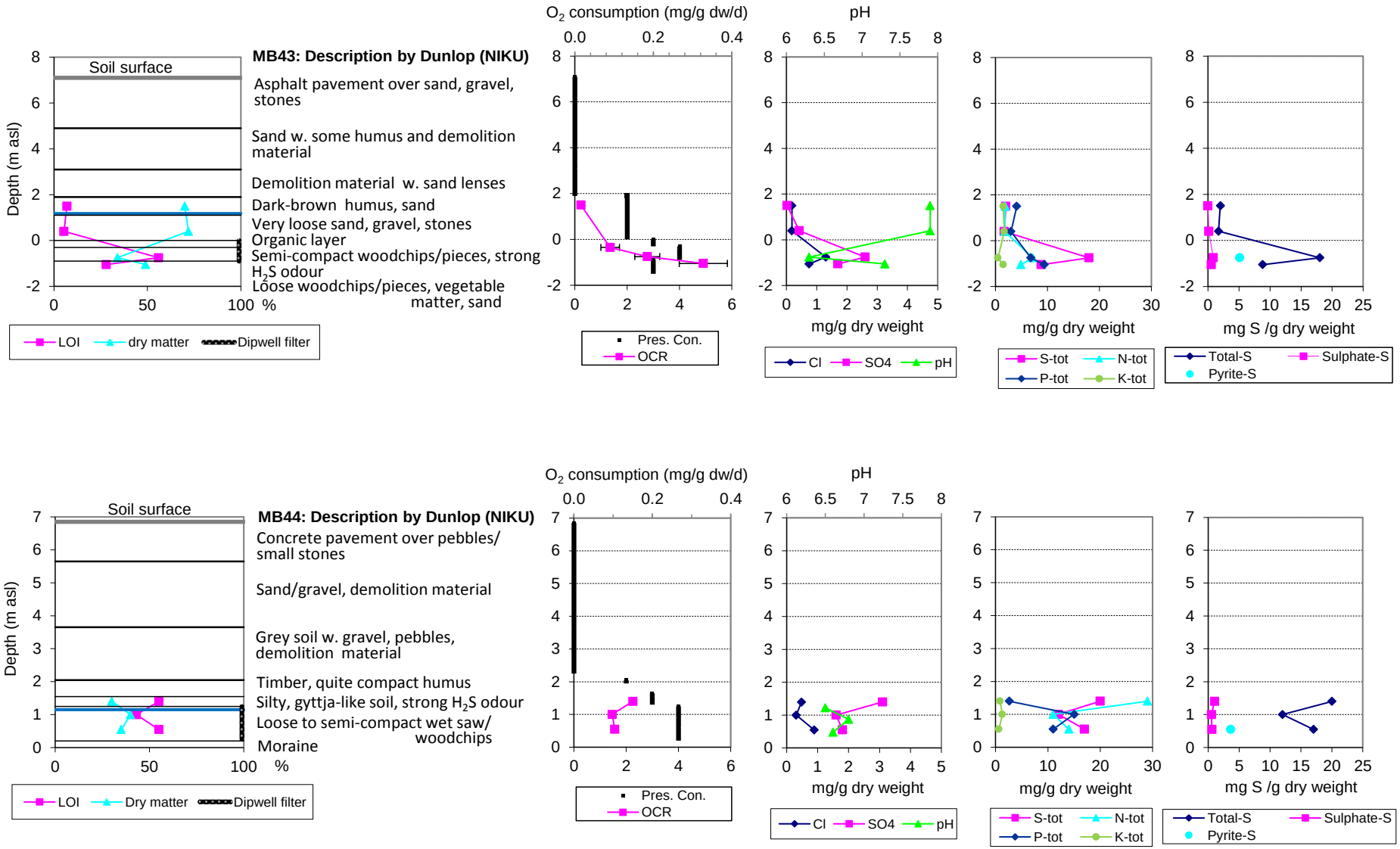


Figure 2c: Description and soil analyses of drillings MB43 and MB44. The blue horizontal line marks the groundwater level measured on 11/6/2012. Pres.Cat is the preservation category evaluated by Dunlop on a scale from 1 (lousy) to 5 (excellent); 0 indicates that no sample was taken. The reactivity of the soil samples was measured as oxygen consumption rates (OCR) at 15 ℃ and in situ water content. Rates are given relative to the dry weight, error bars are 1 standard deviation of 3 replicates. LOI is the loss on ignition; Cl and SO_4 is water extractable chloride and sulphate. S-tot, N-tot, P-tot and K-tot is total amount of sulphur, nitrogen, phosphor and potassium after total digestion of the sample. Pyrite-S is calculated from pyrite-Fe, which is measured as iron extracted in boiling HNO_3 (after removal of non-pyritic iron). Sulphate-S is the water soluble fraction (calculated from SO_4).

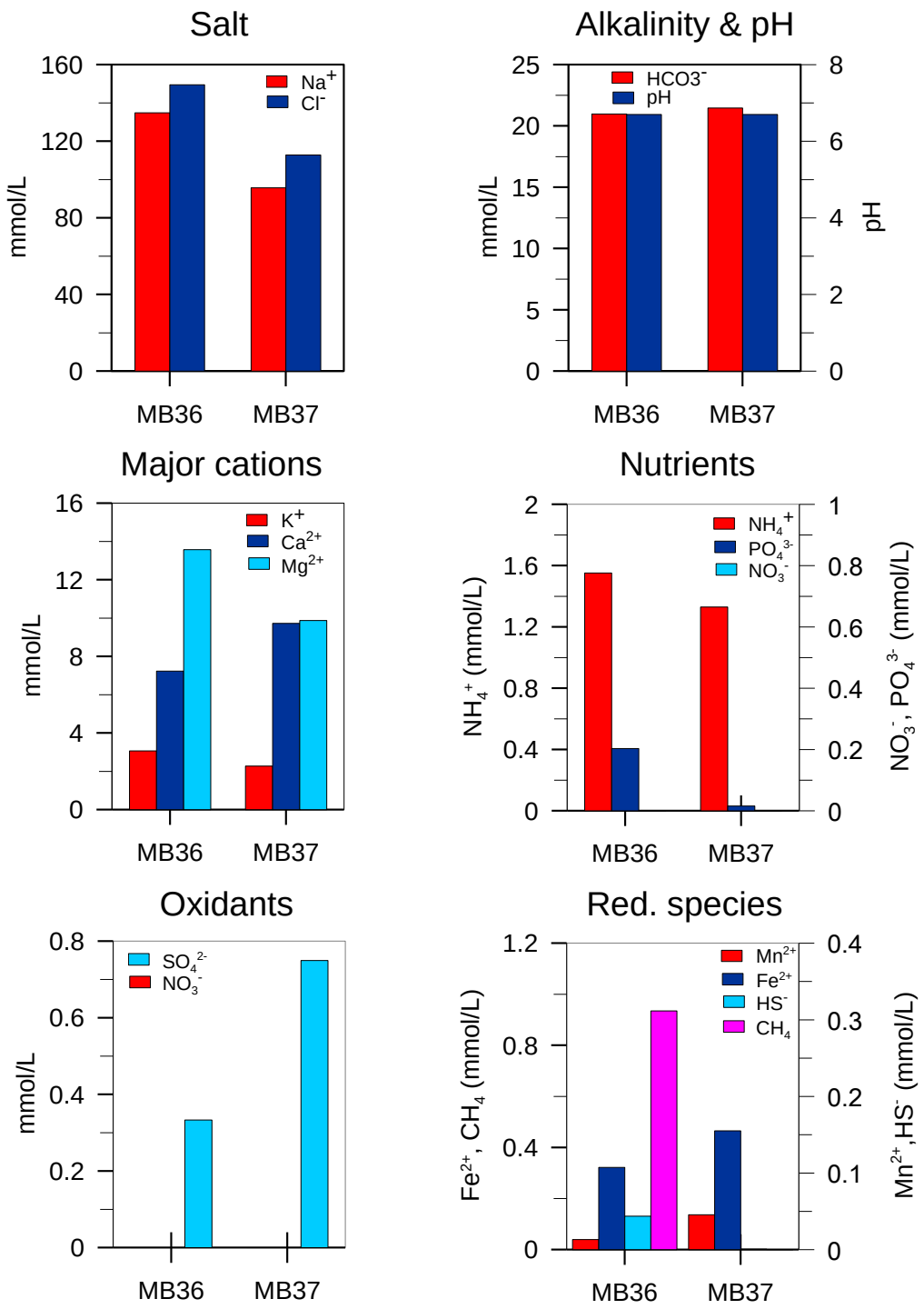


Figure 3a: Groundwater composition from MB36 and MB37 sampled in March 2012. Results for nitrate (NO_3^-) were below detection limit (< 0.01 mmol/L). Results for sulphide and methane data were close to detection limit for MB37 with 0.6 µmol/L HS^- and 0.7 µmol/L CH_4.

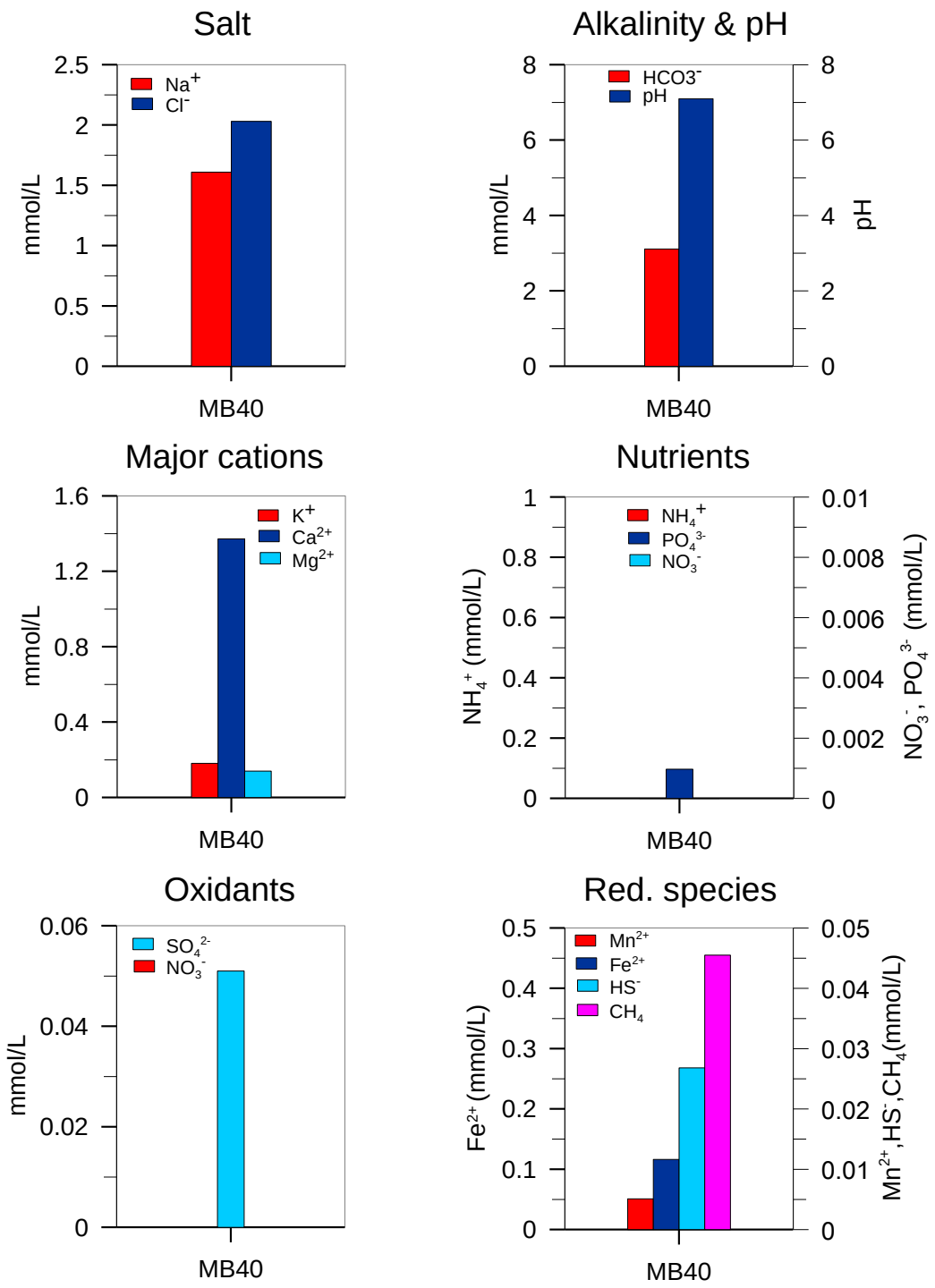


Figure 3b: Groundwater composition from MB40, sampled in May 2012. Results for nitrate (NO_3^-) and ammonium (NH_4^+) were below detection limit (< 0.01 mmol/L and < 0.3 µmol/L) and oxygen was not measured.

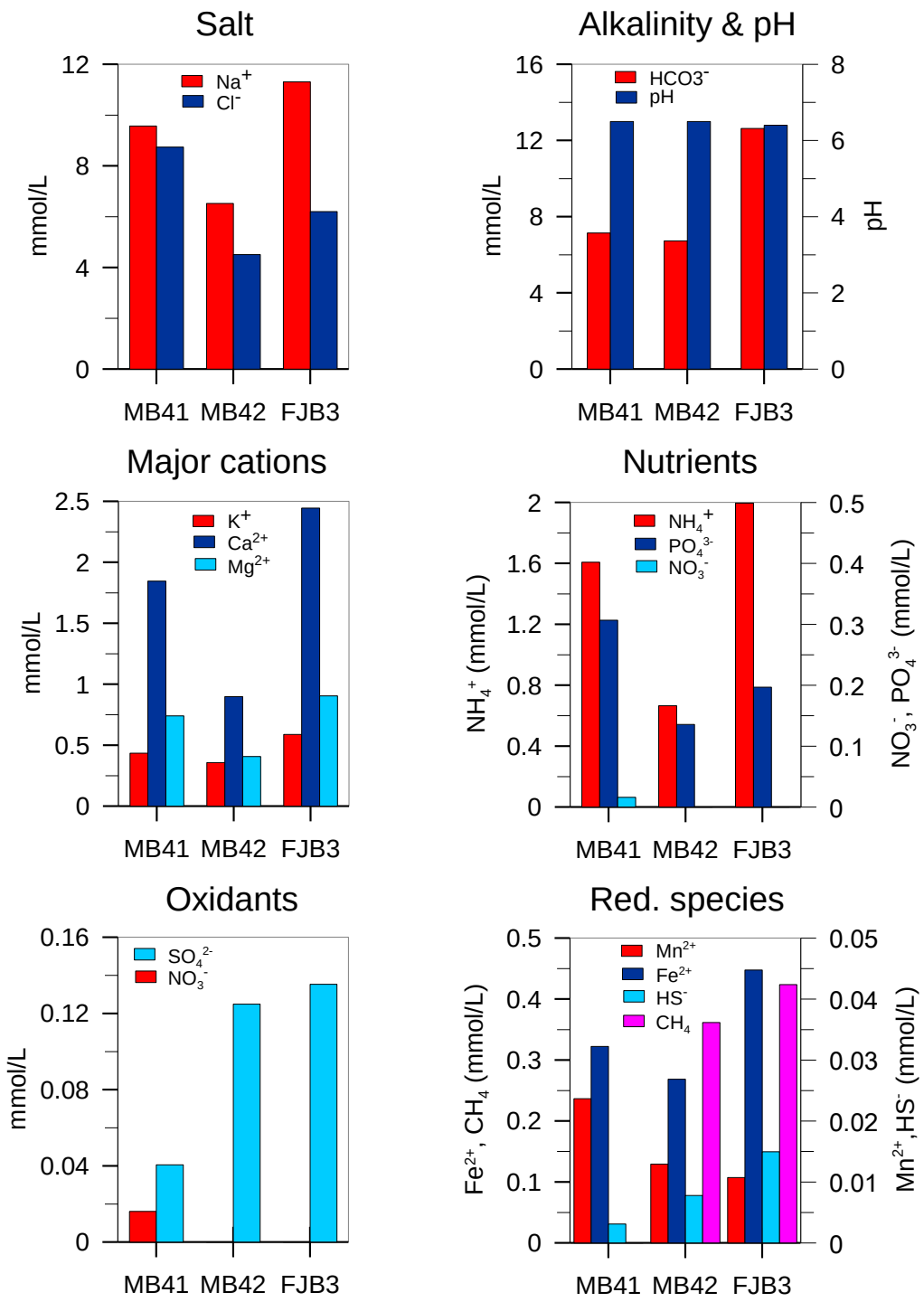


Figure 3c: Groundwater composition from MB41, MB42, sampled in May, and FJB3 sampled in March 2012. Results for nitrate (NO_3^-) were below detection limit (< 0.01 mmol/L) for MB42 and FJB3 and methane (CH_4) concentrations were below detection limit (< 0.3 µmol/L) at MB41.

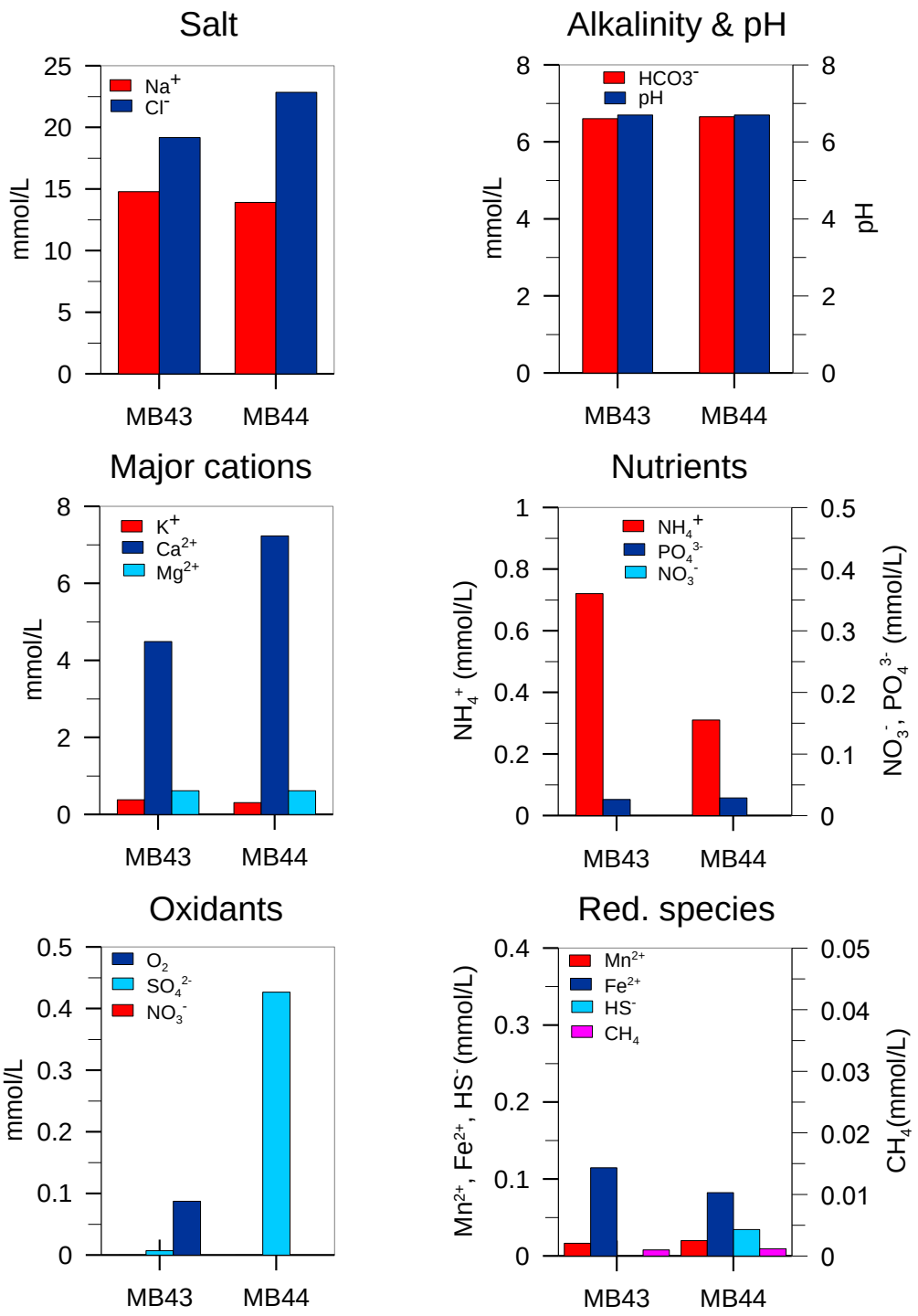


Figure 3d: Groundwater composition from MB43 and MB44, sampled in May and June 2012. Results for nitrate (NO_3^-) were below detection limit (< 0.01 mmol/L) for both dipwells, sulphide (HS^-) was below detection limit (< 0.6 µmol/L) for MB43.

The quality of the groundwater analyses is considered good as demonstrated by a balanced sum of positive and negative charges with a difference of 0 to 5%. The laboratory observed a precipitate in the sample for metals for the dipwells except for MB40 and MB41. The small charge error is in most cases an anion deficit, possibly a result of a slightly underestimated alkalinity due to calcium-carbonate or Fe-oxide precipitation during sample handling, as the samples for alkalinity were not preserved. Dissolved sulphide concentrations might be underestimated in the groundwater of MB36, MB37, MB42 and FJB3 due to a headspace in the sampling bottles and degassing of sulphide into the gas phase. A medium to strong H_2S smell was observed in the soil at the filter depth during sampling (Dunlop 2011/2012) and indicates that at

least some sulphate reduction takes place at all dipwells. The methane results may be too low compared to in situ conditions, as it is very difficult to avoid degassing when pressure is lowered during the sampling, although sampling directly into evacuated bottles was attempted. Conductivity, oxygen content, pH and temperature were measured in a small beaker during the sampling (MB36, MB37, FJB3), 3 days (MB41, MB42) or 12 days later (MB43, MB44), as Multiconsult did not have a flow-through cell for these parameters available. Field-pH was similar to pH values measured later in the laboratory but the method might have introduced oxygen into the samples, thus all oxygen results below 0.05 mmol (1.5 mg) O_2/L have been discarded.

The new results obtained together with already available information is also used for advice on remediation requirements and documentation of the preservation state and conditions prior to any measure to raise the groundwater level. As first steps the drainage level in the most affected area NW of the hotel was lifted from + 0.40 m to + 0.70 m asl in January 2012 and from the first weeks of March construction of an infiltration drain along the sheet piling was begun at Bugården. Infiltration of water started on 1st June 2012 after water samples in the dipwells close to the hotel were taken.

The conceptual model of the groundwater formation in the different areas of Bryggen building on the existing and continuously extended network of dipwells is shown in Figure 4.

Unsaturated surface deposits affected by drainage (A) were particularly found in the north to north-east of the hotel and the groundwater is characterized by elevated manganese, iron and sulphate concentrations. Increased flushing with rainwater (B) was observed along the sheet piling, and seawater impact along the quay front (C). Stagnant conditions prevail in the deeper deposits in central Bryggen (D), and groundwater of the natural sediments has a mixed composition but does not impact the cultural deposits. A depth related comparison of the groundwater composition of the new dipwells sampled in spring 2012 with groundwater from other dipwells at Bryggen sampled in autumn 2011 is presented in Figure 5. A detailed analysis of these results can be found in Matthiesen (2012) and for MB38 and 39 in Walpersdorf (2012).

