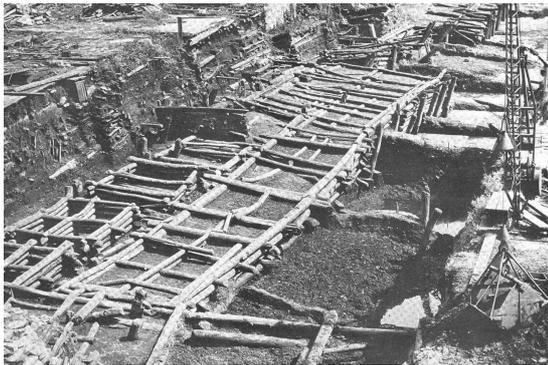




Photo: Sunil Bhawe

Monitoring of cultural deposits below Bryggen in Bergen, Norway

Henning Matthiesen, *in situ* group, National Museum of Denmark
 Rory Dunlop, Norwegian Institute for Cultural Heritage Research
 Jann Atle Jensen, Multiconsult Noteby, Bergen, Norway
 Ann Christensson, Directorate for Cultural Heritage, Norway



Massive wooden structures are present in the cultural layers below Bryggen. Here a 54-m-long section of quay from c. AD 1200.

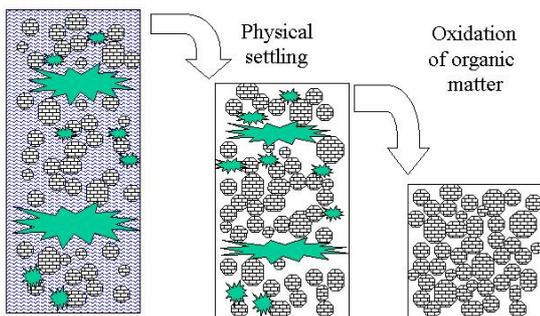
Bryggen, with its traditional timber buildings, is one of the oldest medieval trading ports in northern Europe, and one of the Hanseatic League's four overseas offices. It has a pre-Hanseatic building structure that dates back to the 11th century. These factors contributed to Bryggen's designation as a World Heritage Site in 1979.

Below the buildings lies another important heritage: cultural deposits – up to 10 metres thick – covering the entire span of Bryggen's history. Extensive excavations were carried out between 1955 and 1968 in the northern half of Bryggen after a fierce fire had razed the area. These excavations were among the first to reveal the huge amount of information that urban deposits contain.

The tilting walls of various buildings on Bryggen have long demonstrated that foundation conditions are not ideal. However, it was not until last year that the full extent of the problem became clear. Accurate surveying of the buildings in 2001-2003 and comparison with measurements from the 1950s revealed settling rates of up to 8 mm/year in the Bryggen area. Apart from problems with skewed buildings, the settling may also indicate that important archaeological remains are being either compressed or lost entirely.



Map of Bryggen showing measured settling rates for the buildings and ground surface in mm/year. Orange line indicates sheet piling between the old wooden buildings and the excavated area (now occupied by new buildings).



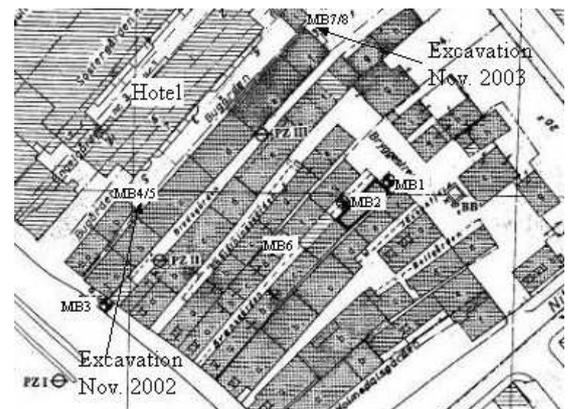
Water Air Organic Inorganic

Drainage may lead to settling through a physical process as well as by the decomposition of organic matter.