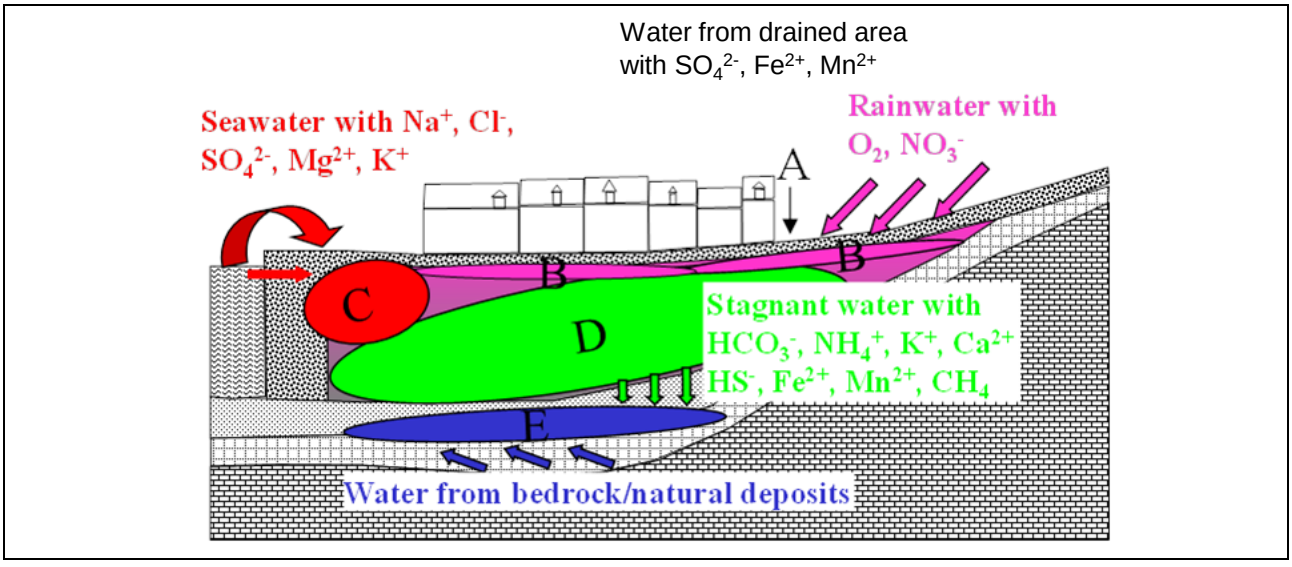


Figure 4: Conceptual model of the groundwater formation in the different areas at Bryggen

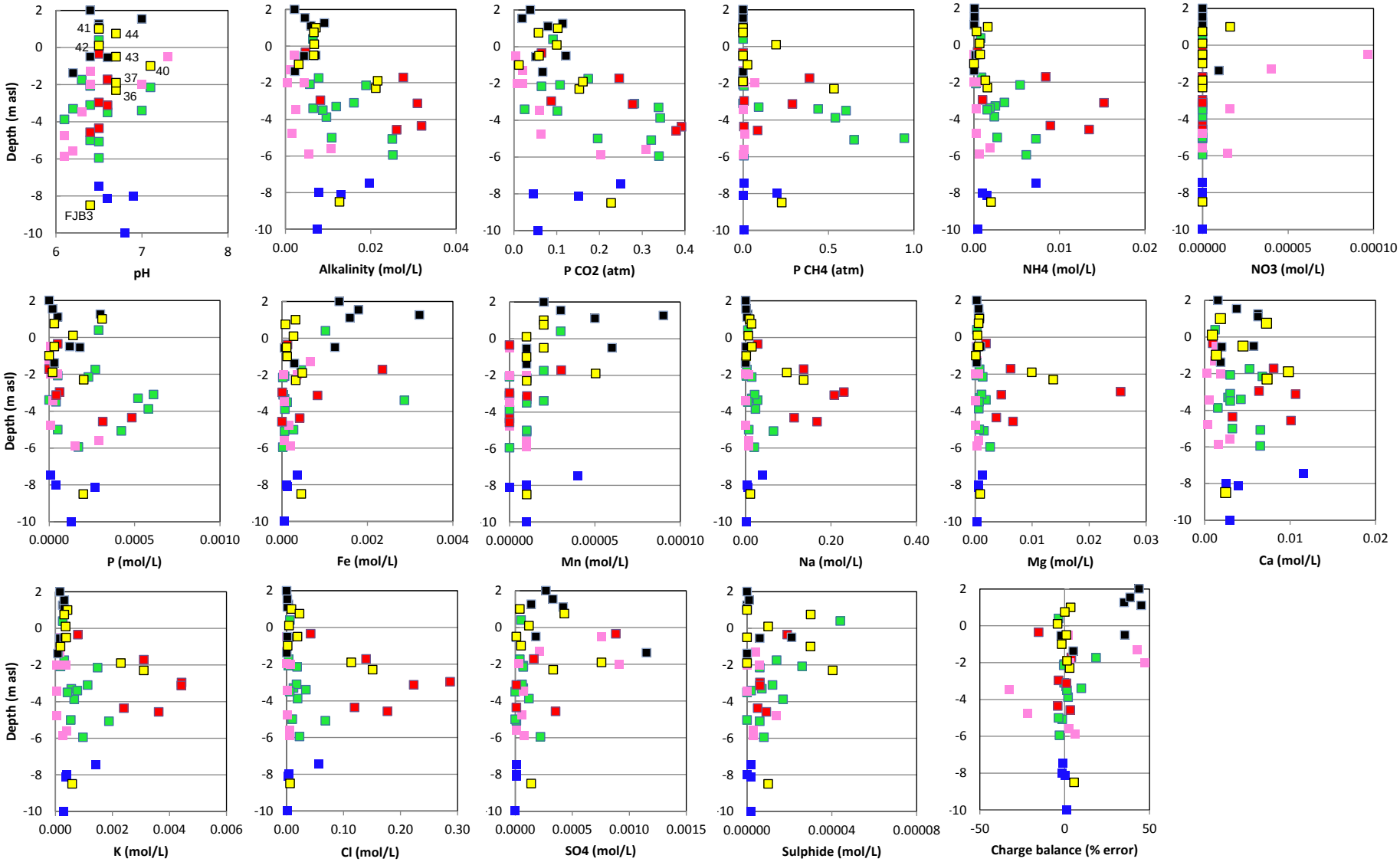


Figure 5: Comparison of groundwater data from the new dipwells (yellow squares) with groundwater data from all other dipwells on Bryggen (sampled in autumn 2011). The different colours indicate: Black – water from the drained area; green – water from relatively stagnant conditions; red – dipwells near the quay front influenced by seawater; pink – dipwells near the sheet piling diluted by rainwater; and blue – water from natural deposits underneath the cultural layers, defined by a conceptual model of groundwater formation and chemistry (de Beer and Matthiesen 2008, Matthiesen 2012).

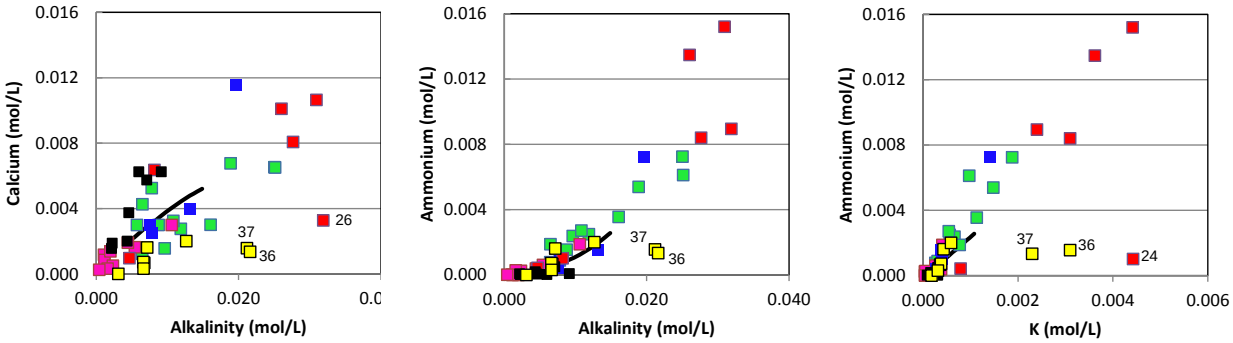
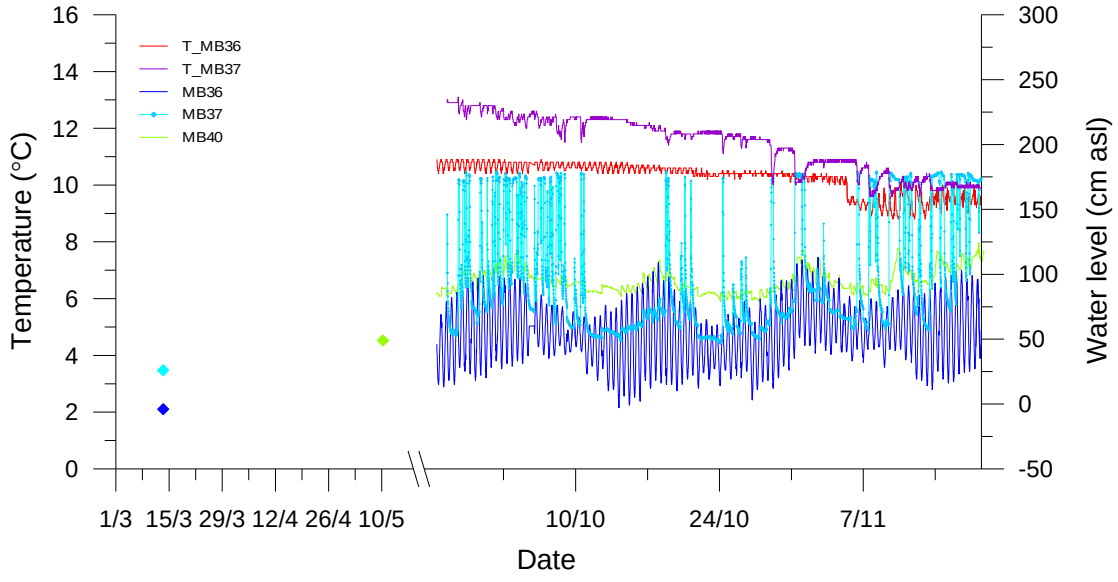
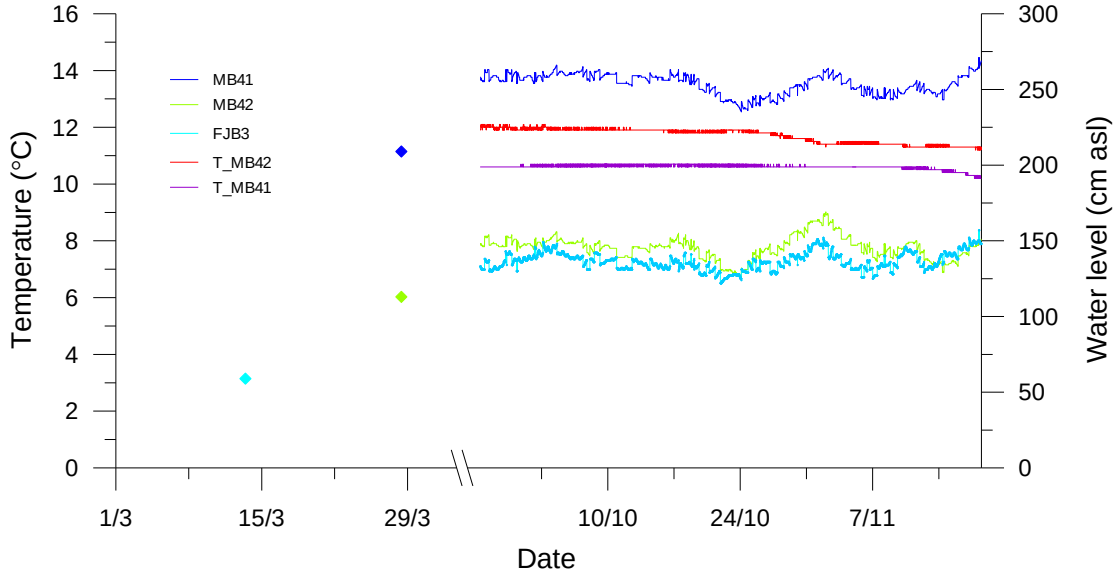


Figure 6: Correlation between alkalinity and calcium and ammonium, and between potassium and ammonium (data from August/September 2011). The new dipwells are included as yellow squares.





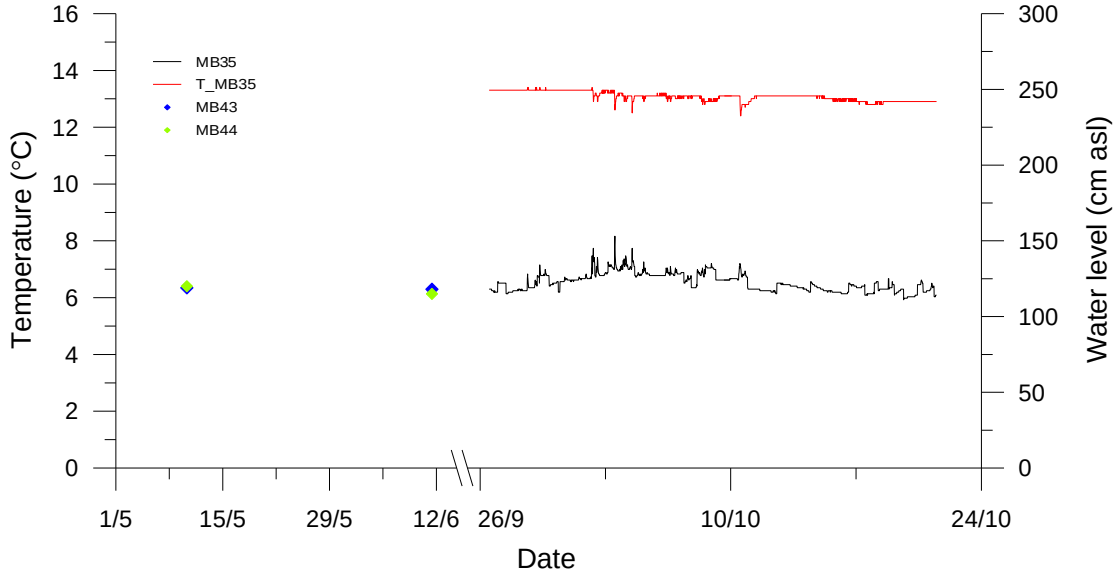


Figure 7: Groundwater level variation recorded at the new dipwells since autumn 2012 (no measurements at MB43 and 44 available) and other dipwells nearby in the different areas of Bryggen (from online database provided by HOUM, http://82.196.194.106:8080/). Due to an error in the calculating software for the automatic measurements the heights relative to sea level at MB37 are not exact but the variations should represent the actual dynamics. Single dots represent water level measurements around the time of sampling.

4. Discussion

The discussion is organized according to areas (Figure 1) and presented separately for the harbour front (MB36 and MB37, here MB40 is included for comparison), the area east of the SAS hotel between sheet piling and the central part of Bryggen (MB41, MB42, FJB3), and an area further to the east separated from central Bryggen by an elevation in terrain (MB43 and MB44). For each area the discussion is structured in the following way: First the state of preservation (SoPS) of the deposits and their potential for further decay will be discussed based on observations during the installation of the dipwells as well as measurements of loss of ignition and reactivity of soil samples. The actual preservation conditions (PresCon) will be estimated from soil and groundwater chemistry and the position of the cultural deposits in relation to groundwater level, and compared with conditions at adjacent earlier installed dipwells.

4.1 Harbour front (MB36, MB37)

4.1.1 State of preservation (SoPS) at MB36 and MB37

The two dipwells MB36 and MB37 (Figure 2a) are located close to the harbour (at a distance of 29 and 33 m respectively) and will be compared to other dipwells at the harbour front.

At MB36 the upper 2.4 m down to -1.2 m asl consist of sand and gravel partly deposited in connection with the building of the modern quay. Beneath follow post-medieval deposits. Here, down to -1.8 m asl, preservation state of a loose mixed deposit of cultural material and sand with low LOI (5.3%) and reactivity (0.074 ± 0.050 mg O_2/g dw/d) is described as poor (C2). Medium preservation state (C3) is found in the metre underneath in a semi-compact and relatively dry organic layer with sawchips (24% LOI) and a loose, wet, mixed deposit of sand and humus. The reactivity of these layers has not been determined. In-between a layer of loose sand, stones and timber with indefinable preservation is found. Drilling was abandoned reaching an impenetrable timber layer at -2.8 m asl.

At MB37 the upper 1.45 m down to sea level consist of modern porous sandy deposits. Just below sea level a very sandy humus layer with poor preservation state (C2), low LOI (8.8%) and reactivity (0.051 ± 0.009 mg O_2/ g dw/d) is found. Beneath -0.9 m asl, reactivity increases to 0.186 ± 0.008 mg O_2/g dw/d in a compact and dry layer rich in woodchips (LOI of 70%). At this depth and down to the end of drilling at -2.55 m asl preservation state of semi-compact to loose organic layers is described as medium (C3).

At the quay front modern fill typically reaches down to approximately -1 to -2 m asl, followed by a zone of moderate organic content and poor to medium preservation state (C2 – C3) from -2 to -4 m asl. Below this transition zone deposits are compact organic to very organic and preservation state medium to good (C3 – C4). Beneath the buildings organic-rich layers with medium to good preservation are already found at a depth of ca. -0.5 m asl (e.g. at MB28 and MB29; Matthiesen 2008b, 2010).
Preservation state and the distribution pattern of porous and organic deposits are shown in Figure 8. Soil chloride and sulphate concentration maxima indicate increased seawater impact in depths from around sea level to -4 m asl.

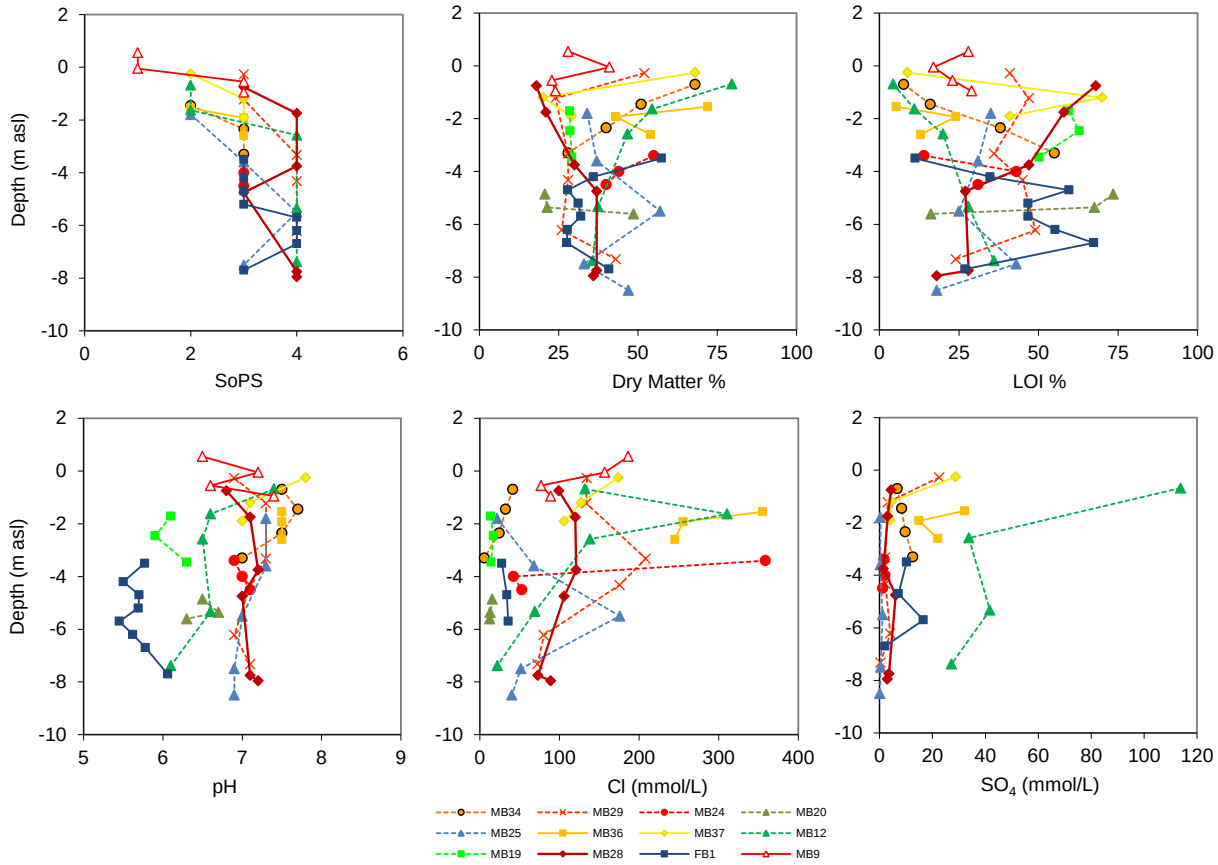


Figure 8: Preservation state (SoPS, lousy (1) to excellent (5) after a scale from Dunlop), dry matter, loss of ignition (LOI), soil pH, and water soluble sulphate and chloride at selected dipwells installed over a period of 11 years.

4.1.2 Preservation conditions (PresCon) at MB36 and MB37

4.1.2.1 Groundwater level

At MB36 water level was at -0.04 m asl on 13th March 2012, 11:20 h. Continuous water level measurements in the dipwell are available from 26th September 2012 (from an online database provided by HOUM, http://82.196.194.106:8080/) and show a strong tidal dynamic. In autumn, minimum and maximum water table varied for ca. 1.1 m with fluctuations of up to 0.9 m over a single ~ 6 hours tidal period. This is a far more extreme tidally induced water table change compared to current online-measurements in other dipwells at the quay front and indicates very permeable layers and a fast water exchange in the deposits at the filter depth (-1.8 to -2.8 m asl).

At MB37 with a filter in -1.4 to -2.4 m asl water level was measured at 0.26 m asl on 13th March 2012, 11:00 h. This dipwell is located close to a car park at the north-west side of the SAS hotel, likely in a fast draining ditch. Tidally induced water level changes are moderate but rain events, also visible by the negative temperature peaks, rapidly increase the water level for up to 1.2 m over a few hours and draining occurs similarly fast. Furthermore, the highest rainwater peaks are all cut-off at the same level. In contrast to the observed dynamic water level change groundwater chemistry (Figure 3a) indicates reduced and relatively stagnant conditions. Possible explanations (pers. com. de Beer) are a damaged dipwell pipe in the porous deposits above filter level or that the installation has cut a drain pipe or caused preferential flow along the dipwell pipe leading to fast infiltration of rainwater down to filter depth. The deposits all the way down to -0.9 m asl are very permeable and allow for equally fast drainage back to the normal groundwater level. The actual impact of rainwater cannot be evaluated from the water level measurements in the dipwell.

At the north-western side of the hotel as far as at 120 m distance from the harbour front a certain impact of tidal pressure propagation and a reaction to rainfall is also visible at MB40. At this location no cultural deposits are present.

Variable hydrologic conditions at MB36 and MB37 may significantly influence water exchange and the availability of SO_4 and NO_3 for microbial decay of the organic cultural deposits as seen at the sheet piling.

4.1.2.2 Groundwater chemistry: Redox conditions, nutrients and pH

Groundwater composition at MB36 and MB37 reflects a reduced environment (Figure 3a). The presence of HS^- and CH_4 in high concentrations in the water from MB36 indicates some ongoing sulphate reduction and methanogenesis. At MB37 water chemistry should be representative for the conditions in the surrounding deposits as the dipwell was emptied several times for resident water prior to sampling. Here, NH_4, Mn^{2+} and Fe^{2+} are the main reduced species**.** Concentrations of Mn^{2+} and SO_4 are elevated compared to other dipwells with a filter in a similar depth but in the range of drainage, rain- and seawater impacted dipwells at and above -2 m asl (Figure 5). NH_4 concentrations in the groundwater of both dipwells are low and comparable to MB9, MB24 and the upper depths of FB1 (-0.5 and -2 m asl) which have shown to be very dynamic and susceptible to seawater intrusion (Matthiesen 2010).

At MB40 (Figure 3b) concentrations of dissolved ions in the groundwater (likely from an old seabed according to a report from the installation, Appendix 3) are low indicating dilution by rainwater. Main reduced species are Mn^{2+} and Fe^{2+}. NH_4 and NO_3 concentrations were below detection limit. Oxygen was not measured and the only oxidant present is SO_4 in very low concentrations.

Groundwater pH is near neutral as for most of Bryggen with 6.7 for both MB36 and MB37 and 7.1 at MB40. Soil pH is 7.5 in all investigated depths at MB36, at MB37 soil pH varies between 7 and 7.8, with the maximum in a layer of very sandy humus from 0 to -0.3 m asl (possibly due to seawater impact).

Processes and sources contributing to the groundwater chemistry can be identified by the relationship between different components (Figure 6, data from groundwater sampled in 2011/12). The correlation of alkalinity with calcium and with ammonium documents that part of the alkalinity is generated by calcite dissolution and anaerobic decomposition of the N-rich organic matter in the cultural deposits of Bryggen. Deviations from the trend are some dipwells from the drained area with elevated calcium content as a result of increased dissolution of calcite from lime or shells or calcium containing minerals such as gypsum, as well as the new dipwells MB36 and MB37, together with MB26, where alkalinity is much higher than expected. This could be due to a higher seawater impact traceable by elevated potassium concentrations as also found for MB24 and for MB9 after a flooding in 2005 (not shown). Seawater intrusion increases the supply of SO_4 and fuels sulphate reduction, the process where sulphate is used by bacteria to oxidize organic matter:

$$SO_4^{2-} + 2\ CH_2O \rightarrow HS^- + 2\ HCO_3^- + H^+ \qquad (2)$$

A complete oxidation of organic matter leads to production of 2 mol HCO_3 for every mol SO_4 being reduced.

4.1.2.3 Seawater intrusion

Matthiesen (2008b, 2010) has shown that sulphate reduction at high rates can be of importance for the decay of organic cultural deposits in marine impacted areas such as Bryggen. However, the actual extent will depend on the actual seawater supply which can be very variable spatially and temporally.

Seawater impact at MB36 and MB37 is shown by very high salt (Na, Cl) content and elevated magnesium and potassium concentrations (see also Figure 10, 11). Compared to pure seawater with a salinity of 35‰ with a chloride content of 546 mmol/L groundwater at the two dipwells is diluted 3.7 and 4.8 times corresponding to 27 or 21% contribution of seawater. High chloride concentrations are also found at MB9, MB24, MB26, MB27 and MB28. At MB37 chloride concentrations in the soil pore water at the filter depth and groundwater are similar, but there is a difference of 100 mmol/L at MB36 corresponding to 46% seawater contribution at the time of installation of the dipwell in December 2011. Seawater and sulphate supply might be quite high and more frequent at MB36. Here, the deepest soil sample from a deposit with strong H_2S smell was also analysed for pyrite and pyrite-S makes up 74% of the total sulphur in this sample, indicating that sulphate reduction has been a dominant process at the location. At MB37, pyrite-S accounts to "only" 42% of the total sulphur.

Previously, high sulphate reduction rates of 0.05 – 0.12 mM/day have been determined in the laboratory (Bioforsk, in Matthiesen 2008b, Appendix 2, and discussed in Matthiesen 2010), but these are maximum rates as the soil was completely mixed with seawater. Under in situ conditions supply of sulphate may vary considerably depending on the permeability of the deposits. Seawater replenishment seems mainly to occur during occasional flooding or by subsurface intrusion through the upper sandy and less compact deposits, compared to the organic deposits underneath, down to ca. -5 m asl.

Seawater contains chloride and sulphate at a fixed molar ratio of 0.052 SO_4/Cl (28 mM SO_4 and 546 mM Cl at a salinity of 35‰). Thus, optimally following a flooding event, theoretical sulphate depletion in the groundwater of the dipwells can be estimated from the difference between the calculated SO_4 concentration for any measured Cl content and the actual SO_4 concentration. This might be used as an indicator for the extent of sulphate reduction providing that there are no other sources for chloride or sulphate (Figure 9).

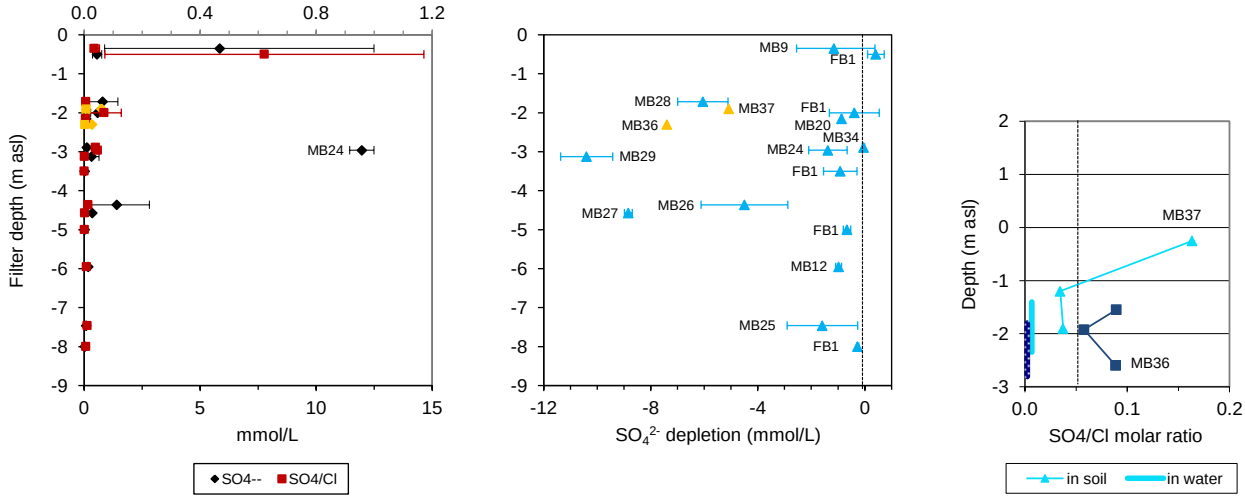


Figure 9: Sulphate concentrations, SO_4/Cl ratio and sulphate depletion in groundwater from dipwells at the harbour front (June 2005, May 2008, April 2009 and August/September 2011). The new dipwells sampled in March 2012, MB36 and MB37, are included (yellow symbols) and for these the SO_4/Cl ratio in groundwater and soil is compared.

A SO_4/Cl ratio close to seawater of 0.04 to 0.05 is found at MB9, MB24 and MB34. FB1 has higher ratios at the upper two sampling depths showing highest variation at -0.50 m asl between 0.07 in 2008 and 1.17 in 2011. Very low or varying sulphate depletion between positive and negative values indicates dynamic supply of seawater in the upper 2-3 m below sea level at these dipwells, where also loose and porous deposits are found. In some cases the supply of SO_4 may be faster than the reduction as these deposits contain low amounts of organic matter of low reactivity. Partly the SO_4 might also come from other sources. Drying and rewetting effects (oxidation of reduced sulphur and wash-out) in the unsaturated zone may result in pulses of SO_4 in the groundwater.

At MB36 and MB37 the SO_4/Cl ratio is much lower than expected (0.002 and 0.007) and sulphate depletion is surprisingly high considering the groundwater dynamics and reaches -7.40 and -5.09 mmol/L respectively (Figure 9). These values fall in the range of other dipwells with relatively stagnant conditions such as MB26, MB27 and MB28. Applying the above mentioned sulphate reduction rates (determined on soil samples from MB24 and MB25 with a much lower sulphate depletion of -1.38 and -1.59 mmol/L), it would have taken some months for the sulphate to disappear following seawater intrusion. In the study investigating seawater intrusion beneath the quay front buildings Matthiesen (2010) found a sulphate depletion of 2 mmol/L in 80 days, or -0.025 mmol SO_4/L · d, for the more dynamic dipwell MB24 corresponding to the degradation of approximately 4 mM organic carbon. At MB28 which is placed near the interface between the very porous and more compact deposits at -2.2 to -3.2 m asl, similarly to MB36 and MB37, a sulphate depletion of -0.014 mmol SO_4/L · d was estimated. This rate seems more realistic for undisturbed soil and, using the observed sulphate depletion, results in a decay of 10 – 15 mM organic matter in 1 – 1.4 years at MB37 and MB36 respectively and is in the range of the decay rate derived from the geochemical model. However, this might underestimate the real sulphate reduction activity as conditions vary locally and most likely are not stable for such a long time period. The discrepancy between groundwater and soil SO_4/Cl (Figure 9), the latter being closer to pure seawater at the filter depth, indicates temporal variation in the sulphate supply via seawater as also documented by an elevated Cl content in the soil at MB36. Some of the SO_4 in the soil pore water (corresponding to 78% contribution of seawater to SO_4 compared to 46% for Cl at MB36) is probably partly also a result of reoxidization of sulphur during sample handling and storage.

Figure 10 and 11 summarize the picture at the harbour front showing that MB36 and MB37 belong to a group of dipwells with high saltwater impact and high but also quite variable concentrations of reduced species and other ions. This zone is found between ca. -2 and -5 m asl as earlier described where conditions are relatively stagnant compared to the sandy porous modern deposits above. At the upper border around -2 m asl, where also the new dipwells are installed, however, conditions seem to be most variable due to a more direct contact to water entering through the porous deposits above. Intrusion of seawater can be traced down to the same depth by the elevated salt, magnesium and potassium concentrations.

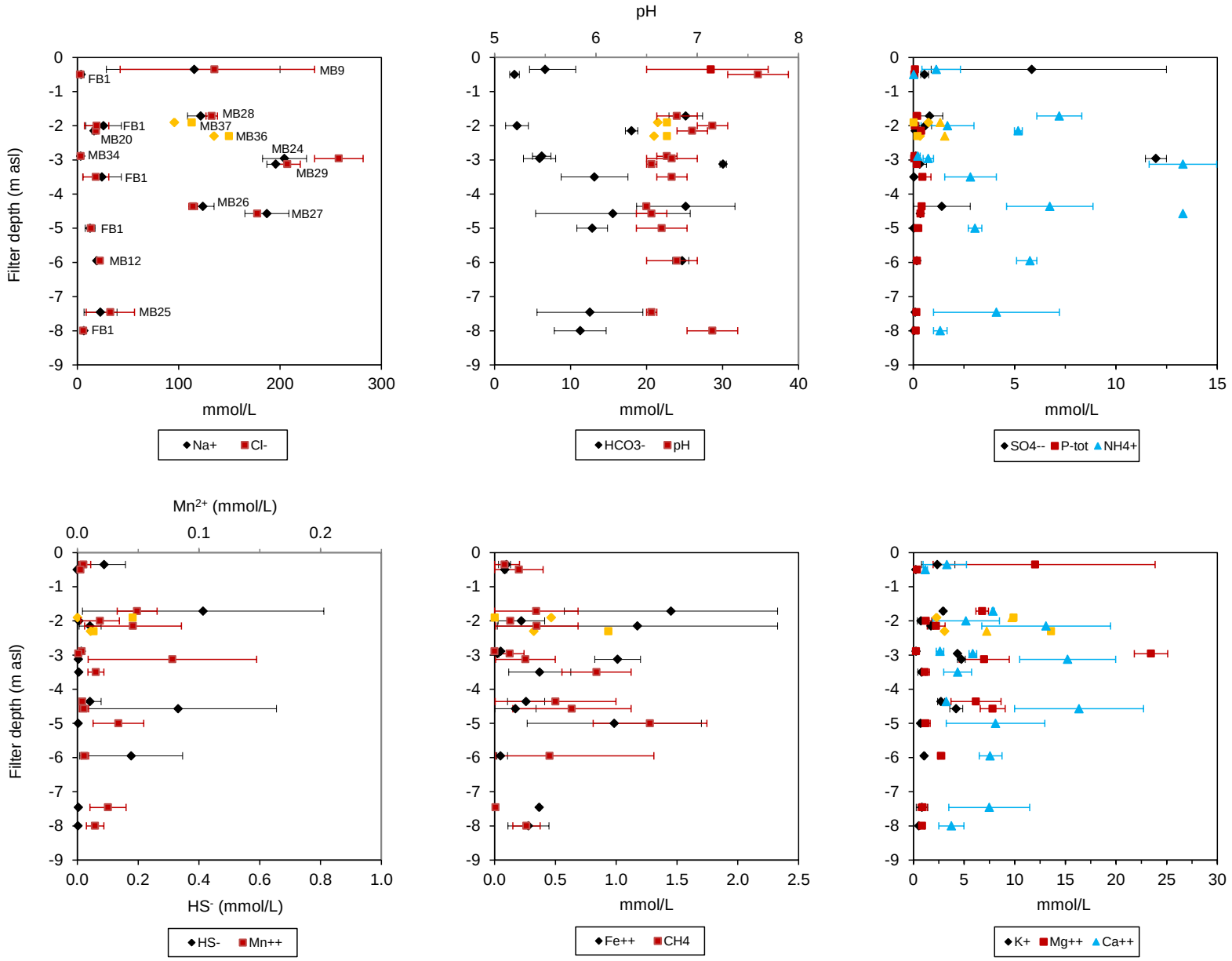
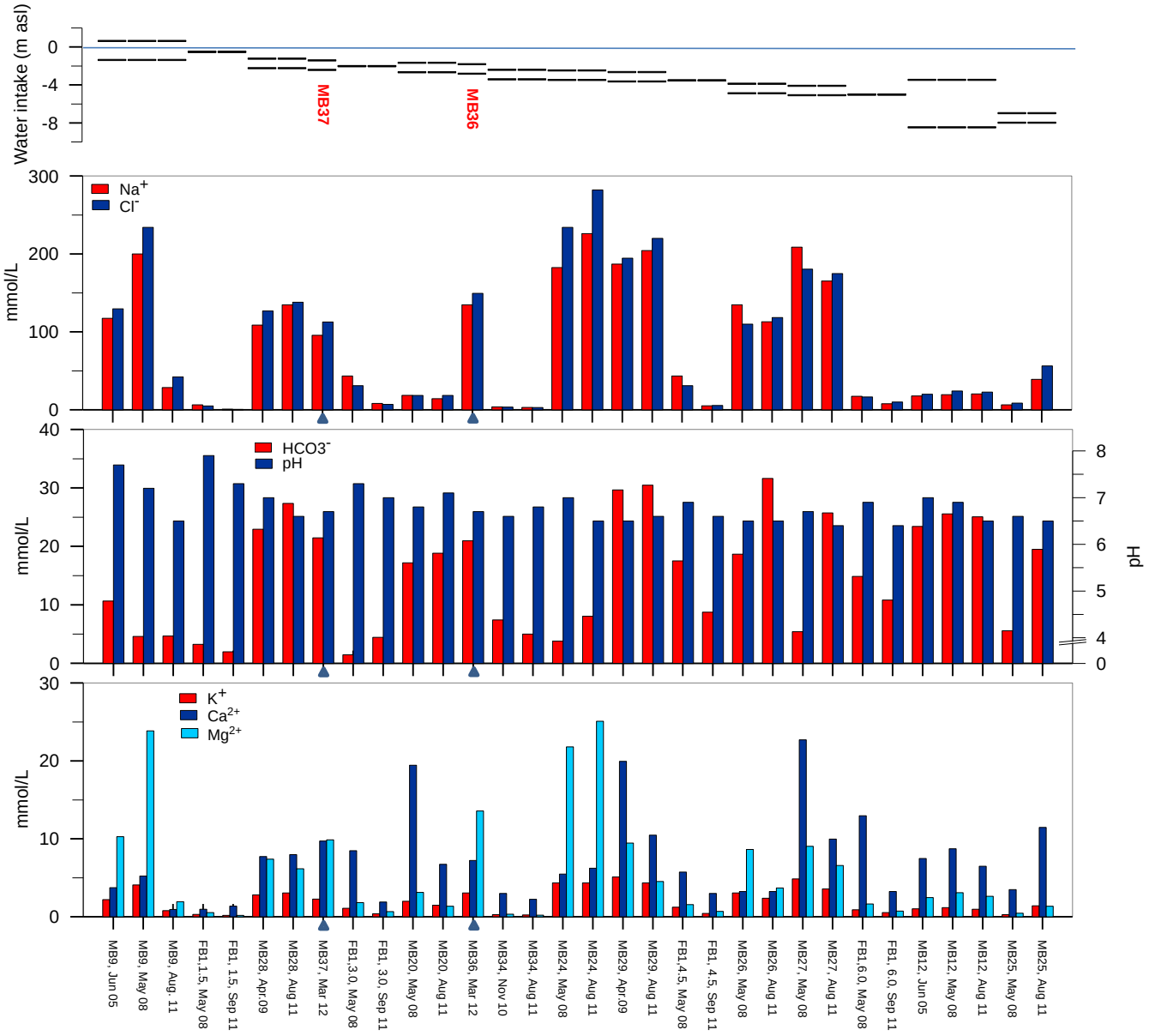


Figure 10: Average depth related groundwater chemistry at the harbour front between June 2005 and March 2012. The error bars represent the range.


Water intake (m asl)
0
-4
-8
MB37
MB36
300
200
100
0
mmol/L
Na+
Cl-
40
30
20
10
0
HCO3-
pH
8
7
6
5
4
0
30
20
10
0
K+
Ca2+
Mg2+
MB9, Jun 05
MB9, May 08
MB9, Aug. 11
FB1.1.5, May 08
FB1, 1.5, Sep 11
MB28, Apr.09
MB28, Aug 11
MB37, Mar 12
FB1,3.0, May 08
FB1, 3.0, Sep 11
MB20, May 08
MB20, Aug 11
MB36, Mar 12
MB34, Nov 10
MB34, Aug 11
MB24, May 08
MB24, Aug 11
MB29, Apr.09
MB29, Aug 11
FB1,4.5, May 08
FB1, 4.5, Sep 11
MB26, May 08
MB26, Aug 11
MB27, May 08
MB27, Aug 11
FB1,6.0, May 08
FB1, 6.0, Sep 11
MB12, Jun 05
MB12, May 08
MB12, Aug 11
MB25, May 08
MB25, Aug 11

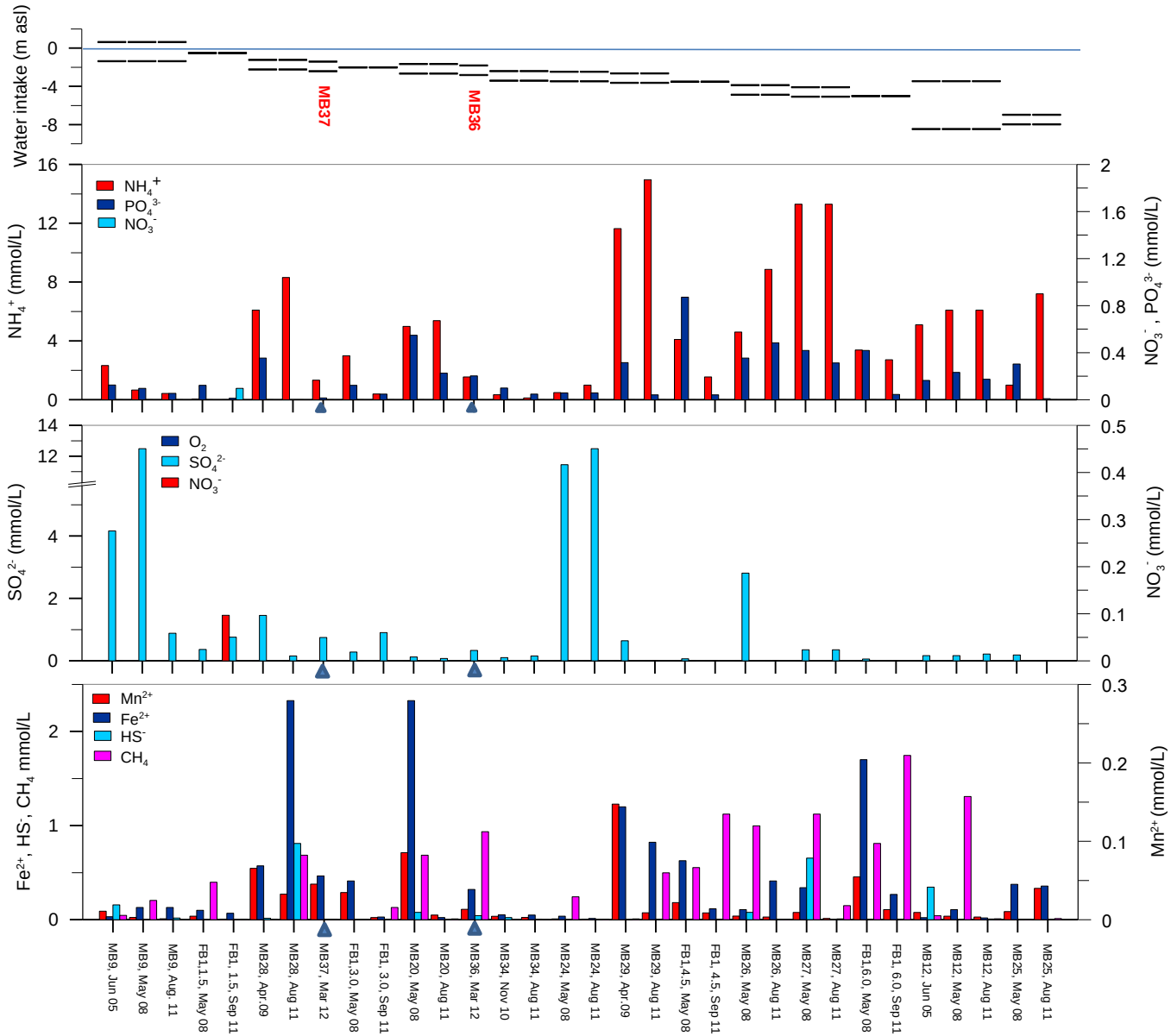


Figure 11: Comparison of the groundwater chemistry of the new dipwells MB36 and MB37 with selected earlier installed dipwells (time series) at the harbour front

4.1.2.4 Conclusion: Preservation conditions and future work

At ***MB36*** from 1.2 to -1.2 m asl modern porous soil material from building of the modern quay is found.

From -1.2 to -1.8 m asl: Modern or post-medieval cultural (?) deposits consist of sandy humus and some timber of poor preservation state. Preservation conditions are lousy (PresCon 1) but sulphate reduction in this loose deposit is probably limited by low LOI (5.3%) and low reactivity (0.074 ± 0.050 mg O_2/g dw/d).

From -1.8 to -2.8 m asl: Organic cultural deposits of medium preservation state and medium LOI (24%) are found. A strong H_2S smell, HS^- in the groundwater and a share of 74% pyrite-S of all sulphur in the soil indicate a high sulphate reduction rate. Tidally controlled groundwater oscillations of up to 0.9 m over 6 hours and a huge difference in chloride concentrations in groundwater and soil corroborate a dynamic environment with possibly frequent seawater supply via the loose sandy layers at this depth. However the actual dynamic needs to be investigated further. In combination with the presence of CH_4 and high theoretical sulphate depletion which indicate that conditions could be quite stable for some weeks/months the first estimate of preservation conditions is poor (PresCon 2).

Beneath -2.8 m asl: Preservation conditions seem to improve because the timber could not be penetrated with the auger.

At ***MB37*** modern permeable deposits are found down to sea level.

A layer of very sandy humus from 0 to -0.3 m asl has a poor preservation state (C2), low LOI (8.8%) and low reactivity (0.051 ± 0.009 mg O_2/g dw/d). This layer is likely affected by rainwater (PresCon 1). Tidal dynamics are less pronounced but seawater could penetrate via the sandy deposits above and below sea level, e.g. the layer of loose fine to coarse sand from -0.3 to -0.9 m asl.

From -0.9 to -2.55 m asl the deposits become more compact and organic also seen by a high LOI (up to 71%) and nutrient content, and a high reactivity (0.186 ± 0.008 mg O_2/g dw/d) comparable to rates measured in more compact layers at other dipwells (Figure 2). High sulphate depletion indicates that sulphate reduction is limited by a low sulphate supply. Here, preservation conditions could be regarded as medium (PresCon 3).

<u>Future work</u>

At both dipwells high resolution sampling of groundwater and measurement of salinity or conductivity in the dipwells will allow for a better estimation of possible sea- or rainwater impact. In order to evaluate the actual effect of rainwater on groundwater level and chemistry the installation conditions at MB37 and possible damage of the pipe should be checked. It is also recommended to sample water separately from the upper more porous layers for comparison and add a tracer to investigate the local hydrological conditions.

4.2 Bredsgården (MB41, MB42), Enhjørningsgården (FJB3)

4.2.1 State of preservation (SoPS) at MB41, MB42 and FJB3

At MB41 (Figure 2b) the upper 1 m down to a depth of 2.5 m asl consist of modern and post-medieval deposits with an indefinable state of preservation (mostly stones from the central drain and semi-compact sand and silt). These upper deposits have not been analysed but the LOI is expected to be low. Below, down to a depth of 0.5 m asl, post-medieval and medieval layers are found where semi-compact humus and the sapwood of a wooden post have a poor state of preservation (C2). LOI of ca. 30% in organic layers between 2.5 and 1.25 m asl indicates that there is a comparably high degradation potential of organic matter. Although LOI increases to 50% at 0.75 m asl the state of preservation is described as poor. There is no information about the depths below sea level as at MB41 rotary drilling was abandoned at ca. 0.50 m asl.

At MB42, ca. 22 m further down from MB41 towards the harbour front, the upper 1.35 m (down to 0.8 m asl) consist of modern and post-medieval material (Figure 2b). LOI in all investigated depths below 0.8 m asl is high (40-51%) and the state of preservation changes at 0.45 m asl from poor (C2) to medium (C3). There is some potential for further decay of organic matter in particular in the deposits above sea level, but the compact mud, silt and humus containing layer at 0.8 m asl might act as a protecting cover for the underlying semi-compact organic deposits. Rotary drilling was abandoned at -0.85 m asl.

The deposits at FJB3 (located adjacent to MB23, Figure 2b) consist of 1.35 m modern (and possibly post-medieval) disturbed soil and a layer of poorly preserved timber (C2). Beneath or from 0.65 m asl follow post-medieval and medieval organic, moss and timber layers of medium to good preservation state (C3-C4) and LOI increases almost linearly with depth from 47% to 83% in -4.25 m asl. Excellent state of preservation (C5) is found in a layer of laminated moss (LOI 35-36%) overlying the old seabed at -5.20 m asl. Risk of further degradation is low, as not much of the cultural deposits are found above sea level, and due to their relatively compact nature transport of oxidizing agents to the deeper deposits will be restricted.

Comparison with other dipwells nearby:
Figure 12 shows the distribution of the dipwells and Figure 13 depth profiles of the state of preservation and other results of chemical analysis of soil samples from selected depths. However, a direct comparison must take into account that the dipwells were installed over a period of 11 years. More detailed descriptions of the soil strata for the dipwells included in the comparison can be found in the respective reports from Dunlop.

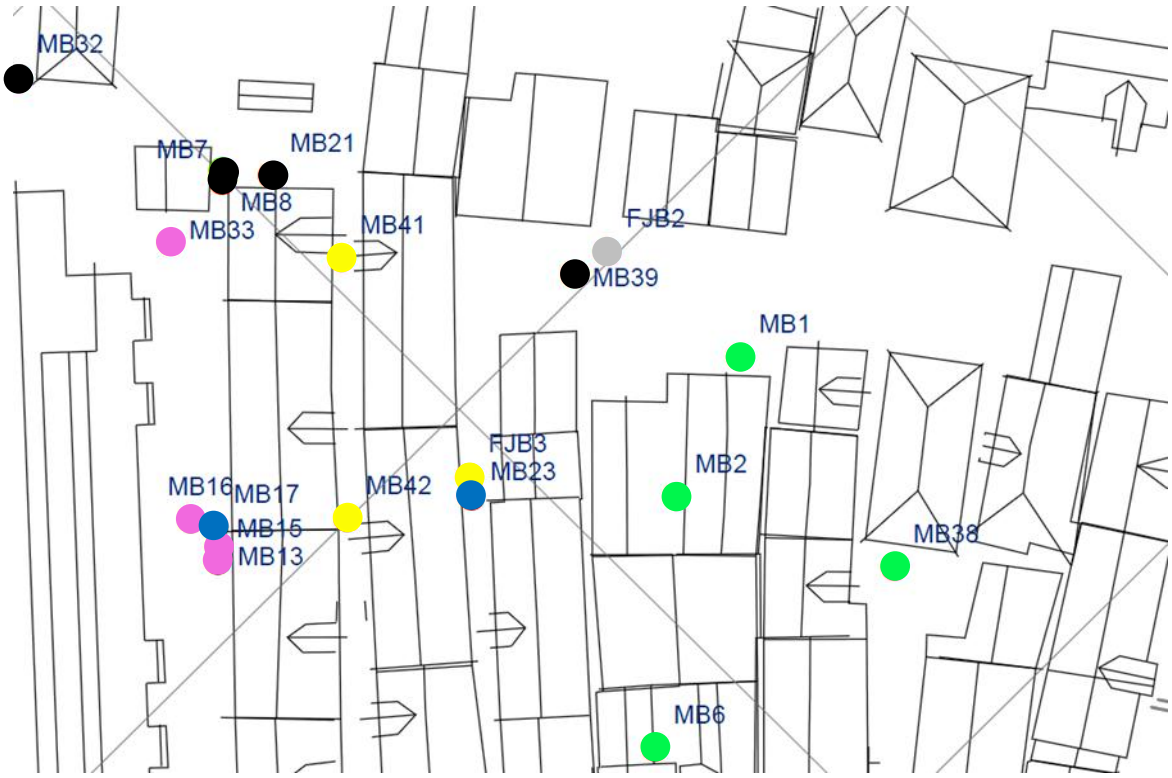


Figure 12: Position of selected dipwells included in the comparison with the new dipwells MB41, MB42 and FJB3 (yellow). Colours indicate in which area or soil volume the filter of the dipwell is placed as defined by the conceptual model of groundwater formation and preservation conditions (de Beer and Matthiesen 2008, Matthiesen 2008a, 2012) to which the dipwells belong (black: drained; pink: enhanced flow of rainwater; green: stagnant), grey: not included in comparison; MB22 in the drained area NE of the hotel and MB40 at Bryggens museum on the opposite side of the hotel are not shown.

State of preservation (SoPS), dry matter and LOI content (Figure 13) is quite variable in the unsaturated zone and the deposits down to ca. -2 m asl. In this depth interval state of preservation and LOI are more determined by the origin of the deposits, which also include sand and gravel containing layers with low organic content (e.g. deposits with poor preservation above 1.85 m asl at MB21, all the way down to sea level at MB6, and below sea level at MB15 and MB39). High LOI for some of the soil samples above groundwater level indicates a still quite large settling potential for the soil. But the actual decay rate also depends on the accessibility (loose or dense packing, transport rate of oxidants) as well on the quality of the organic matter (e.g. Vidal-Beaudet et al. 2012). From -2 m to ca. -5 m asl or to the natural bedrock/seabed deposits seem to be of more homogeneous and organic composition. LOI reaches maximum values here and the preservation state of the cultural deposits shifts to good and excellent. This is for instance the case for FJB3 but also for the dipwells close to the sheet piling where compact humus layers or even sandy layers with little humus have good state of preservation (e.g. at MB13), and very organic layers with little humus but very compact laminated and only slowly degradable moss can have maintained an excellent state of preservation.

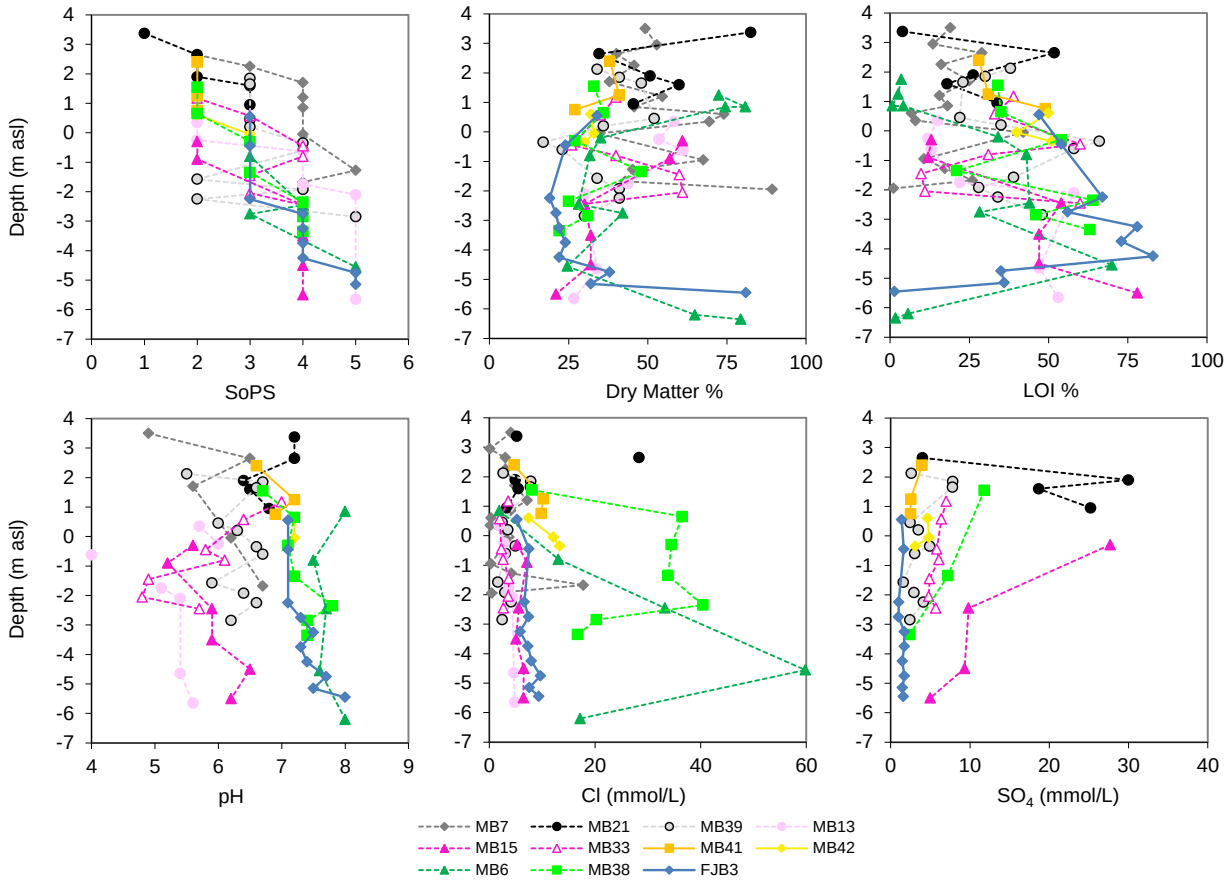


Figure 13: Preservation state (SoPS, lousy (1) to excellent (5) after a scale from Dunlop), dry matter, loss of ignition (LOI), soil pH, and water soluble sulphate and chloride at selected dipwells installed over a period of 11 years.

At this point it is still difficult to decide, if the visible decay took place in the past or if it is still on-going. In order to better estimate the potential for further microbial decay of the organic cultural deposits oxygen consumption rates were measured in the laboratory (Figure 2b). Reactivity was only measured in one sample from the occasionally unsaturated zone where groundwater table fluctuates showing a rate of 0.160 ± 0.020 mg O_2/g dw/d (MB41, 2.4 m asl). This rate is at least a factor 15 higher than rates measured in the unsaturated zone at the test pit (Hollesen and Matthiesen 2012). Reactivity of samples below groundwater level is also high with rates of 0.116 ± 0.007, 0.181 ± 0.007 and 0.372 ±0.050 mg O_2/g dw/d at FJB3 (0.55 m asl), MB41 (1.25 m asl) and MB42 (0.60 m asl) respectively. The high oxygen consumption at 0.60 m asl at MB42 is connected to a fine grained organo-mineralic deposit, which usually is characterized by a high microbial density and the presence of more easily degradable organic matter. In this layer is found some excrement and an elevated N content (Figure 2b), which may also contribute to a higher reactivity. This emphasizes that microbial decay rates depend on the quality (composition, maturity) of the organic matter. In general, the reactivity seems to correlate with the organic matter content (LOI) of the soil and increases in depths below sea level 2 to 3 times, e.g. to ca. 0.3 mg O_2/g dw/d (LOI > 70%) as at -3.75 m asl at FJB3. There is a certain risk for enhanced degradation in the groundwater table oscillation zone, but this will strongly depend on the duration of exposure to oxygen and the availability which might be limited in compact deposits with a high water holding capacity. For the deeper deposits it is unlikely that oxygen is available at all.

4.2.2 Preservation conditions (PresCon) at MB41, MB42 and FJB3

4.2.2.1 Groundwater level

Groundwater level is measured continuously in the dipwells (Figure 7) and data corrected to m asl (NN1954) are available from 26th September 2012 onwards (online-database provided by HOUM, http://82.196.194.106:8080/).

At the time of groundwater sampling on 28/3/2012 water level was measured at 2.09 m asl at MB41 and at 1.13 m asl at MB42, and about 0.4 to 0.6 m below the very stable level observed in the period between 26th September and 20th October. Thereafter and up to 18th November (last access to the online database) some half-weekly to weekly variation occurred for MB41 between 2.30 and 2.7 m asl and between 1.30 and 1.70 m asl for MB42. FJB3 has a filter in -8 to -9 m asl and the changes in pore water pressure (approximate groundwater level) follow a similar pattern. Also here a very low level was measured in March with 0.59 m asl on 13/3/2012. These observations document that in this area changes occur more gradually and over a couple of days to weeks, and that conditions also can be quite stable for some weeks.

However, the distribution of poorly preserved post-medieval and medieval cultural deposits at the dipwells above ca. 0.5 to 1 m asl and improved preservation state below corresponds well with the groundwater level minimum. Longer periods with decreasing water level will lead to increased downward transport of oxidants from the upper layers and combined with a decrease in water content make loose and sandy deposits more susceptible to decay. The very wet appearance of a semi-compact humus layer with quite a lot of fine to coarse sand at 2.5 m asl at MB41 documents a low water holding capacity. At MB42 a compact humus layer, although of poor preservation state, might act as a barrier for downward transport of oxidants keeping the deposits underneath, below groundwater table, in a better preservation state.

4.2.2.2 Groundwater chemistry: Redox conditions, nutrients and pH

The chemical composition of the groundwater at MB41, MB42 and FJB3 is shown in Figure 3c. Water at MB41 is sampled from a depth between 1.5 to 0.5 m asl below the groundwater table. Oxygen was not measured at the day of sampling. In comparison to the majority of dipwells, NO_3 concentrations at MB41 are elevated and clearly show a similarity to rainwater/increased flow impacted dipwells (Figure 5) indicating a possible threat for the cultural deposits at the filter depth. As characteristic for dipwells with a filter above sea level manganese concentrations at MB41 are elevated compared to conditions in depths below sea level and in particular beneath -2 m asl. Dissolved iron concentrations at MB41 are three to six times lower than measured in the drained area. Concentrations of SO_4 are also low in contrast to some drainage impacted dipwells in the neighbourhood showing much higher SO_4 concentrations (e.g. ten times higher at MB21). NH_4 and PO_4 concentrations at MB41 are significantly elevated compared to other dipwells above sea level which may indicate intense mineralization processes in the semi-compact humus at the filter depth. NH_4 concentrations of 1.6 mmol/L are ca. twofold higher than at MB1. PO_4 concentrations of ca. 0.3 mmol/L are similar to concentrations found at MB1 in the stagnant area which has a 3 m filter reaching from 1.9 m to -1.1 m asl and at MB8 in the drained area with a filter from 2.26 to 0.26 m asl. These observations can be a result of intensified mineralization processes at the filter depth itself due to increased downward transport of oxidants. A possible other source for high nutrient concentrations in the groundwater could be a layer of fine grained sediment from an earlier drain in 2.7 to 2.5 m asl within the groundwater table oscillation zone. But these upper deposits have not been analysed and from only one water sample it is difficult to estimate how stable these conditions are.

MB42 has its filter in 0.6 to -0.4 m asl covering layers with poor and medium preservation state. Compared to MB41 salt (Cl) and the contents of Ca, NH_4, and PO_4 are reduced to about half but the amount of sulphate increased threefold to 0.12 mmol/L (similar conditions prevail at MB1). Besides some iron and manganese, there is also sulphide and methane present documenting the transition to more stagnant and reduced conditions in the deeper soil below sea level.

Alkalinity at MB41 and MB42 is with 7 mmol/L in the range of values measured at other dipwells with water intake in the unsaturated zone and down to ca. -1 m asl as f. ex. at MB32, MB21, MB1 and MB39 (Figure 14). Groundwater and soil pH values are near neutral with 6.5 for both dipwells but soil pH was slightly higher. Values > 7 as measured in all depths at MB42 are also encountered under more stagnant conditions in deposits of the central area of Bryggen (MB6, MB38 and FJB3).

The groundwater chemistry at FJB3 with its filter underneath the cultural deposits reflects a mixture of groundwater and water from the cultural deposits above and has a slightly higher SO_4 and HS^- content than other deep dipwells in bedrock or natural sediment. Some past and on-going sulphate reduction is corroborated by the observation of a medium to strong H_2S odour throughout the depth profile to -6 m asl during installation of the dipwell and the finding of ca. 5 mg/g dw pyrite-S at -4.75 m asl. Otherwise it is not clear where the water comes from and no conclusions about the preservation conditions in the cultural layers above can be drawn from the groundwater chemistry.

4.2.2.3 Conclusion: Preservation conditions and future work

At ***MB41*** from 2.5 to 0.5 m asl the PresCon is regarded poor (2). The deposits have a porous loose to semi-compact nature, are partly located above groundwater level and therefore more accessible for oxidants in an area with groundwater level variations of approximately 1 m. The presence of nitrate in the groundwater indicates impact of increased rainwater flow and only moderately reducing conditions at the filter depth. Enrichment of NH_4 and PO_4 in the water and the at least 15 times higher reactivity (O_2 consumption) compared to soil from the unsaturated zone corroborate on-going intense mineralization of organic matter. The actual decay rate will depend on the supply of oxidants and nutrients and cannot be estimated from only one sampling.

At ***MB42*** from 0.8 to 0.45 m asl preservation conditions are regarded poor (PresCon 2) due to the proximity to the minimum groundwater level which might alter redox conditions and fuel microbial decay of organic matter in the fine grained and N-rich layer. The vulnerability of this layer is confirmed by a high reactivity to oxygen, which is in the upper range of rates found below sea level. However, the effect of further degradation will be limited as not much of the cultural deposits are found above groundwater level.
Below 0.45 to -0.85 m asl preservation conditions can be estimated as medium (PresCon 3). The deposits are less prone to groundwater table changes and the compact layer above may act as protection for the organic deposits below with respect to the supply of oxidants. There is some sulphate present in the groundwater, which may stem from the upper layer as the filter reaches into both poor and medium preserved layers, but the supply rate to the deeper deposits may be low. More stagnant conditions in these depths are indicated by the presence of methane and increasing water soluble soil Cl concentrations with depth which are up to three times higher than the groundwater concentration.

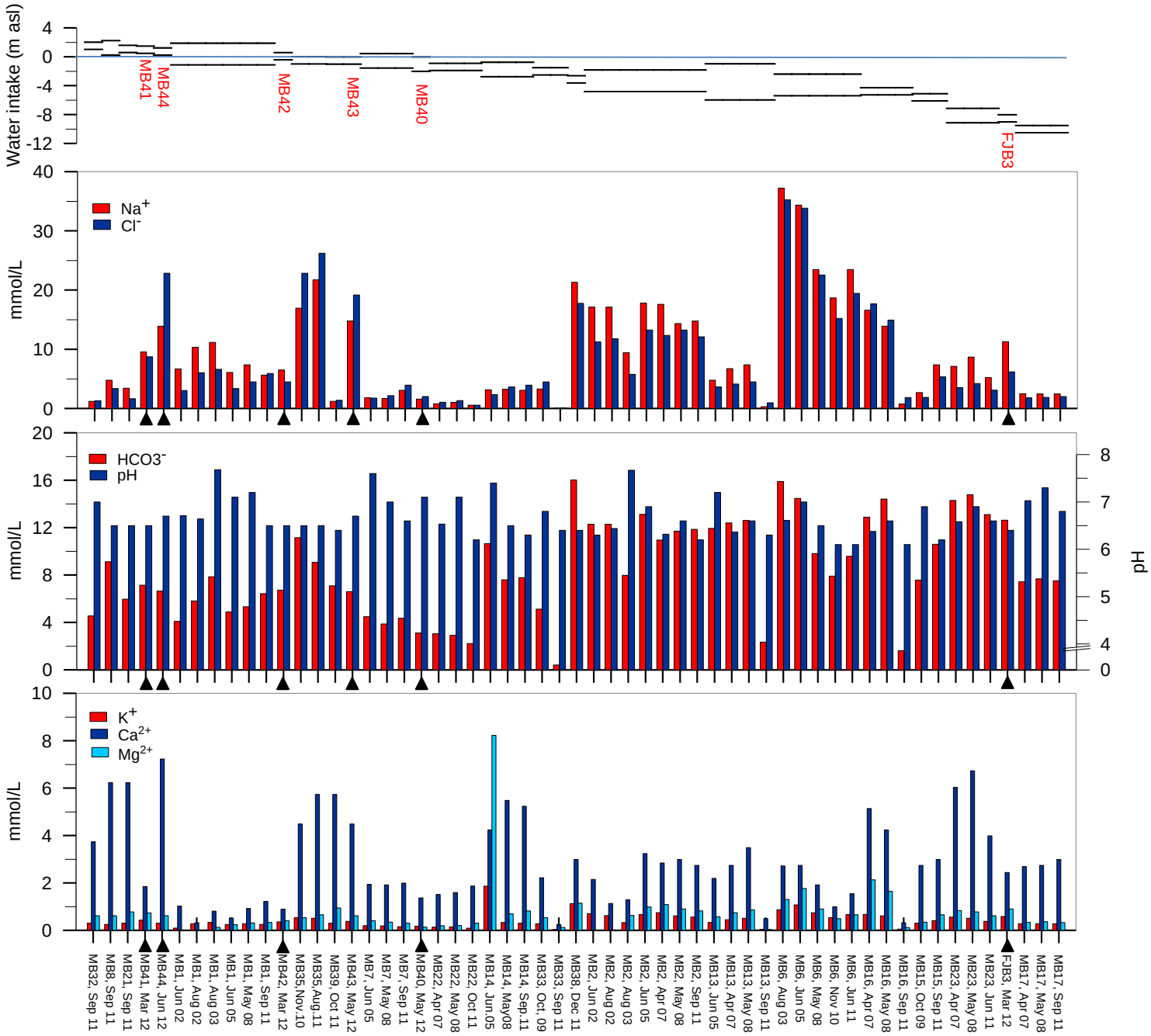
At ***FJB3*** the preservation conditions in surface deposits down to 0.65 m asl, approximately the groundwater level minimum, can be described as poor (PresCon 2). A relatively compact organic layer from 0.65 to 0.35 m asl with the lowest reactivity for oxygen in the profile might also preserve the layers

below (semi-compact to relatively compact humus and timber layers), which therefore have maintained a medium to good preservation state down to -2.4 m asl. Below sea level, increasing and very high LOI of the organic layers and a higher reactivity indicate improving preservation conditions with depth. All in all, preservation conditions of compact to semi-compact highly organic and moss containing layers beneath -2.4 m asl can be regarded good or even excellent (PresCon 4 – 5). The groundwater chemistry cannot be used to evaluate the actual preservation conditions in the cultural deposits above but sulphate concentrations in the soil and dipwell are still very moderate.

These are first estimates of the preservation conditions and from only one groundwater sampling it is difficult to evaluate if these conditions are stable. They will most likely have changed already due to the groundwater level elevation and beginning infiltration of water since June 2012.

Future work

Groundwater level elevation also affects the dipwells MB41 and MB42 (and FJB3), which should be included in the monitoring of the impact of the nearby water infiltration. This will enable us to follow the effects of the changing redox conditions and possible initial leaching of nutrients and SO_4 from the surface deposits on microbial decay and in particular sulphate reduction.


Water intake (m asl)
4
0
-4
-8
-12
MB41
MB44
MB42
MB43
MB40
FJB3
40
30
20
10
0
mmol/L
Na+
Cl-
20
16
12
8
4
0
HCO3-
pH
8
7
6
5
4
0
pH
10
8
6
4
2
0
K+
Ca2+
Mg2+
MB32, Sep 11
MB8, Sep 11
MB21, Sep 11
MB41, Mar 12
MB44, Jun 12
MB1, Jun 02
MB1, Aug 02
MB1, Aug 03
MB1, Jun 05
MB1, May 08
MB1, Sep 11
MB42, Mar 12
MB35,Nov.10
MB35,Aug.11
MB39, Oct 11
MB43, May 12
MB7, Jun 05
MB7, May 08
MB7, Sep 11
MB40, May 12
MB22, Apr 07
MB22, May 08
MB22, Oct 11
MB14, Jun.05
MB14, May08
MB14, Sep.11
MB33, Oct. 09
MB33, Sep 11
MB38, Dec 11
MB2, Jun 02
MB2, Aug 02
MB2, Aug 03
MB2, Jun 05
MB2, Apr 07
MB2, May 08
MB2, Sep 11
MB13, Jun 05
MB13, Apr 07
MB13, May 08
MB13, Sep 11
MB6, Aug 03
MB6, Jun 05
MB6, May 08
MB6, Nov 10
MB6, Jun 11
MB16, Apr 07
MB16, May 08
MB16, Sep 11
MB15, Oct 09
MB15, Sep 11
MB23, Apr 07
MB23, May 08
MB23, Jun 11
FJB3, Mar 12
MB17, Apr 07
MB17, May 08
MB17, Sep 11

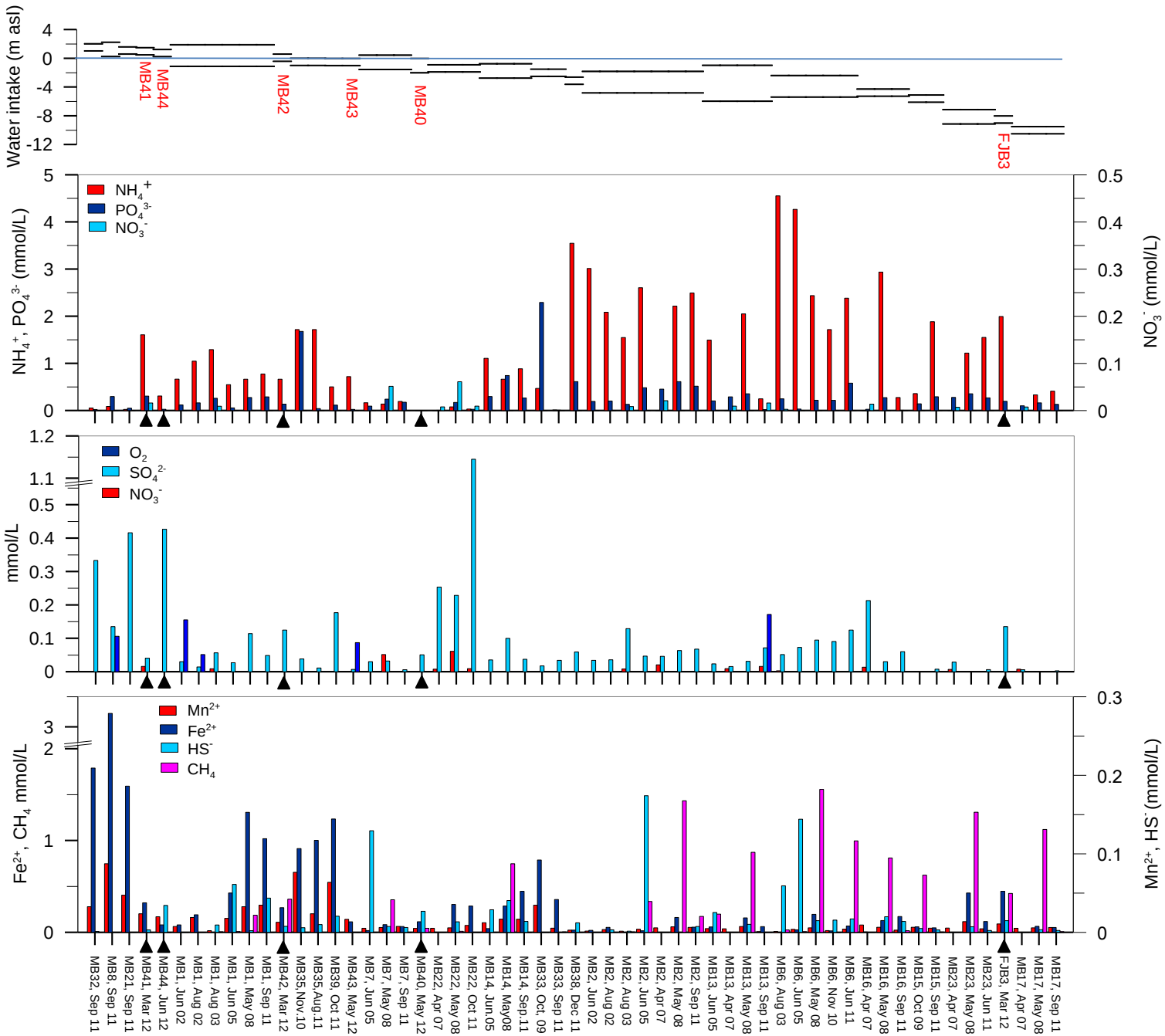


Figure 14: Comparison of the groundwater chemistry of the new dipwells MB41, MB42 and FJB3 with selected earlier installed dipwells (time series) in the area east of the hotel

4.3 Rosenkrantzgate (MB43) and Lodin Lepps gate (MB44)

4.3.1 State of preservation (SoPS) at MB43 and MB44

The upper soil profile at MB43 (Figure 2c) consists of 5.2 m modern deposits, mainly sand and demolition material down to 1.90 m asl. Medieval deposits from 1.90 to 0 m asl comprise layers of wet quite sandy humus and very loose sand and gravel with a poor state of preservation (A2/B2/C2) and a low LOI of 5 – 7%. Further degradation in these depths can be expected to be low as confirmed by the very low reactivity of the wet sandy humus layer in 1.9 to 1.1 m asl with an oxygen consumption of 0.016 ±0.003 mg O_2 /g dw/d. Similar low reactivity has been measured in layers above the groundwater level at the test pit (Hollesen and Matthiesen 2012). The reactivity of the sand and gravel layer has not been analysed but is expected to be even lower. Beneath 0 to -1.5 m asl more organic and semi-compact to loose layers rich in woodchips with medium to good preservation (C3, C4) are found. The reactivity of the material, mainly woodchips, shows a steep increase in depths below sea level to a maximum consumption of 0.327 ±0.061 mg O_2/g dw/d at about -1 m asl. Good preservation state coincides with intermediate O_2 consumption of about 0.2 mg/g dw/d and a maximum in LOI of up to 56%. Drilling was abandoned at -1.50 m asl.

At MB44 the uppermost ca. 4.6 m consist of modern fill of sand, gravel, and demolition material down to 2.25 m asl. Beneath, down to 1.65 m asl, follow 0.6 m of medieval deposits (timber, humus) of indefinable to poor preservation state (A2). Below 1.65 m asl and down to the (minimum) groundwater table at ca. 1.2 m asl preservation state of the organic deposits improves to medium (A3/B3). LOI and reactivity is high (55% and 0.15 mg O_2/g dw/d) for the compact gyttja-like silty soil at 1.55 m to 1.30 m asl. The depths beneath 1.25 m asl, and just below groundwater table, have a high LOI (43 – 55%) and the preservation state of wet, loose to semi-compact saw- and woodchips is good (C4). However, a reactivity of 0.1 mg O_2/g dw/d is much lower than expected for organic material in good preservation state, e.g. at FJB3. The top of the natural moraine was reached at ca. 0.20 m asl.

Also other dipwells in this area are characterized by a cover of sandy porous modern and post-medieval deposits. At MB34 and MB35 at Finnegården preservation state of the first metre of post-medieval material, down to -2 m asl and 0.35 m asl respectively, is indefinable to poor and LOI content is low (8 – 16%). At MB34 preservation state of the post-medieval and medieval deposits below -2 m asl ranges from medium (C3, with an LOI of up to 55%) in loose but highly organic layers to good (C4) in a compact layer with laminated turf. At MB35 laminated highly organic medieval layers below 0.35 m asl have medium preservation (C3, LOI 21 – 38%). Intercalated sand and gravel containing layers with a couple of woodchips are of indefinable preservation.

MB14 is situated on the opposite side of the terrain elevation separating this part from central Bryggen. Here the upper 2.6 m consist of sticky soil, sandy humus and fire layer material. The medieval deposits from -0.34 m asl and downwards have a good to excellent preservation state (C4, C5, little humus, very organic, mostly plant remains, fresh woodchips, LOI > 60%).

Figure 15 compares preservation state and selected soil properties of the above mentioned dipwells.

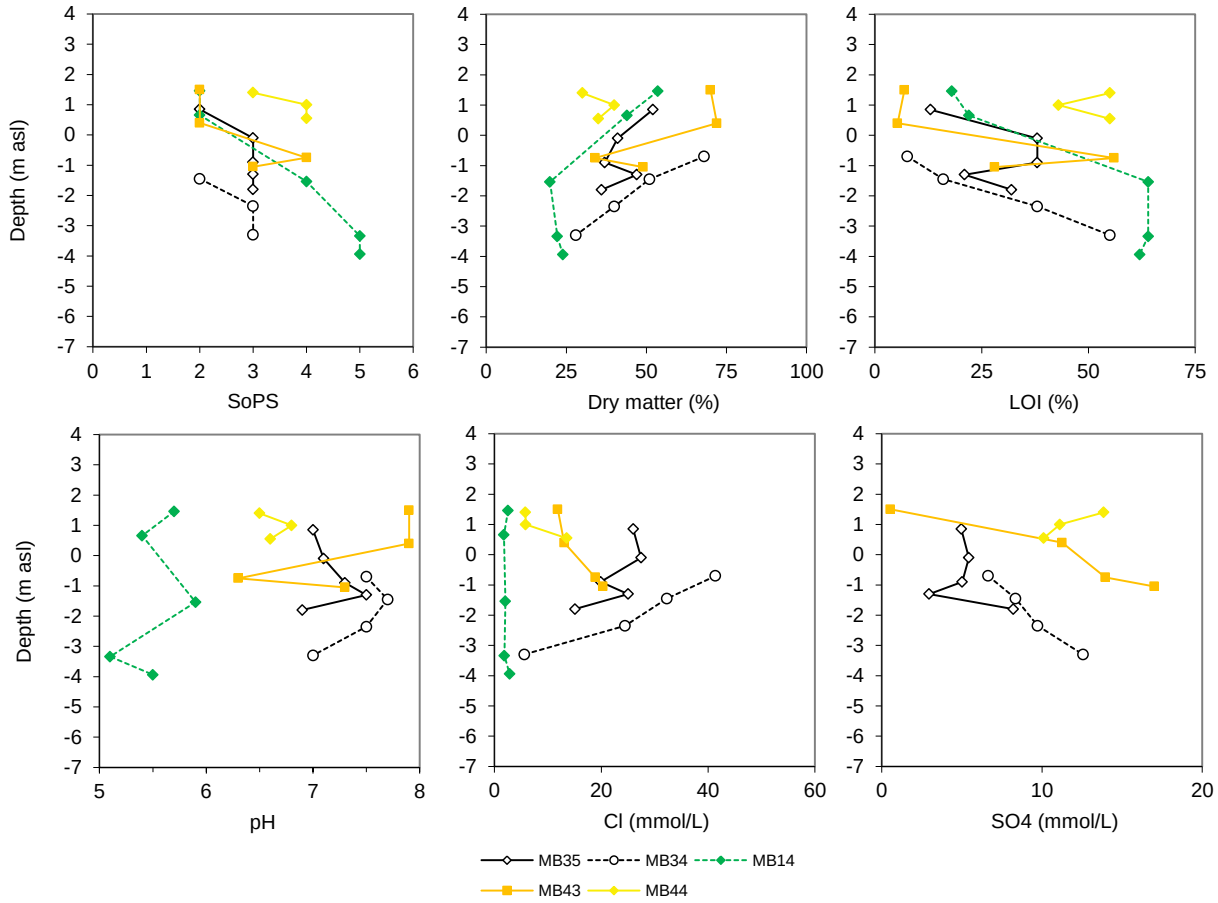


Figure 15 : Preservation state (SoPS, lousy (1) to excellent (5) after a scale from Dunlop), dry matter, loss of ignition (LOI), soil pH, and water soluble sulphate and chloride at selected dipwells installed between 2005 and 2012.

4.3.2 Preservation conditions (PresCon) at MB43 and MB44

4.3.2.1 Groundwater level

Groundwater level was measured on 10/5 and 11/6/2012 at ca. 1.2 m asl for both MB43 and MB44 (Figure 7). No continuous water level measurements are available for the two dipwells to date. Instead logger data from MB35 with a filter reaching from 0.03 m to -0.97 m asl, similar to MB43, is taken as a first hint of prevailing hydrodynamic conditions. Although the water table at MB35 remains on a stable level in autumn 2012, some rapid peaks in water level and temperature indicate impact of rainfall on the deposits below sea level down to filter depth. In this case, this is due to the presence of loose sand and gravel containing layers at the filter depth and it has to be verified, to which extent these conditions are also applicable for MB43 and MB44.

4.3.2.2 Groundwater chemistry: Redox conditions, nutrients and pH

Compared to other dipwells with a similar filter depth the results of MB43 and MB44 are not extraordinary (Figure 5 and 14).

Groundwater analysis of MB43 (Figure 3d) with a water intake between 0 and -1 m asl documents reduced conditions with NH_4 as the main reduced species. No HS^- was measured although a strong H_2S odour was noticed during installation of the dipwell. SO_4 concentrations are very low (0.01 mmol/L)

despite of a quite big pool of soil SO_4 reaching concentrations with up to 14-17 mmol/L at the filter depth at the time of installation (April 2012). Groundwater was first sampled approximately one month later, and another twelve days after groundwater sampling oxygen corresponding to ca. 26% air saturation was measured in the dipwell. These observations all indicate that transport and redox conditions could be quite variable at MB43. The water chemistry of MB44 with a filter in 1.25 to 0.25 m asl, and where the groundwater level was measured at 1.2 m asl at the time of sampling, shows only very weakly reducing conditions (Figure 3d) where the sum of concentrations of reduced species (Mn^{2+}, Fe^{2+}, HS^-, CH_4, NH_4) was almost equal to the concentration of oxidized species (only SO_4), oxygen was not measured.

Groundwater pH was 6.7 for both locations, soil pH varied between 6.3 and 7.9 at MB43 and between 6.5 and 6.8 at MB44. The pH minimum coincides with high LOI, maximum SO_4 and total sulphide content at the dipwells. The C/N ratio is in the typical range for Bryggen between 17 and 45 at MB43 and between 11 and 23 at MB44. The different nature of the deposits above sea level is clearly reflected in a low nutrient content in the loose sandy material at MB43 in contrast to the fine grained and organic layers at MB44, where the gyttja-like soil is enriched in N (almost 30 mg/g dw), S and SO_4. Higher availability of nutrients and oxidants is also reflected in a high reactivity of this layer.

MB43 and MB44, and MB35 from the same area east of central Bryggen, have a significantly higher salt content, in particular Cl, than other dipwells with a filter placed above or at sea level in the same distance from the harbour (Figure 14 and 15). At MB44 the chloride concentration in the groundwater is ca. 9 mmol/L or 1.7 times higher than in the soil, indicating that conditions might not be stable over time. An earlier study at Finnegården, MB34 and MB35 (Matthiesen 2011), analysed mixing of sea- and freshwater and concluded that a small marine contribution (1 – 5%) can explain the elevated salt concentrations in the area. Seawater could f. ex. penetrate through the porous and loose deposits, but an effect of tidally induced pressure changes is not visible in the water level dynamics at MB35. Use of de-icing salt in the area is a possible additional source of chloride.

The groundwater of the two dipwells is also enriched in calcium indicating a larger freshwater contribution to the water chemistry. Immediate reaction of the water level to rain events at MB35 corroborates a facilitated flow of rain and groundwater through the permeable deposits.

Strong H_2S odour noticed at both dipwells and the presence of 5 and 4 mg pyrite S/g dw in the deepest sample at MB43 and MB44 respectively, indicates that some sulphate reduction has been taken place and possibly is on-going. The gradient in the soil at MB43 indicates the deeper deposits as a source of SO_4. Assuming that all SO_4 and Cl in the groundwater stems from a seawater contribution alone, theoretical sulphate depletion can be calculated and results in the case of MB43 in a depletion of -0.75 mmol/L and -0.98 mmol/L at MB44. This is in the same order of magnitude as observed at MB35, where sulphate depletion in the groundwater was ca. -1.2 mmol/L (2010 and 2011), and confirms that some sulphate reduction has been going on. Overall the effect on actual degradation will be limited as the measured SO_4 concentrations at MB43 where very low and the input of seawater as a major source of SO_4 is only minor. At MB44 drying and rewetting processes as well as intensive organic matter mineralization processes in the unsaturated zone might be a substantial source for SO_4 in groundwater and soil. This is also reflected in a high SO_4/Cl ratio in the soil (Figure 16). However, for an assessment of the temporal variability of redox conditions and the actual contribution of SO_4 reduction to organic matter decay at rainwater and to a lesser degree seawater impacted dipwells more data are needed.

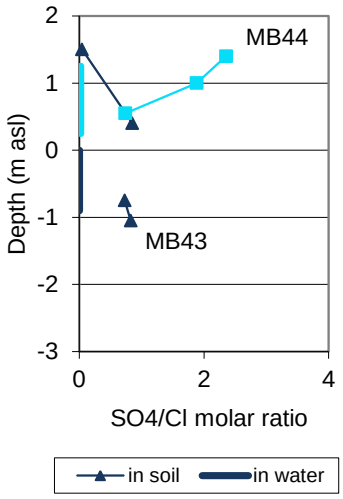


Figure 16: SO_4/Cl ratio in groundwater and soil at MB43 and MB44.

4.3.2.3 Conclusion: Preservation conditions and future work

The medieval deposits at MB43 and MB44 are covered by a few metres of porous modern material, leaving ca. 2 m cultural deposits above sea level, corresponding to the total depth of the cultural deposits at MB44.

Preservation conditions seem to be mainly controlled by the distribution of sandy or other permeable deposits. These porous layers act as preferential flow path for water draining from the unsaturated zone and rainwater and facilitate the supply of oxidants and nutrients. At and below sea level tidally induced propagation of seawater can increase the supply of SO_4 to the cultural deposits.

At MB43 sandy deposits reach down to sea level and the preservation conditions have to be regarded as lousy (PresCon 1), but the risk of further decay is low due to a low organic matter content (LOI 5 – 7%). Conditions at the filter depth, which with a position at ca. 0.05 to -0.95 m asl reaches just a few centimetres into permeable deposits, seem variable between reduced and the temporary presence of oxygen. Here, the loose sand and gravel layer at 1.1 to 0 m asl acts as preferential flow path and enables easy access for oxidants to the cultural layers below. It is therefore estimated that the loose to semi-compact organic layers below from 0 to -0.4 m asl, where reactivity is comparatively low, are threatened and preservation conditions are poor (PresCon 2). The deposits below -0.4 m asl have a high organic matter content and are more susceptible for decay as shown by the steep increase in reactivity. Here sulphate reduction could be the main risk, but measured HS^- concentrations were below detection limit and SO_4 concentrations were very low. Preservation conditions could be regarded as medium to good (PresCon 3 – 4). Further groundwater sampling as well as oxygen measurements could clarify how stable these conditions are and how frequently the deposits might be exposed to oxygen.

Weakly reducing conditions at MB44 with high concentrations of sulphate comparable to dipwells showing impact of drainage (e.g. MB21) and some on-going sulphate reduction under the wet conditions at and below groundwater level (shown by elevated sulphide concentrations similar to conditions found at other dipwells down to -2 m asl, Figure 5) indicate poor preservation conditions at the filter depth. There is a risk for further decay due to a high LOI (43 – 55%) and a still two to ten times higher reactivity of the soil than observed under lousy preservation conditions e.g. at MB37 and MB43. The effect might be limited. A compact gyttja-like soil with a dry appearance due to a high water-holding capacity might also act to a certain degree as barrier for downward transport of oxidants or drainage slowing down/retarding

potential degradation of the loose to semi-compact organic layers below groundwater level, but at this stage no information about the variability of the groundwater level is available.

Further studies

Further water sampling, logging of water level, temperature, salinity and measurement of oxygen in the dipwells is recommended for a better evaluation of the hydrodynamics (frequency of water table change and exchange of groundwater/seawater) and the long-term preservation conditions.

A more detailed investigation (on-going) about the contribution of the different components in a soil sample (humus, wood etc.) to the observed reactivity could help to estimate the susceptibility for decay from the soil composition together with the in situ supply of oxidants.

4.4 Areal summary

This paragraph summarizes the results for each area.

Harbour front (MB36 and MB37)

- MB36 and 37 have a high chloride content reflecting a considerable marine impact.

- Groundwater dynamics show a strong tidal or rainwater impact on the deposits at the NW side of the hotel which seem to be much more permeable than in other places at the harbour front. Tidal pressure propagates up to 120 m inland in the hotel area, as observed at MB40 at Bryggens Museum.

- Supply of oxidants can occur from the upper very porous sandy deposits which reach down to ca. -3 m asl (filter depth) at MB36. In general, most variable conditions are found around -2 to -3 m asl. Seawater impact near the harbour can be traced down to ca. -5 m asl. However, times with high concentrations of reduced species and/or sulphate depletion indicate that there can be more stable periods when pore water solutes can accumulate and supply of sulphate is restricted.

- Sulphate reduction can be locally important, also seen by the high content of sulphur and pyrite-S at MB36, but the dynamics and supply of sulphate are still not fully understood.

- Besides seawater rainwater infiltration and transport could be an additional threat in the upper deposits, but these are mostly inorganic. An exception is MB37, where an organic-rich compact layer seems to act as efficient barrier against downward transport of oxidants.

- ***Preservation conditions*** of the cultural deposits at ***MB36***
  From -1.2 to -1.8 m asl: Lousy (PresCon 1),
  from -1.8 to -2.8 m asl: Poor (PresCon 2),
  below -2.8 m asl: Preservation conditions seem to improve (a layer of timber could not be penetrated with the auger) but could not be evaluated.

- ***Preservation conditions*** of the cultural deposits at ***MB37***
  From 0 to -0.9 m asl (mostly sand): Lousy (PresCon 1),
  from -0.9 m asl to -2.55 m asl: Medium (PresCon 3, evaluated from soil and groundwater chemistry as the installation of the dipwell could have induced the observed high rainfall effect on groundwater level).

Bredsgården and Enjørningsgården (MB41, MB42 and FJB3)

- There is a pronounced rainwater impact at MB41, which indicates that this dipwell belongs to the drainage/rainwater impacted area north and north-east of the hotel.

- Groundwater level changes are gradually and increase the residence time of rainwater in the soil, in contrast to the drastic changes observed at MB37 in more porous deposits where rainwater drains fast and is replaced by "normal" groundwater without NO_3.

- Preservation state and conditions are poor above groundwater level, but increase to medium below coincident with a more stagnant environment in soil with a higher organic matter content, compactness and reactivity.

- Reactivity is related to the organic matter content and quality, a higher N content and some excrement in fine grained deposits is an important contributor.

- Compact organic-rich layers above groundwater level can act as a barrier against downward transport of oxidants.

- Conditions between -2 to ca. -4 or -5 m asl in the central part of Bryggen are significantly better than at the harbour front: Preservation state changes to good already at -2.4 m and to excellent from -4.4 m asl at FJB3.

- ***Preservation conditions*** of the cultural deposits at ***MB41****:*
  From 2.5 to 0.5 m asl: PresCon 2, poor,
  below 0.5 m asl: No information about the cultural deposits is available as drilling was abandoned at 0.5 m asl.

- ***Preservation conditions*** of the cultural deposits at ***MB42****:*
  From 0.8 to 0.45 m asl: PresCon 2, poor,
  from 0.45 m to -0.85 m asl (end of drilling): PresCon 3, medium.

- ***Preservation conditions*** of the cultural deposits at ***FJB3****:*
  From 0.9 to 0.65 m asl: PresCon 2, poor,
  from 0.65 m to -2.4 m asl: Medium to good, PresCon 3 – 4,
  from -2.4 m to -5.2 m asl (seabed): Good to excellent (PresCon 4 – 5)

Rosenkrantzgate (MB43) and Lodin Lepps gate (MB44)

- The upper soil layers are sandy with a low organic matter content (5 – 7% LOI) and almost unreactive and only a very small part of the cultural deposits is located above groundwater level.

- There is a certain seawater impact of a few percent reaching as far as ca. 77 m inland from the harbour front.

- Water level changes at MB35 and the presence of oxygen at MB43 indicate some rainwater impact and that the environmental conditions might not be stable over time.

- The extent of sulphate reduction is not known, also other sources, e.g. drying/rewetting processes in the unsaturated zone, contribute to high SO_4 concentrations in the soil and at MB44 also in the groundwater.

- Depending on the distribution of porous deposits, preservation conditions are lousy (PresCon 1) at least down to groundwater level, but improve to medium and good (PresCon 3 – 4) just below sea level. At MB44 a compact gyttja-like soil seems to protect the underlying more organic layers from decay, but there reactivity has already decreased to around 0.1 mg O_2/g dw/d, which is closer to values found under poor preservation conditions. Furthermore, the groundwater chemistry documents only very weakly reducing conditions at the groundwater table.

- ***Preservation conditions*** of the cultural deposits at ***MB43***
  From 1.9 to 0 m asl: Lousy, PresCon 1,
  from 0 to -0.4 m asl: Poor, PresCon 2,
  from -0.4 to -1.5 m asl: Medium to good, PresCon 3 – 4.

- ***Preservation conditions*** of the cultural deposits at ***MB44***
  From 2.25 to 1.65 m asl: Above groundwater table, lousy, PresCon 1,
  from 1.65 to 1.25 asl: Fluctuating groundwater table, poor, PresCon 2,
  from 1.25 to 0.20 m asl: Below groundwater table, medium, PresCon 3.
  The cultural deposits at and below groundwater level are still in a state of medium to good preservation (SoPS 3 – 4) but seem to be under threat from supply of oxidants from above.

To evaluate the actual dynamics at the new dipwells more frequent groundwater samplings and further long-term monitoring of salinity and oxygen are required.

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Appendix 1

Results from analysis of soil samples from MB36, MB37, MB41, MB42, MB43, MB44 and FJB3 (Eurofins)

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Nationalmuseet
Bevaringsafdelingen, Arkæologi
I.C.Modewegs vej
2800 Kgs.Lyngby

Att.: Henning Matthiesen

Registernr.:	C70285
Kundenr.:	82983
Ordrenr.:	407823
Prøvenr.:	C7028501
Sagsnr.:	407823
Modt. dato:	2012.02.13
Sidenr.:	1 af 12

ANALYSERAPPORT

Rekvirent.....: Nationalmuseet, Bevaringsafdelingen, Arkæologi
I.C.Modewegs vej, 2800 Kgs.Lyngby
Prøvested.....: **Kundenr. 82983**
Prøvetype.....: Jord
Prøvemærke.....: **MB36-01**
Prøveudtagning...: 2011.12.11
Prøvetager.....: Rekvirenten
Kundeoplysninger.:
Analyseperiode...: 2012.02.15 - 2012.02.24

Prøvenr.:	**C7028501**			
Prøve ID:				
Prøvemærke:		Detekt. grænse	Metoder	Um (%)
pH	**7.4 pH**		DS/EN 12176	
Tørstof	**72 %**	0.05	DS 204 mod.	10
Glødetab på tørstof	**5.3 % i ts.**	0.10	DS 204	20
Kvælstof, total	**640 mg/kg**	5	NF 1975	20
Kvælstof, total	**890 mg/kg ts.**		Beregning	20
Phosphor, total	**1400 mg/kg ts.**	100	DS259/SM3120ICP	30
Phosphor, total	**990 mg/kg**		Beregning	
Chlorid, vandopløselig	**4900 mg/kg ts.**	5	*SM 17.udg. 4500	20
Sulfat,vandopløselig	**1200 mg/kg ts.**	1	*SM 17.udg. 4500	20
Svovl, total	**23000 mg/kg ts.**	50.0	DS259/SM3120ICP	30

*) Ikke omfattet af akkrediteringen.

Um(%): Den ekspanderede måleusikkerhed Um er lig 2 x RSD%, se i øvrigt www.eurofins.dk, søgeord: Måleusikkerhed.

Tegnforklaring:
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Ordrenr.:	407823
Prøvenr.:	C7028502
Sagsnr.:	407823
Modt. dato:	2012.02.13
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ANALYSERAPPORT

Rekvirent.....: Nationalmuseet, Bevaringsafdelingen, Arkæologi
I.C.Modewegs vej, 2800 Kgs.Lyngby
Prøvested.....: **Kundenr. 82983**
Prøvetype.....: Jord
Prøvemærke.....: **MB36-02**
Prøveudtagning...: 2011.12.11
Prøvetager.....: Rekvirenten
Kundeoplysninger.:
Analyseperiode...: 2012.02.15 - 2012.02.24

Prøvenr.:	**C7028502**			
Prøve ID:				
Prøvemærke:		Detekt. grænse	Metoder	Um (%)
pH	**7.5 pH**		DS/EN 12176	
Tørstof	**43 %**	0.05	DS 204 mod.	10
Glødetab på tørstof	**24 % i ts.**	0.10	DS 204	20
Kvælstof, total	**1700 mg/kg**	5	NF 1975	20
Kvælstof, total	**3900 mg/kg ts.**		Beregning	20
Phosphor, total	**3100 mg/kg ts.**	100	DS259/SM3120ICP	30
Phosphor, total	**1300 mg/kg**		Beregning	
Chlorid, vandopløselig	**12000 mg/kg ts.**	5	*SM 17.udg. 4500	20
Sulfat,vandopløselig	**1900 mg/kg ts.**	1	*SM 17.udg. 4500	20
Svovl, total	**7100 mg/kg ts.**	50.0	DS259/SM3120ICP	30

*) Ikke omfattet af akkrediteringen.

Um(%): Den ekspanderede måleusikkerhed Um er lig 2 x RSD%, se i øvrigt www.eurofins.dk, søgeord: Måleusikkerhed.

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Sagsnr.:	407823
Modt. dato:	2012.02.13
Sidenr.:	3 af 12

ANALYSERAPPORT

Rekvirent.....: Nationalmuseet, Bevaringsafdelingen, Arkæologi
I.C.Modewegs vej, 2800 Kgs.Lyngby
Prøvested.....: **Kundenr. 82983**
Prøvetype.....: Jord
Prøvemærke.....: **MB36-03**
Prøveudtagning...: 2011.12.11
Prøvetager.....: Rekvirenten
Kundeoplysninger.:
Analyseperiode...: 2012.02.15 - 2012.02.24

Prøvenr.:	**C7028503**			
Prøve ID:				
Prøvemærke:		Detekt. grænse	Metoder	Um (%)
pH	**7.5 pH**		DS/EN 12176	
Tørstof	**54 %**	0.05	DS 204 mod.	10
Glødetab på tørstof	**13 % i ts.**	0.10	DS 204	20
Kvælstof, total	**1000 mg/kg**	5	NF 1975	20
Kvælstof, total	**1900 mg/kg ts.**		Beregning	20
Phosphor, total	**1900 mg/kg ts.**	100	DS259/SM3120ICP	30
Phosphor, total	**1000 mg/kg**		Beregning	
Chlorid, vandopløselig	**7400 mg/kg ts.**	5	*SM 17.udg. 4500	20
Sulfat,vandopløselig	**1800 mg/kg ts.**	1	*SM 17.udg. 4500	20
Svovl, total	**7900 mg/kg ts.**	50.0	DS259/SM3120ICP	30
Pyrit, FeS2	**1.1 % i ts.**	0.01	*SM3120 mod.	

*) Ikke omfattet af akkrediteringen.

Um(%): Den ekspanderede måleusikkerhed Um er lig 2 x RSD%, se i øvrigt www.eurofins.dk, søgeord: Måleusikkerhed.

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Prøvenr.:	C7028504
Sagsnr.:	407823
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ANALYSERAPPORT

Rekvirent.....: Nationalmuseet, Bevaringsafdelingen, Arkæologi
I.C.Modewegs vej, 2800 Kgs.Lyngby
Prøvested.....: **Kundenr. 82983**
Prøvetype.....: Jord
Prøvemærke.....: **MB37-01**
Prøveudtagning...: 2011.12.11
Prøvetager.....: Rekvirenten
Kundeoplysninger.:
Analyseperiode...: 2012.02.15 - 2012.02.24

Prøvenr.: / Prøve ID: / Prøvemærke:		Detekt. grænse	Metoder	Um (%)
pH	**7.8 pH**		DS/EN 12176	
Tørstof	**68 %**	0.05	DS 204 mod.	10
Glødetab på tørstof	**8.8 % i ts.**	0.10	DS 204	20
Kvælstof, total	**1200 mg/kg**	5	NF 1975	20
Kvælstof, total	**1700 mg/kg ts.**		Beregning	20
Phosphor, total	**2600 mg/kg ts.**	100	DS259/SM3120ICP	30
Phosphor, total	**1800 mg/kg**		Beregning	
Chlorid, vandopløselig	**2900 mg/kg ts.**	5	*SM 17.udg. 4500	20
Sulfat,vandopløselig	**1300 mg/kg ts.**	1	*SM 17.udg. 4500	20
Svovl, total	**1600 mg/kg ts.**	50.0	DS259/SM3120ICP	30

*) Ikke omfattet af akkrediteringen.

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Sagsnr.:	407823
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ANALYSERAPPORT

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Prøvested.....: **Kundenr. 82983**
Prøvetype.....: Jord
Prøvemærke.....: **MB37-02**
Prøveudtagning...: 2011.12.11
Prøvetager.....: Rekvirenten
Kundeoplysninger.:
Analyseperiode...: 2012.02.15 - 2012.02.24

Prøvenr.: / Prøve ID: / Prøvemærke:	**C7028505**	Detekt. grænse	Metoder	Um (%)
pH	**7.1 pH**		DS/EN 12176	
Tørstof	**20 %**	0.05	DS 204 mod.	10
Glødetab på tørstof	**70 % i ts.**	0.10	DS 204	20
Kvælstof, total	**2700 mg/kg**	5	NF 1975	20
Kvælstof, total	**13000 mg/kg ts.**		Beregning	20
Phosphor, total	**3700 mg/kg ts.**	100	DS259/SM3120ICP	30
Phosphor, total	**750 mg/kg**		Beregning	
Chlorid, vandopløselig	**18000 mg/kg ts.**	5	*SM 17.udg. 4500	20
Sulfat,vandopløselig	**1700 mg/kg ts.**	1	*SM 17.udg. 4500	20
Svovl, total	**19000 mg/kg ts.**	50.0	DS259/SM3120ICP	30

*) Ikke omfattet af akkrediteringen.

Um(%): Den ekspanderede måleusikkerhed Um er lig 2 x RSD%, se i øvrigt www.eurofins.dk, søgeord: Måleusikkerhed.

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Sagsnr.:	407823
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ANALYSERAPPORT

Rekvirent.....: Nationalmuseet, Bevaringsafdelingen, Arkæologi
I.C.Modewegs vej, 2800 Kgs.Lyngby
Prøvested.....: **Kundenr. 82983**
Prøvetype.....: Jord
Prøvemærke.....: **MB37-03**
Prøveudtagning...: 2011.12.11
Prøvetager.....: Rekvirenten
Kundeoplysninger.:
Analyseperiode...: 2012.02.15 - 2012.02.24

Prøvenr.: / Prøve ID: / Prøvemærke:	**C7028506**	Detekt. grænse	Metoder	Um (%)
pH	**7.0 pH**		DS/EN 12176	
Tørstof	**29 %**	0.05	DS 204 mod.	10
Glødetab på tørstof	**41 % i ts.**	0.10	DS 204	20
Kvælstof, total	**1900 mg/kg**	5	NF 1975	20
Kvælstof, total	**6500 mg/kg ts.**		Beregning	20
Phosphor, total	**6500 mg/kg ts.**	100	DS259/SM3120ICP	30
Phosphor, total	**1900 mg/kg**		Beregning	
Chlorid, vandopløselig	**9200 mg/kg ts.**	5	*SM 17.udg. 4500	20
Sulfat,vandopløselig	**940 mg/kg ts.**	1	*SM 17.udg. 4500	20
Svovl, total	**11000 mg/kg ts.**	50.0	DS259/SM3120ICP	30
Pyrit, FeS2	**0.86 % i ts.**	0.01	*SM3120 mod.	

*) Ikke omfattet af akkrediteringen.

Um(%): Den ekspanderede måleusikkerhed Um er lig 2 x RSD%, se i øvrigt www.eurofins.dk, søgeord: Måleusikkerhed.

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Att.: Henning Matthiesen

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Kundenr.:	82983
Ordrenr.:	407823
Prøvenr.:	C7028507
Sagsnr.:	407823
Modt. dato:	2012.02.13
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ANALYSERAPPORT

Rekvirent.....: Nationalmuseet, Bevaringsafdelingen, Arkæologi
I.C.Modewegs vej, 2800 Kgs.Lyngby
Prøvested.....: **Kundenr. 82983**
Prøvetype.....: Jord
Prøvemærke.....: **MB41-01**
Prøveudtagning...: 2011.12.11
Prøvetager.....: Rekvirenten
Kundeoplysninger.:
Analyseperiode...: 2012.02.15 - 2012.02.24

Prøvenr.: / Prøve ID: / Prøvemærke:	**C7028507**	Detekt. grænse	Metoder	Um (%)
pH	**6.6 pH**		DS/EN 12176	
Tørstof	**38 %**	0.05	DS 204 mod.	10
Glødetab på tørstof	**28 % i ts.**	0.10	DS 204	20
Kvælstof, total	**2300 mg/kg**	5	NF 1975	20
Kvælstof, total	**5900 mg/kg ts.**		Beregning	20
Phosphor, total	**8300 mg/kg ts.**	100	DS259/SM3120ICP	30
Phosphor, total	**3200 mg/kg**		Beregning	
Chlorid, vandopløselig	**270 mg/kg ts.**	5	*SM 17.udg. 4500	20
Sulfat,vandopløselig	**620 mg/kg ts.**	1	*SM 17.udg. 4500	20
Svovl, total	**17000 mg/kg ts.**	50.0	DS259/SM3120ICP	30

*) Ikke omfattet af akkrediteringen.

Um(%): Den ekspanderede måleusikkerhed Um er lig 2 x RSD%, se i øvrigt www.eurofins.dk, søgeord: Måleusikkerhed.

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Kundenr.: 82983
Ordrenr.: 407823
Prøvenr.: C7028508
Sagsnr.: 407823
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ANALYSERAPPORT

Rekvirent.....: Nationalmuseet, Bevaringsafdelingen, Arkæologi
I.C.Modewegs vej, 2800 Kgs.Lyngby
Prøvested.....: **Kundenr. 82983**
Prøvetype.....: Jord
Prøvemærke.....: **MB41-02**
Prøveudtagning...: 2011.12.11
Prøvetager.....: Rekvirenten
Kundeoplysninger.:
Analyseperiode...: 2012.02.15 - 2012.02.24

Prøvenr.: / Prøve ID: / Prøvemærke:	**C7028508**	Detekt. grænse	Metoder	Um (%)
pH	**7.2 pH**		DS/EN 12176	
Tørstof	**41 %**	0.05	DS 204 mod.	10
Glødetab på tørstof	**31 % i ts.**	0.10	DS 204	20
Kvælstof, total	**4300 mg/kg**	5	NF 1975	20
Kvælstof, total	**10000 mg/kg ts.**		Beregning	20
Phosphor, total	**5000 mg/kg ts.**	100	DS259/SM3120ICP	30
Phosphor, total	**2000 mg/kg**		Beregning	
Chlorid, vandopløselig	**520 mg/kg ts.**	5	*SM 17.udg. 4500	20
Sulfat,vandopløselig	**350 mg/kg ts.**	1	*SM 17.udg. 4500	20
Svovl, total	**3600 mg/kg ts.**	50.0	DS259/SM3120ICP	30

*) Ikke omfattet af akkrediteringen.

Um(%): Den ekspanderede måleusikkerhed Um er lig 2 x RSD%, se i øvrigt www.eurofins.dk, søgeord: Måleusikkerhed.

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ANALYSERAPPORT

Rekvirent.....: Nationalmuseet, Bevaringsafdelingen, Arkæologi
I.C.Modewegs vej, 2800 Kgs.Lyngby
Prøvested.....: **Kundenr. 82983**
Prøvetype.....: Jord
Prøvemærke.....: **MB41-03**
Prøveudtagning...: 2011.12.11
Prøvetager.....: Rekvirenten
Kundeoplysninger.:
Analyseperiode...: 2012.02.15 - 2012.02.24

Prøvenr.:	**C7028509**			
Prøve ID:				
Prøvemærke:		Detekt. grænse	Metoder	Um (%)
pH	**6.9 pH**		DS/EN 12176	
Tørstof	**27 %**	0.05	DS 204 mod.	10
Glødetab på tørstof	**49 % i ts.**	0.10	DS 204	20
Kvælstof, total	**4100 mg/kg**	5	NF 1975	20
Kvælstof, total	**15000 mg/kg ts.**		Beregning	20
Phosphor, total	**7400 mg/kg ts.**	100	DS259/SM3120ICP	30
Phosphor, total	**2000 mg/kg**		Beregning	
Chlorid, vandopløselig	**940 mg/kg ts.**	5	*SM 17.udg. 4500	20
Sulfat,vandopløselig	**650 mg/kg ts.**	1	*SM 17.udg. 4500	20
Svovl, total	**6500 mg/kg ts.**	50.0	DS259/SM3120ICP	30

*) Ikke omfattet af akkrediteringen.

Um(%): Den ekspanderede måleusikkerhed Um er lig 2 x RSD%, se i øvrigt www.eurofins.dk, søgeord: Måleusikkerhed.

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Sagsnr.:	407823
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ANALYSERAPPORT

Rekvirent.....: Nationalmuseet, Bevaringsafdelingen, Arkæologi
I.C.Modewegs vej, 2800 Kgs.Lyngby
Prøvested.....: **Kundenr. 82983**
Prøvetype.....: Jord
Prøvemærke.....: **MB42-01**
Prøveudtagning...: 2011.12.11
Prøvetager.....: Rekvirenten
Kundeoplysninger.:
Analyseperiode...: 2012.02.15 - 2012.02.24

Prøvenr.: / Prøve ID: / Prøvemærke:	**C7028510**	Detekt. grænse	Metoder	Um (%)
pH	**7.2 pH**		DS/EN 12176	
Tørstof	**32 %**	0.05	DS 204 mod.	10
Glødetab på tørstof	**50 % i ts.**	0.10	DS 204	20
Kvælstof, total	**6200 mg/kg**	5	NF 1975	20
Kvælstof, total	**19000 mg/kg ts.**		Beregning	20
Phosphor, total	**2400 mg/kg ts.**	100	DS259/SM3120ICP	30
Phosphor, total	**770 mg/kg**		Beregning	
Chlorid, vandopløselig	**560 mg/kg ts.**	5	*SM 17.udg. 4500	20
Sulfat,vandopløselig	**950 mg/kg ts.**	1	*SM 17.udg. 4500	20
Svovl, total	**14000 mg/kg ts.**	50.0	DS259/SM3120ICP	30

*) Ikke omfattet af akkrediteringen.

Um(%): Den ekspanderede måleusikkerhed Um er lig 2 x RSD%, se i øvrigt www.eurofins.dk, søgeord: Måleusikkerhed.

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Nationalmuseet
Bevaringsafdelingen, Arkæologi
I.C.Modewegs vej
2800 Kgs.Lyngby

Att.: Henning Matthiesen

Registernr.: C70285
Kundenr.: 82983
Ordrenr.: 407823
Prøvenr.: C7028511
Sagsnr.: 407823
Modt. dato: 2012.02.13

ANALYSERAPPORT

Rekvirent.....: Nationalmuseet, Bevaringsafdelingen, Arkæologi
I.C.Modewegs vej, 2800 Kgs.Lyngby
Prøvested.....: **Kundenr. 82983**
Prøvetype.....: Jord
Prøvemærke.....: **MB42-02**
Prøveudtagning...: 2011.12.11
Prøvetager.....: Rekvirenten
Kundeoplysninger.:
Analyseperiode...: 2012.02.15 - 2012.02.24

Prøvenr.: / Prøve ID: / Prøvemærke:	**C7028511**	Detekt. grænse	Metoder	Um (%)
pH	**7.2 pH**		DS/EN 12176	
Tørstof	**33 %**	0.05	DS 204 mod.	10
Glødetab på tørstof	**40 % i ts.**	0.10	DS 204	20
Kvælstof, total	**3000 mg/kg**	5	NF 1975	20
Kvælstof, total	**9100 mg/kg ts.**		Beregning	20
Phosphor, total	**3500 mg/kg ts.**	100	DS259/SM3120ICP	30
Phosphor, total	**1100 mg/kg**		Beregning	
Chlorid, vandopløselig	**870 mg/kg ts.**	5	*SM 17.udg. 4500	20
Sulfat,vandopløselig	**940 mg/kg ts.**	1	*SM 17.udg. 4500	20
Svovl, total	**9700 mg/kg ts.**	50.0	DS259/SM3120ICP	30

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Att.: Henning Matthiesen

Registernr.: C70285
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Ordrenr.: 407823
Prøvenr.: C7028512
Sagsnr.: 407823
Modt. dato: 2012.02.13

ANALYSERAPPORT

Rekvirent.....: Nationalmuseet, Bevaringsafdelingen, Arkæologi
I.C.Modewegs vej, 2800 Kgs.Lyngby
Prøvested.....: **Kundenr. 82983**
Prøvetype.....: Jord
Prøvemærke.....: **MB42-03**
Prøveudtagning...: 2011.12.11
Prøvetager.....: Rekvirenten
Kundeoplysninger.:
Analyseperiode...: 2012.02.15 - 2012.02.24

Prøvenr.: / Prøve ID: / Prøvemærke:	**C7028512**	Detekt. grænse	Metoder	Um (%)
pH	**7.1 pH**		DS/EN 12176	
Tørstof	**30 %**	0.05	DS 204 mod.	10
Glødetab på tørstof	**51 % i ts.**	0.10	DS 204	20
Kvælstof, total	**4700 mg/kg**	5	NF 1975	20
Kvælstof, total	**16000 mg/kg ts.**		Beregning	20
Phosphor, total	**7400 mg/kg ts.**	100	DS259/SM3120ICP	30
Phosphor, total	**2200 mg/kg**		Beregning	
Chlorid, vandopløselig	**1100 mg/kg ts.**	5	*SM 17.udg. 4500	20
Sulfat,vandopløselig	**690 mg/kg ts.**	1	*SM 17.udg. 4500	20
Svovl, total	**12000 mg/kg ts.**	50.0	DS259/SM3120ICP	30

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24. februar 2012

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Att.: Henning Matthiesen

Registernr.: C78482
Kundenr.: 82983
Ordrenr.: 407823

Sagsnr.: 11031305
Modt. dato: 2012.05.21

ANALYSERAPPORT

Sidenr.: 1 af 2

Rekvirent.....: Nationalmuseet, Bevaringsafdelingen, Arkæologi
I.C.Modewegs vej, 2800 Kgs.Lyngby
Prøvested.....: **Bryggen MB43, MB44 (statsbyg) ref**
Prøvetype.....: Sediment
Prøveudtagning...:
Prøvetager.....: Rekvirenten
Kundeoplysninger.: april 2012
Analyseperiode...: 2012.05.23 - 2012.06.01

Prøvenr.:	C7848201	C7848202	C7848203	C7848204				
Prøve ID:						Detekt.		Um
Prøvemærke:	MB43-01	MB43-02	MB43-04	MB43-05	Enheder	grænse	Metoder	(%)
pH	**7.9**	**7.9**	**6.3**	**7.3**	pH		DS/EN 12176	
Tørstof	**70**	**72**	**34**	**49**	%	0.05	DS 204 mod.	10
Glødetab på tørstof	**6.9**	**5.3**	**56**	**28**	% i ts.	0.10	DS 204	20
Kvælstof, total	**1300**	**1300**	**2500**	**2400**	mg/kg	5	NF 1975	20
Kvælstof, total	**1900**	**1800**	**7200**	**4900**	mg/kg ts.		Beregning	20
Phosphor, total	**4100**	**3000**	**6800**	**9400**	mg/kg ts.	100	DS259/SM3120ICP	30
Phosphor, total	**2900**	**2200**	**2300**	**4600**	mg/kg		Beregning	
Chlorid, vandopløselig	**180**	**180**	**1300**	**750**	mg/kg ts.	5	*SM 17.udg. 4500	20
Sulfat,vandopløselig	**22**	**420**	**2600**	**1700**	mg/kg ts.	1	*SM 17.udg. 4500	20
Svovl, total	**2000**	**1700**	**18000**	**8800**	mg/kg ts.	50.0	DS259/SM3120ICP	30
Pyrit, FeS2			**0.96**		% i ts.	0.01	*SM3120 mod.	
Kalium (K)	**1500**	**1700**	**480**	**1500**	mg/kg ts.	20	DS259/SM3120ICP	30

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Kundenr.: 82983
Ordrenr.: 407823

Sagsnr.: 11031305
Modt. dato: 2012.05.21

Sidenr.: 2 af 2

ANALYSERAPPORT

Rekvirent.....: Nationalmuseet, Bevaringsafdelingen, Arkæologi
I.C.Modewegs vej, 2800 Kgs.Lyngby
Prøvested.....: **Bryggen MB43, MB44 (statsbyg) ref**
Prøvetype.....: Sediment
Prøveudtagning...:
Prøvetager.....: Rekvirenten
Kundeoplysninger.: april 2012
Analyseperiode...: 2012.05.23 - 2012.06.01

Prøvenr.:	C7848205	C7848206	C7848207	C7848208				
Prøve ID:						Detekt.		Um
Prøvemærke:	MB44-01	MB44-02	MB44-03	RefSD60171	Enheder	grænse	Metoder	(%)
pH	**6.5**	**6.8**	**6.6**	**8.2**	pH		DS/EN 12176	
Tørstof	**30**	**40**	**35**	**72**	%	0.05	DS 204 mod.	10
Glødetab på tørstof	**55**	**43**	**55**	**3.7**	% i ts.	0.10	DS 204	20
Kvælstof, total	**8500**	**4200**	**4800**	**1600**	mg/kg	5	NF 1975	20
Kvælstof, total	**29000**	**11000**	**14000**	**2200**	mg/kg ts.		Beregning	20
Phosphor, total	**2600**	**15000**	**11000**	**3800**	mg/kg ts.	100	DS259/SM3120ICP	30
Phosphor, total	**790**	**6200**	**3800**	**2800**	mg/kg		Beregning	
Chlorid, vandopløselig	**480**	**310**	**890**	**540**	mg/kg ts.	5	*SM 17.udg. 4500	20
Sulfat,vandopløselig	**3100**	**1600**	**1800**	**620**	mg/kg ts.	1	*SM 17.udg. 4500	20
Svovl, total	**20000**	**12000**	**17000**	**4200**	mg/kg ts.	50.0	DS259/SM3120ICP	30
Pyrit, FeS2			**0.68**		% i ts.	0.01	*SM3120 mod.	
Kalium (K)	**850**	**1300**	**640**	**2500**	mg/kg ts.	20	DS259/SM3120ICP	30

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01. juni 2012

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Nationalmuseet
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I.C.Modewegs vej
2800 Kgs.Lyngby

Att.: Henning Matthiesen

Registernr.:	C71344
Kundenr.:	82983
Ordrenr.:	407823
Prøvenr.:	C7134401
Sagsnr.:	11031305
Modt. dato:	2012.02.28
Sidenr.:	1 af 10

ANALYSERAPPORT

Rekvirent.....: Nationalmuseet, Bevaringsafdelingen, Arkæologi
I.C.Modewegs vej, 2800 Kgs.Lyngby
Prøvested.....: **Kundenr. 72983 Bryggen FJB3(Statsbyg)**
Prøvetype.....: Jord
Prøvemærke.....: **FJB3-01**
Prøveudtagning...:
Prøvetager.....: Rekvirenten
Kundeoplysninger.: Januar 2012
Analyseperiode...: 2012.02.28 - 2012.03.19

Prøvenr.: / Prøve ID: / Prøvemærke:	**C7134401**	Detekt. grænse	Metoder	Um (%)
pH	**7.1 pH**		DS/EN 12176	
Tørstof	**34 %**	0.05	DS 204 mod.	10
Glødetab på tørstof	**47 % i ts.**	0.10	DS 204	20
Kvælstof, total	**3300 mg/kg**	5	NF 1975	20
Kvælstof, total	**9900 mg/kg ts.**		Beregning	20
Phosphor, total	**38000 mg/kg ts.**	100	DS259/SM3120ICP	30
Phosphor, total	**13000 mg/kg**		Beregning	
Chlorid, vandopløselig	**360 mg/kg ts.**	5	*SM 17.udg. 4500	20
Sulfat,vandopløselig	**260 mg/kg ts.**	1	*SM 17.udg. 4500	20
Svovl, total	**8700 mg/kg ts.**	50.0	DS259/SM3120ICP	30
Kalium (K)	**2700 mg/kg ts.**	20	DS259/SM3120ICP	30

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I.C.Modewegs vej
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Att.: Henning Matthiesen

Registernr.:	C71344
Kundenr.:	82983
Ordrenr.:	407823
Prøvenr.:	C7134402
Sagsnr.:	11031305
Modt. dato:	2012.02.28

ANALYSERAPPORT

Rekvirent.....: Nationalmuseet, Bevaringsafdelingen, Arkæologi
I.C.Modewegs vej, 2800 Kgs.Lyngby
Prøvested.....: **Kundenr. 72983 Bryggen FJB3(Statsbyg)**
Prøvetype.....: Jord
Prøvemærke.....: **FJB3-02**
Prøveudtagning...:
Prøvetager.....: Rekvirenten
Kundeoplysninger.: Januar 2012
Analyseperiode...: 2012.02.28 - 2012.03.19

Prøvenr.: / Prøve ID: / Prøvemærke:	C7134402	Detekt. grænse	Metoder	Um (%)
pH	**7.1 pH**		DS/EN 12176	
Tørstof	**24 %**	0.05	DS 204 mod.	10
Glødetab på tørstof	**54 % i ts.**	0.10	DS 204	20
Kvælstof, total	**4600 mg/kg**	5	NF 1975	20
Kvælstof, total	**19000 mg/kg ts.**		Beregning	20
Phosphor, total	**6400 mg/kg ts.**	100	DS259/SM3120ICP	30
Phosphor, total	**1500 mg/kg**		Beregning	
Chlorid, vandopløselig	**840 mg/kg ts.**	5	*SM 17.udg. 4500	20
Sulfat,vandopløselig	**500 mg/kg ts.**	1	*SM 17.udg. 4500	20
Svovl, total	**16000 mg/kg ts.**	50.0	DS259/SM3120ICP	30
Kalium (K)	**600 mg/kg ts.**	20	DS259/SM3120ICP	30

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Nationalmuseet
Bevaringsafdelingen, Arkæologi
I.C.Modewegs vej
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Att.: Henning Matthiesen

Registernr.:	C71344
Kundenr.:	82983
Ordrenr.:	407823
Prøvenr.:	C7134403
Sagsnr.:	11031305
Modt. dato:	2012.02.28
Sidenr.:	3 af 10

ANALYSERAPPORT

Rekvirent.....: Nationalmuseet, Bevaringsafdelingen, Arkæologi
I.C.Modewegs vej, 2800 Kgs.Lyngby
Prøvested.....: **Kundenr. 72983 Bryggen FJB3(Statsbyg)**
Prøvetype.....: Jord
Prøvemærke.....: **FJB3-03**
Prøveudtagning...:
Prøvetager.....: Rekvirenten
Kundeoplysninger.: Januar 2012
Analyseperiode...: 2012.02.28 - 2012.03.19

Prøvenr.:	**C7134403**			
Prøve ID:		Detekt.		Um
Prøvemærke:		grænse	Metoder	(%)
pH	**7.1 pH**		DS/EN 12176	
Tørstof	**19 %**	0.05	DS 204 mod.	10
Glødetab på tørstof	**67 % i ts.**	0.10	DS 204	20
Chlorid, vandopløselig	**1000 mg/kg ts.**	5	*SM 17.udg. 4500	20
Sulfat,vandopløselig	**410 mg/kg ts.**	1	*SM 17.udg. 4500	20

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Ordrenr.:	407823
Prøvenr.:	C7134404
Sagsnr.:	11031305
Modt. dato:	2012.02.28
Sidenr.:	4 af 10

ANALYSERAPPORT

Rekvirent.....: Nationalmuseet, Bevaringsafdelingen, Arkæologi
I.C.Modewegs vej, 2800 Kgs.Lyngby
Prøvested.....: **Kundenr. 72983 Bryggen FJB3(Statsbyg)**
Prøvetype.....: Jord
Prøvemærke.....: **FJB3-04**
Prøveudtagning...:
Prøvetager.....: Rekvirenten
Kundeoplysninger.: Januar 2012
Analyseperiode...: 2012.02.28 - 2012.03.19

Prøvenr.: / Prøve ID: / Prøvemærke:	**C7134404**	Detekt. grænse	Metoder	Um (%)
pH	**7.3 pH**		DS/EN 12176	
Tørstof	**21 %**	0.05	DS 204 mod.	10
Glødetab på tørstof	**56 % i ts.**	0.10	DS 204	20
Chlorid, vandopløselig	**990 mg/kg ts.**	5	*SM 17.udg. 4500	20
Sulfat,vandopløselig	**360 mg/kg ts.**	1	*SM 17.udg. 4500	20

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Att.: Henning Matthiesen

Registernr.:	C71344
Kundenr.:	82983
Ordrenr.:	407823
Prøvenr.:	C7134405
Sagsnr.:	11031305
Modt. dato:	2012.02.28
Sidenr.:	5 af 10

ANALYSERAPPORT

Rekvirent.....: Nationalmuseet, Bevaringsafdelingen, Arkæologi
I.C.Modewegs vej, 2800 Kgs.Lyngby
Prøvested.....: **Kundenr. 72983 Bryggen FJB3(Statsbyg)**
Prøvetype.....: Jord
Prøvemærke.....: **FJB3-05**
Prøveudtagning...:
Prøvetager.....: Rekvirenten
Kundeoplysninger.: Januar 2012
Analyseperiode...: 2012.02.28 - 2012.03.19

Prøvenr.: / Prøve ID: / Prøvemærke:	**C7134405**	Detekt. grænse	Metoder	Um (%)
pH	**7.5 pH**		DS/EN 12176	
Tørstof	**22 %**	0.05	DS 204 mod.	10
Glødetab på tørstof	**78 % i ts.**	0.10	DS 204	20
Kvælstof, total	**3700 mg/kg**	5	NF 1975	20
Kvælstof, total	**17000 mg/kg ts.**		Beregning	20
Phosphor, total	**6100 mg/kg ts.**	100	DS259/SM3120ICP	30
Phosphor, total	**1400 mg/kg**		Beregning	
Chlorid, vandopløselig	**730 mg/kg ts.**	5	*SM 17.udg. 4500	20
Sulfat,vandopløselig	**580 mg/kg ts.**	1	*SM 17.udg. 4500	20
Svovl, total	**17000 mg/kg ts.**	50.0	DS259/SM3120ICP	30
Kalium (K)	**1800 mg/kg ts.**	20	DS259/SM3120ICP	30

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Um(%): Den ekspanderede måleusikkerhed Um er lig 2 x RSD%, se i øvrigt www.eurofins.dk, søgeord: Måleusikkerhed.

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Att.: Henning Matthiesen

Registernr.:	C71344
Kundenr.:	82983
Ordrenr.:	407823
Prøvenr.:	C7134406
Sagsnr.:	11031305
Modt. dato:	2012.02.28
Sidenr.:	6 af 10

ANALYSERAPPORT

Rekvirent.....: Nationalmuseet, Bevaringsafdelingen, Arkæologi
I.C.Modewegs vej, 2800 Kgs.Lyngby
Prøvested.....: **Kundenr. 72983 Bryggen FJB3(Statsbyg)**
Prøvetype.....: Jord
Prøvemærke.....: **FJB3-06**
Prøveudtagning...:
Prøvetager.....: Rekvirenten
Kundeoplysninger.: Januar 2012
Analyseperiode...: 2012.02.28 - 2012.03.19

Prøvenr.: / Prøve ID: / Prøvemærke:	**C7134406**	Detekt. grænse	Metoder	Um (%)
pH	**7.3 pH**		DS/EN 12176	
Tørstof	**24 %**	0.05	DS 204 mod.	10
Glødetab på tørstof	**73 % i ts.**	0.10	DS 204	20
Chlorid, vandopløselig	**820 mg/kg ts.**	5	*SM 17.udg. 4500	20
Sulfat,vandopløselig	**520 mg/kg ts.**	1	*SM 17.udg. 4500	20

*) Ikke omfattet af akkrediteringen.

Um(%): Den ekspanderede måleusikkerhed Um er lig 2 x RSD%, se i øvrigt www.eurofins.dk, søgeord: Måleusikkerhed.

Tegnforklaring:
RSD : Relativ Analyseusikkerhed.
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TEST Reg.nr. 168

Nationalmuseet
Bevaringsafdelingen, Arkæologi
I.C.Modewegs vej
2800 Kgs.Lyngby

Att.: Henning Matthiesen

Registernr.:	C71344
Kundenr.:	82983
Ordrenr.:	407823
Prøvenr.:	C7134407
Sagsnr.:	11031305
Modt. dato:	2012.02.28
Sidenr.:	7 af 10

ANALYSERAPPORT

Rekvirent.....: Nationalmuseet, Bevaringsafdelingen, Arkæologi
I.C.Modewegs vej, 2800 Kgs.Lyngby
Prøvested.....: **Kundenr. 72983 Bryggen FJB3(Statsbyg)**
Prøvetype.....: Jord
Prøvemærke.....: **FJB3-07**
Prøveudtagning...:
Prøvetager.....: Rekvirenten
Kundeoplysninger.: Januar 2012
Analyseperiode...: 2012.02.28 - 2012.03.19

Prøvenr.: / Prøve ID: / Prøvemærke:	**C7134407**	Detekt. grænse	Metoder	Um (%)
pH	**7.4 pH**		DS/EN 12176	
Tørstof	**22 %**	0.05	DS 204 mod.	10
Glødetab på tørstof	**83 % i ts.**	0.10	DS 204	20
Chlorid, vandopløselig	**1000 mg/kg ts.**	5	*SM 17.udg. 4500	20
Sulfat,vandopløselig	**500 mg/kg ts.**	1	*SM 17.udg. 4500	20

*) Ikke omfattet af akkrediteringen.

Um(%): Den ekspanderede måleusikkerhed Um er lig 2 x RSD%, se i øvrigt www.eurofins.dk, søgeord: Måleusikkerhed.

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Nationalmuseet
Bevaringsafdelingen, Arkæologi
I.C.Modewegs vej
2800 Kgs.Lyngby

Att.: Henning Matthiesen

Registernr.:	C71344
Kundenr.:	82983
Ordrenr.:	407823
Prøvenr.:	C7134408
Sagsnr.:	11031305
Modt. dato:	2012.02.28
Sidenr.:	8 af 10

ANALYSERAPPORT

Rekvirent.....: Nationalmuseet, Bevaringsafdelingen, Arkæologi
I.C.Modewegs vej, 2800 Kgs.Lyngby
Prøvested.....: **Kundenr. 72983 Bryggen FJB3(Statsbyg)**
Prøvetype.....: Jord
Prøvemærke.....: **FJB3-08**
Prøveudtagning...:
Prøvetager.....: Rekvirenten
Kundeoplysninger.: Januar 2012
Analyseperiode...: 2012.02.28 - 2012.03.19

Prøvenr.: / Prøve ID: / Prøvemærke:	C7134408	Detekt. grænse	Metoder	Um (%)
pH	**7.7 pH**		DS/EN 12176	
Tørstof	**38 %**	0.05	DS 204 mod.	10
Glødetab på tørstof	**35 % i ts.**	0.10	DS 204	20
Kvælstof, total	**6300 mg/kg**	5	NF 1975	20
Kvælstof, total	**16000 mg/kg ts.**		Beregning	20
Phosphor, total	**15000 mg/kg ts.**	100	DS259/SM3120ICP	30
Phosphor, total	**5900 mg/kg**		Beregning	
Chlorid, vandopløselig	**560 mg/kg ts.**	5	*SM 17.udg. 4500	20
Sulfat,vandopløselig	**270 mg/kg ts.**	1	*SM 17.udg. 4500	20
Svovl, total	**16000 mg/kg ts.**	50.0	DS259/SM3120ICP	30
Pyrit, FeS2	**0.92 % i ts.**	0.01	*SM3120 mod.	
Kalium (K)	**1900 mg/kg ts.**	20	DS259/SM3120ICP	30

*) Ikke omfattet af akkrediteringen.

Um(%): Den ekspanderede måleusikkerhed Um er lig 2 x RSD%, se i øvrigt www.eurofins.dk, søgeord: Måleusikkerhed.

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TEST Reg.nr. 168

Nationalmuseet
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I.C.Modewegs vej
2800 Kgs.Lyngby

Att.: Henning Matthiesen

Registernr.:	C71344
Kundenr.:	82983
Ordrenr.:	407823
Prøvenr.:	C7134409
Sagsnr.:	11031305
Modt. dato:	2012.02.28
Sidenr.:	9 af 10

ANALYSERAPPORT

Rekvirent.....: Nationalmuseet, Bevaringsafdelingen, Arkæologi
I.C.Modewegs vej, 2800 Kgs.Lyngby
Prøvested.....: **Kundenr. 72983 Bryggen FJB3(Statsbyg)**
Prøvetype.....: Jord
Prøvemærke.....: **FJB3-09**
Prøveudtagning...:
Prøvetager.....: Rekvirenten
Kundeoplysninger.: Januar 2012
Analyseperiode...: 2012.02.28 - 2012.03.19

Prøvenr.: / Prøve ID: / Prøvemærke:	**C7134409**	Detekt. grænse	Metoder	Um (%)
pH	**7.5 pH**		DS/EN 12176	
Tørstof	**32 %**	0.05	DS 204 mod.	10
Glødetab på tørstof	**36 % i ts.**	0.10	DS 204	20
Chlorid, vandopløselig	**570 mg/kg ts.**	5	*SM 17.udg. 4500	20
Sulfat,vandopløselig	**300 mg/kg ts.**	1	*SM 17.udg. 4500	20

*) Ikke omfattet af akkrediteringen.

Um(%): Den ekspanderede måleusikkerhed Um er lig 2 x RSD%, se i øvrigt www.eurofins.dk, søgeord: Måleusikkerhed.

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TEST Reg.nr. 168

Nationalmuseet
Bevaringsafdelingen, Arkæologi
I.C.Modewegs vej
2800 Kgs.Lyngby

Att.: Henning Matthiesen

Registernr.:	C71344
Kundenr.:	82983
Ordrenr.:	407823
Prøvenr.:	C7134410
Sagsnr.:	11031305
Modt. dato:	2012.02.28
Sidenr.:	10 af 10

ANALYSERAPPORT

Rekvirent.....: Nationalmuseet, Bevaringsafdelingen, Arkæologi
I.C.Modewegs vej, 2800 Kgs.Lyngby
Prøvested.....: **Kundenr. 72983 Bryggen FJB3(Statsbyg)**
Prøvetype.....: Jord
Prøvemærke.....: **FJB3-10**
Prøveudtagning...:
Prøvetager.....: Rekvirenten
Kundeoplysninger.: Januar 2012
Analyseperiode...: 2012.02.28 - 2012.03.19

Prøvenr.:	**C7134410**			
Prøve ID:				
Prøvemærke:		Detekt. grænse	Metoder	Um (%)
pH	**8.0 pH**		DS/EN 12176	
Tørstof	**81 %**	0.05	DS 204 mod.	10
Glødetab på tørstof	**1.4 % i ts.**	0.10	DS 204	20
Chlorid, vandopløselig	**78 mg/kg ts.**	5	*SM 17.udg. 4500	20
Sulfat,vandopløselig	**36 mg/kg ts.**	1	*SM 17.udg. 4500	20

*) Ikke omfattet af akkrediteringen.

Um(%): Den ekspanderede måleusikkerhed Um er lig 2 x RSD%, se i øvrigt www.eurofins.dk, søgeord: Måleusikkerhed.

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19. marts 2012

Kundecenter: tlf.70224267 Hanne Jensen
Kontaktperson Godkendt af

Appendix 2

Results from analysis of groundwater from MB36, MB37, MB40, MB41, MB42, MB43, MB44 and FJB3 (Eurofins).

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Nationalmuseet, Bevaringsafdelingen

I.C. Modewegs Vej
2800 Kgs.Lyngby

Att.: Henning Matthiesen

Registernr.: C74330
Kundenr.: 602325
Ordrenr.: 813114
Prøvenr.: C7433001

Modt. dato: 2012.03.16

Sidenr.: 1 af 1

ANALYSERAPPORT

Rekvirent.....: Nationalmuseet, Bevaringsafdelingen
I.C. Modewegs Vej, 2800 Kgs.Lyngby
Prøvested.....:
Prøvetype.....: Grundvand - Andet
Prøvemærke.....: **MB36**
Prøveudtagning...: 2012.03.13
Prøvetager.....: Rekvirenten
Kundeoplysninger.:
Analyseperiode...: 2012.03.16 - 2012.03.22

Prøvenr.: / Prøve ID: / Prøvemærke:	**C7433001**	Detekt. grænse	Metoder	Um (%)
pH	**6.7 pH**		DS 287:1978	
Ledningsevne	**1600 mS/m**	0.1	DS/EN 27888	10
Calcium (Ca)	**290 mg/l**	0.50	SM3120-ICP	30
Magnesium (Mg)	**330 mg/l**	0.10	SM3120-ICP	30
Kalium (K)	**120 mg/l**	0.20	SM3120-ICP	30
Natrium (Na)	**3100 mg/l**	0.10	SM3120-ICP	30
Jern (Fe)	**18 mg/l**	0.010	SM3120-ICP	30
Mangan (Mn)	**0.73 mg/l**	0.005	SM3120-ICP	30
Ammonium	**28 mg/l**	0.006	SM 17.udg. 4500	10
Nitrat	**<0.50 mg/l**	0.50	SM 17.udg. 4500	10
Orthophosphat-P	**6.3 mg/l**	0.0050	SM 17.udg. 4500	10
Chlorid	**5300 mg/l**	1.00	SM 17.udg. 4500	10
Sulfat	**32 mg/l**	0.50	SM 17.udg. 4500	10
Hydrogencarbonat	**1280 mg/l**	3.0	DS/EN I 9963	10
Inddampningsrest	**13000 mg/l**	10	DS 204:1980	12
Sulfid-S	**1.4 mg/l**	0.02	DS 278:1976auto	28
Methan	**15 mg/l**	0.005	M0066 GC/FID	38

Analysekommentarer:
Prøven til metaller indeholdt bundfald. Bundfaldet kan evt. indeholde udfældninger som ikke er medanalyseret, og desuden kan der være frigivet metaller fra bundfaldet som ikke oprindeligt var opløst i vandprøven

Flaskerne til sulfid var ikke fyldt helt op, og derfor skal resultatet af analysen tages med forbehold.

Um(%): Den ekspanderede måleusikkerhed Um er lig 2 x RSD%, se i øvrigt www.eurofins.dk, søgeord: Måleusikkerhed.

Tegnforklaring:
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22. marts 2012
Annette Vendel
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TEST Reg.nr. 168

Nationalmuseet, Bevaringsafdelingen

I.C. Modewegs Vej
2800 Kgs.Lyngby

Att.: Henning Matthiesen

Registernr.: C74329
Kundenr.: 602325
Ordrenr.: 813114
Prøvenr.: C7432901

Modt. dato: 2012.03.16

Sidenr.: 1 af 1

ANALYSERAPPORT

Rekvirent.....: Nationalmuseet, Bevaringsafdelingen
I.C. Modewegs Vej, 2800 Kgs.Lyngby
Prøvested.....:
Prøvetype.....: Grundvand - Andet
Prøvemærke.....: **MB37**
Prøveudtagning...: 2012.03.13
Prøvetager.....: Rekvirenten
Kundeoplysninger.:
Analyseperiode...: 2012.03.16 - 2012.03.22

Prøvenr.: / Prøve ID: / Prøvemærke:	**C7432901**	Detekt. grænse	Metoder	Um (%)
pH	**6.7 pH**		DS 287:1978	
Ledningsevne	**1300 mS/m**	0.1	DS/EN 27888	10
Calcium (Ca)	**390 mg/l**	0.50	SM3120-ICP	30
Magnesium (Mg)	**240 mg/l**	0.10	SM3120-ICP	30
Kalium (K)	**89 mg/l**	0.20	SM3120-ICP	30
Natrium (Na)	**2200 mg/l**	0.10	SM3120-ICP	30
Jern (Fe)	**26 mg/l**	0.010	SM3120-ICP	30
Mangan (Mn)	**2.5 mg/l**	0.005	SM3120-ICP	30
Ammonium	**24 mg/l**	0.006	SM 17.udg. 4500	10
Nitrat	**<0.50 mg/l**	0.50	SM 17.udg. 4500	10
Orthophosphat-P	**0.49 mg/l**	0.0050	SM 17.udg. 4500	10
Chlorid	**4000 mg/l**	1.00	SM 17.udg. 4500	10
Sulfat	**72 mg/l**	0.50	SM 17.udg. 4500	10
Hydrogencarbonat	**1310 mg/l**	3.0	DS/EN I 9963	10
Inddampningsrest	**13000 mg/l**	10	DS 204:1980	12
Sulfid-S	**0.02 mg/l**	0.02	DS 278:1976auto	28
Methan	**0.011 mg/l**	0.005	M0066 GC/FID	38

Analysekommentarer:
Prøven til metaller indeholdt bundfald. Bundfaldet kan evt. indeholde udfældninger som ikke er medanalyseret, og desuden kan der være frigivet metaller fra bundfaldet som ikke oprindeligt var opløst i vandprøven

Flaskerne til sulfid var ikke fyldt helt op, og derfor skal resultatet af analysen tages med forbehold.

Um(%): Den ekspanderede måleusikkerhed Um er lig 2 x RSD%, se i øvrigt www.eurofins.dk, søgeord: Måleusikkerhed.

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22. marts 2012
Annette Vendel

Kundecenter: tlf.70224256 Annette Vendel
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TEST Reg.nr. 168

Nationalmuseet, Bevaringsafdelingen

I.C. Modewegs Vej
2800 Kgs.Lyngby

Att.: Henning Matthiesen

Registernr.: C78691
Kundenr.: 602325
Ordrenr.: 813114
Prøvenr.: C7869101

Modt. dato: 2012.06.01

Sidenr.: 1 af 1

ANALYSERAPPORT

Rekvirent.....: Nationalmuseet, Bevaringsafdelingen
I.C. Modewegs Vej, 2800 Kgs.Lyngby
Prøvested.....:
Prøvetype.....: Råvand - Andet
Prøvemærke.....: **MB 40**
Prøveudtagning...: 2012.05.29 kl. 10:15
Prøvetager.....: Rekvirenten
Kundeoplysninger.:
Analyseperiode...: 2012.06.01 - 2012.06.08

	Prøvenr.: C7869101 Prøve ID: Prøvemærke:		**Grænseværdier Vejl.	Max.	Metoder	Um (%)
pH	**7.1**	**pH**			DS 287:1978	
Ledningsevne	**53**	**mS/m**			DS/EN 27888	10
Calcium (Ca)	**55**	**mg/l**			SM3120-ICP	30
Magnesium (Mg)	**3.4**	**mg/l**			SM3120-ICP	30
Kalium (K)	**7.1**	**mg/l**			SM3120-ICP	30
Natrium (Na)	**37**	**mg/l**			SM3120-ICP	30
Jern (Fe)	**6.5**	**mg/l**			SM3120-ICP	30
Mangan (Mn)	**0.28**	**mg/l**			SM3120-ICP	30
Ammonium	**<0.006**	**mg/l**			SM 17.udg. 4500	10
Nitrat	**<0.50**	**mg/l**			SM 17.udg. 4500	10
Orthophosphat-P	**0.030**	**mg/l**			SM 17.udg. 4500	10
Chlorid	**72**	**mg/l**			SM 17.udg. 4500	10
Sulfat	**4.9**	**mg/l**			SM 17.udg. 4500	10
Hydrogencarbonat	**190**	**mg/l**			DS/EN I 9963	10
Inddampningsrest	**330**	**mg/l**			DS 204:1980	12
Sulfid-S	**0.86**	**mg/l**			DS 278:1976auto	28
Methan	**0.73**	**mg/l**			M0066 GC/FID	38

**) Miljøministeriets bekendtgørelse nr. 1024 af 31. oktober 2011
Um(%): Den ekspanderede måleusikkerhed Um er lig 2 x RSD%, se i øvrigt www.eurofins.dk, søgeord: Måleusikkerhed.

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08. juni 2012
Annette Vendel

Kundecenter: tlf.70224256 Annette Vendel
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DANAK TEST Reg.nr. 168

Nationalmuseet, Bevaringsafdelingen

I.C. Modewegs Vej
2800 Kgs.Lyngby

Att.: Henning Matthiesen

Registernr.: C75695
Kundenr.: 602325
Ordrenr.: 813114
Prøvenr.: 10223755

Modt. dato: 2012.04.04

Sidenr.: 1 af 1

ANALYSERAPPORT

Rekvirent.....: Nationalmuseet, Bevaringsafdelingen
I.C. Modewegs Vej, 2800 Kgs.Lyngby
Prøvested.....:
Udtagningsadresse: **Bryggen**
Prøvetype.....: Grundvand - Andet
Prøvemærke.....: **MB 41**
Prøveudtagning...: 2012.03.30 kl. 13:00
Prøvetager.....: Rekvirenten
Kundeoplysninger.:
Analyseperiode...: 2012.04.04 - 2012.04.13

Prøvenr.: / Prøve ID: / Prøvemærke:		Detekt. grænse	Metoder	Um (%)
pH	**6.5 pH**		DS 287:1978	
Ledningsevne	**160 mS/m**	0.1	DS/EN 27888	10
Calcium (Ca)	**74 mg/l**	0.50	SM3120-ICP	30
Magnesium (Mg)	**18 mg/l**	0.10	SM3120-ICP	30
Kalium (K)	**17 mg/l**	0.20	SM3120-ICP	30
Natrium (Na)	**220 mg/l**	0.10	SM3120-ICP	30
Jern (Fe)	**18 mg/l**	0.010	SM3120-ICP	30
Mangan (Mn)	**1.3 mg/l**	0.005	SM3120-ICP	30
Ammonium	**29 mg/l**	0.006	SM 17.udg. 4500	10
Nitrat	**1.0 mg/l**	0.50	SM 17.udg. 4500	10
Orthophosphat-P	**9.5 mg/l**	0.0050	SM 17.udg. 4500	10
Chlorid	**310 mg/l**	1.00	SM 17.udg. 4500	10
Sulfat	**3.9 mg/l**	0.20	DS/EN 10304-1	10
Hydrogencarbonat	**436 mg/l**	3.0	DS/EN I 9963	10
Inddampningsrest	**970 mg/l**	10	DS 204:1980	12
Sulfid-S	**0.10 mg/l**	0.02	DS 278:1976auto	28
Methan	**<0.005 mg/l**	0.005	M0066 GC/FID	38

Um(%): Den ekspanderede måleusikkerhed Um er lig 2 x RSD%, se i øvrigt www.eurofins.dk, søgeord: Måleusikkerhed.

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: ingen af parametrene er påvist.

13. april 2012

Kundecenter: tlf.70224256 Annette Vendel
Kontaktperson Godkendt af

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TEST Reg.nr. 168

Nationalmuseet, Bevaringsafdelingen

I.C. Modewegs Vej
2800 Kgs.Lyngby

Att.: Henning Matthiesen

Registernr.: C75694
Kundenr.: 602325
Ordrenr.: 813114
Prøvenr.: 10223753

Modt. dato: 2012.04.04

Sidenr.: 1 af 1

ANALYSERAPPORT

Rekvirent.....: Nationalmuseet, Bevaringsafdelingen
I.C. Modewegs Vej, 2800 Kgs.Lyngby
Prøvested.....:
Udtagningsadresse: **Bryggen**
Prøvetype.....: Grundvand - Andet
Prøvemærke.....: **MB 42**
Prøveudtagning...: 2012.03.30 kl. 13:00
Prøvetager.....: Rekvirenten
Kundeoplysninger.:
Analyseperiode...: 2012.04.04 - 2012.04.12

Prøvenr.: **10223753** / Prøve ID: / Prøvemærke:		Detekt. grænse	Metoder	Um (%)
pH	**6.5 pH**		DS 287:1978	
Ledningsevne	**110 mS/m**	0.1	DS/EN 27888	10
Calcium (Ca)	**36 mg/l**	0.50	SM3120-ICP	30
Magnesium (Mg)	**9.9 mg/l**	0.10	SM3120-ICP	30
Kalium (K)	**14 mg/l**	0.20	SM3120-ICP	30
Natrium (Na)	**150 mg/l**	0.10	SM3120-ICP	30
Jern (Fe)	**15 mg/l**	0.010	SM3120-ICP	30
Mangan (Mn)	**0.71 mg/l**	0.005	SM3120-ICP	30
Ammonium	**12 mg/l**	0.006	SM 17.udg. 4500	10
Nitrat	**<0.50 mg/l**	0.50	SM 17.udg. 4500	10
Orthophosphat-P	**4.2 mg/l**	0.0050	SM 17.udg. 4500	10
Chlorid	**160 mg/l**	1.00	SM 17.udg. 4500	10
Sulfat	**12 mg/l**	0.50	SM 17.udg. 4500	10
Hydrogencarbonat	**411 mg/l**	3.0	DS/EN I 9963	10
Inddampningsrest	**680 mg/l**	10	DS 204:1980	12
Sulfid-S	**0.25 mg/l**	0.02	DS 278:1976auto	28
Methan	**5.8 mg/l**	0.005	M0066 GC/FID	38

Analysekommentarer:
Komplexbinder var for gammel og flasken var ikke fyldt korrekt, så resultatet for sulfid-S skal tages med forbehold.

Um(%): Den ekspanderede måleusikkerhed Um er lig 2 x RSD%, se i øvrigt www.eurofins.dk, søgeord: Måleusikkerhed.

Tegnforklaring:
RSD : Relativ Analyseusikkerhed.
< : mindre end. i.p.: ikke påvist.
> : større end. i.m.: ikke målelig.
: ingen af parametrene er påvist.

12. april 2012

Kundecenter: tlf.70224256 Flemming M. Christensen
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TEST Reg.nr. 168

Nationalmuseet, Bevaringsafdelingen

I.C. Modewegs Vej
2800 Kgs.Lyngby

Att.: Henning Matthiesen

Registernr.: C78752
Kundenr.: 602325
Ordrenr.: 813114
Prøvenr.: C7875201

Modt. dato: 2012.06.06

Sidenr.: 1 af 1

ANALYSERAPPORT

Rekvirent.....: Nationalmuseet, Bevaringsafdelingen
I.C. Modewegs Vej, 2800 Kgs.Lyngby
Prøvested.....:
Prøvetype.....: Vand - Andet
Prøvemærke.....: **1. MB43**
Prøveudtagning...: 2012.05.30 kl. 14:00
Prøvetager.....: Rekvirenten
Kundeoplysninger.:
Analyseperiode...: 2012.06.06 - 2012.06.18

Prøvenr.: / Prøve ID: / Prøvemærke:	**C7875201**	Detekt. grænse	Metoder	Um (%)
pH	**6.7 pH**		DS 287:1978	
Ledningsevne	**270 mS/m**	0.1	DS/EN 27888	10
Calcium (Ca)	**180 mg/l**	0.50	SM3120-ICP	30
Magnesium (Mg)	**15 mg/l**	0.10	SM3120-ICP	30
Kalium (K)	**15 mg/l**	0.20	SM3120-ICP	30
Natrium (Na)	**340 mg/l**	0.10	SM3120-ICP	30
Jern (Fe)	**6.4 mg/l**	0.010	SM3120-ICP	30
Mangan (Mn)	**0.91 mg/l**	0.005	SM3120-ICP	30
Ammonium	**13 mg/l**	0.006	SM 17.udg. 4500	10
Nitrat	**<0.50 mg/l**	0.50	SM 17.udg. 4500	10
Orthophosphat-P	**0.81 mg/l**	0.0050	SM 17.udg. 4500	10
Chlorid	**680 mg/l**	1.00	SM 17.udg. 4500	10
Sulfat	**0.70 mg/l**	0.20	DS/EN 10304-1	10
Hydrogencarbonat	**403 mg/l**	3.0	DS/EN I 9963	10
Inddampningsrest	**1800 mg/l**	10	DS 204:1980	12
Sulfid-S	**<0.02 mg/l**	0.02	DS 278:1976auto	28
Methan	**0.016 mg/l**	0.005	M0066 GC/FID	38

Analysekommentarer:
Kommentar fra prøvetager:
Brønnen er lensa.
Prøven til metaller indeholdt bundfald. Bundfaldet kan evt. indeholde udfældninger som ikke er medanalyseret, og desuden kan der være frigivet metaller fra bundfaldet som ikke oprindeligt var opløst i vandprøven

Um(%): Den ekspanderede måleusikkerhed Um er lig 2 x RSD%, se i øvrigt www.eurofins.dk, søgeord: Måleusikkerhed.

Tegnforklaring:
RSD : Relativ Analyseusikkerhed.
< : mindre end. i.p.: ikke påvist.
> : større end. i.m.: ikke målelig.
: ingen af parametrene er påvist.

18. juni 2012
Annette Vendel
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TEST Reg.nr. 168

Nationalmuseet, Bevaringsafdelingen

I.C. Modewegs Vej
2800 Kgs.Lyngby

Att.: Henning Matthiesen

Registernr.: C78753
Kundenr.: 602325
Ordrenr.: 813114
Prøvenr.: C7875301

Modt. dato: 2012.06.06

Sidenr.: 1 af 1

ANALYSERAPPORT

Rekvirent.....: Nationalmuseet, Bevaringsafdelingen
I.C. Modewegs Vej, 2800 Kgs.Lyngby
Prøvested.....:
Prøvetype.....: Vand - Andet
Prøvemærke.....: **3. MB44**
Prøveudtagning...: 2012.05.31 kl. 05:45
Prøvetager.....: Rekvirenten
Kundeoplysninger.:
Analyseperiode...: 2012.06.06 - 2012.06.18

Prøvenr.: / Prøve ID: / Prøvemærke:	**C7875301**	Detekt. grænse	Metoder	Um (%)
pH	**6.7 pH**		DS 287:1978	
Ledningsevne	**56 mS/m**	0.1	DS/EN 27888	10
Calcium (Ca)	**290 mg/l**	0.50	SM3120-ICP	30
Magnesium (Mg)	**15 mg/l**	0.10	SM3120-ICP	30
Kalium (K)	**12 mg/l**	0.20	SM3120-ICP	30
Natrium (Na)	**320 mg/l**	0.10	SM3120-ICP	30
Jern (Fe)	**4.6 mg/l**	0.010	SM3120-ICP	30
Mangan (Mn)	**1.1 mg/l**	0.005	SM3120-ICP	30
Ammonium	**5.6 mg/l**	0.006	SM 17.udg. 4500	10
Nitrat	**<0.50 mg/l**	0.50	SM 17.udg. 4500	10
Orthophosphat-P	**0.89 mg/l**	0.0050	SM 17.udg. 4500	10
Chlorid	**810 mg/l**	1.00	SM 17.udg. 4500	10
Sulfat	**41 mg/l**	0.50	SM 17.udg. 4500	10
Hydrogencarbonat	**406 mg/l**	3.0	DS/EN I 9963	10
Inddampningsrest	**2800 mg/l**	10	DS 204:1980	12
Sulfid-S	**1.1 mg/l**	0.02	DS 278:1976auto	28
Methan	**0.019 mg/l**	0.005	M0066 GC/FID	38

Analysekommentarer:
Kommentar fra prøvetager:
Brønnen er ikkje lensa.
Prøven til metaller indeholdt bundfald. Bundfaldet kan evt. indeholde udfældninger som ikke er medanalyseret, og desuden kan der være frigivet metaller fra bundfaldet som ikke oprindeligt var opløst i vandprøven

Um(%): Den ekspanderede måleusikkerhed Um er lig 2 x RSD%, se i øvrigt www.eurofins.dk, søgeord: Måleusikkerhed.

Tegnforklaring:
RSD : Relativ Analyseusikkerhed.
< : mindre end. i.p.: ikke påvist.
> : større end. i.m.: ikke målelig.
: ingen af parametrene er påvist.

18. juni 2012
Annette Vendel
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TEST Reg.nr. 168

Nationalmuseet, Bevaringsafdelingen

I.C. Modewegs Vej
2800 Kgs.Lyngby

Att.: Henning Matthiesen

Registernr.: C74328
Kundenr.: 602325
Ordrenr.: 813114
Prøvenr.: C7432801

Modt. dato: 2012.03.16

Sidenr.: 1 af 1

ANALYSERAPPORT

Rekvirent.....: Nationalmuseet, Bevaringsafdelingen
I.C. Modewegs Vej, 2800 Kgs.Lyngby
Prøvested.....:
Prøvetype.....: Grundvand - Andet
Prøvemærke.....: **FJB3**
Prøveudtagning...: 2012.03.13
Prøvetager.....: Rekvirenten
Kundeoplysninger.:
Analyseperiode...: 2012.03.16 - 2012.03.22

Prøvenr.: C7432801 Prøve ID: Prøvemærke:		Detekt. grænse	Metoder	Um (%)
pH	**6.4 pH**		DS 287:1978	
Ledningsevne	**180 mS/m**	0.1	DS/EN 27888	10
Calcium (Ca)	**98 mg/l**	0.50	SM3120-ICP	30
Magnesium (Mg)	**22 mg/l**	0.10	SM3120-ICP	30
Kalium (K)	**23 mg/l**	0.20	SM3120-ICP	30
Natrium (Na)	**260 mg/l**	0.10	SM3120-ICP	30
Jern (Fe)	**25 mg/l**	0.010	SM3120-ICP	30
Mangan (Mn)	**0.59 mg/l**	0.005	SM3120-ICP	30
Ammonium	**36 mg/l**	0.006	SM 17.udg. 4500	10
Nitrat	**<0.50 mg/l**	0.50	SM 17.udg. 4500	10
Orthophosphat-P	**6.1 mg/l**	0.0050	SM 17.udg. 4500	10
Chlorid	**220 mg/l**	1.00	SM 17.udg. 4500	10
Sulfat	**13 mg/l**	0.50	SM 17.udg. 4500	10
Hydrogencarbonat	**771 mg/l**	3.0	DS/EN I 9963	10
Inddampningsrest	**1100 mg/l**	10	DS 204:1980	12
Sulfid-S	**0.48 mg/l**	0.02	DS 278:1976auto	28
Methan	**6.8 mg/l**	0.005	M0066 GC/FID	38

Analysekommentarer:
Prøven til metaller indeholdt bundfald. Bundfaldet kan evt. indeholde udfældninger som ikke er medanalyseret, og desuden kan der være frigivet metaller fra bundfaldet som ikke oprindeligt var opløst i vandprøven

Flaskerne til sulfid var ikke fyldt helt op, og derfor skal resultatet af analysen tages med forbehold.

Um(%): Den ekspanderede måleusikkerhed Um er lig 2 x RSD%, se i øvrigt www.eurofins.dk, søgeord: Måleusikkerhed.

Tegnforklaring:
RSD : Relativ Analyseusikkerhed.
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> : større end. i.m.: ikke målelig.
: ingen af parametrene er påvist.

22. marts 2012
Annette Vendel
Kundecenter: tlf.70224256 Annette Vendel
Kontaktperson Godkendt af

Appendix 3
Notat brønnboring Bryggen 25.-27.11.11

Rapport

Anlegg Boring Bryggen i Bergen
Dato 27.11.2011
Boreriggførar Egon Lie

Oppsummering

Det er bora to hol iht bestilling. Nedanståande notat viser status for desse hola.

Borehol v/museum MB 40.Not

Vi fikk en kote høyde på en trapp v/museum på 4,61m.o.h. som fastmerke. Brønnen skulle ned på -2,00 m.u.h

Dybde brønn er 6 meter med 193,7 x 5 mm stål rør .

De første tre meter var i singel og pukk. Deretter ca en meter i morene . Dei to siste meter var det veldig liten motstand på boring, sannsynligvis gammel sjøbunn /evje som var særs blaut.

Startrør er på tre meter derav to meter er perforert med 20mm hull frå bunn og oppover. Røyr er vidare skøyta med nytt rør på tre meter .

Bore hull bak SAS hotellet FBJ 1.

Dei første to meter var bløt jord, neste to meter grov morene, deretter ein meter finere morene, ca 20 cm med ganske hard morene. Etter dette ingen motstand før fjell, muligens sjøbunn / evje. Traff fjell på 7,20 m. Litt løst i ca 40 cm i begynnelsen, deretter ca 1,60 meter i fast fjell.

Totalt 9 meter stål rør før fjellboring starter. Røret ble limt til fjell med mikolit sealing.

Bora videre i fjell ca 26 meter , dybde total med rør er ca 35 meter.

Fjellets kvalitet var myk med små små slepper innimellom , farge på bor kaks frå fjell er mørk grå.

Bore kaks frå løsmasser ligger i big bags , og borkaks frå fjellboring ligger inne i presenning på plassen.

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