The cultural deposits are wet and richly organic. Soil samples typically have a water content exceeding 100% and loss-on-ignition values of 10-70%. Settling of such layers may be caused by for instance drainage, causing both physical settling and decomposition of the organic components. Work is ongoing to model the settling potential of a soil based on its water content and loss on ignition. This can then be compared with archaeological descriptions, to find correlations.

An extensive monitoring programme for Bryggen was initiated in 2001, both in order to understand the settling and to map preservation conditions for and threats to the cultural deposits. The highest settling rates are found towards Bryggen's north-western border, so investigations have been focused on that area.

The monitoring programme includes small test excavations, drillings, soil and water analysis, monitoring of the water-table, settling measurements, and the burial/retrieval of modern wood samples to assess the ongoing deterioration.



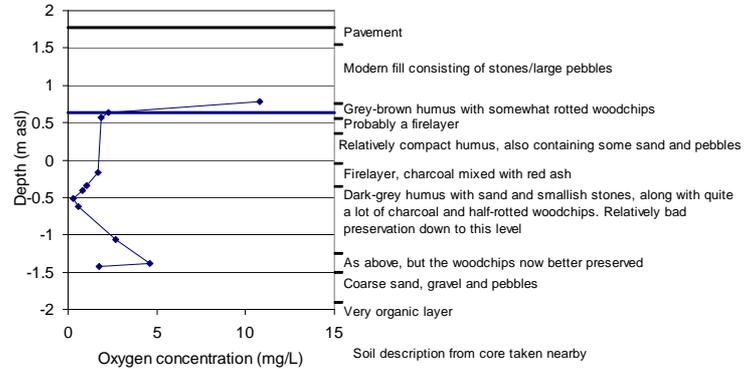
Map of Bryggen showing position of dipwells (MB1-8) and test excavations. The hotel was built in 1980 on the site excavated during the 1950s and -60s.



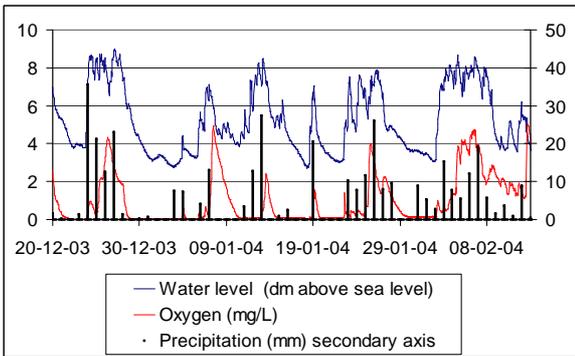
Minor test excavation from November 2002 in the area between the hotel site and the old buildings on Bryggen.

The lowered water-table near the sheet piling is worrying, as it increases oxygen supply in the unsaturated zone, thus accelerating decomposition. Furthermore, measurements taken directly in undisturbed soil layers during the test excavation revealed the presence of oxygen at surprisingly deep levels; there were considerable concentrations as far down as 2 m below the water-table. The shape of the oxygen profile was quite irregular, showing both decreasing and increasing concentrations with depth. This suggests that the flow pattern of the groundwater is complex.

A minor test excavation was carried out in the area between the hotel and the old buildings of Bryggen where high settling rates were found. Even if the excavation pit of 1 m² was not as spectacular as the excavations in the 1950s and -60s, it gave some very useful information. Among other things it revealed that the uppermost deposit next to the sheet piling consisted of fist-sized stones, forming a very efficient draining material that has contributed to a lowered water-table. Soil samples from the excavation pit and from 10-m-long cores were analysed for nutrients, organic matter and salt content. Low salt levels in the upper 2-3 metres of the soil indicated a substantial through-flow of water.



Oxygen profile measured directly in undisturbed soil by Ev Kretschmar, University of Göttingen. Soil surface is at 1.77 m above sea-level (asl) and blue line indicates the groundwater level at time of recording.



Example of results from dipwell MB4, where porous deposits give instant responses after rainfall, resulting in increased water-level and oxygen content. The logger is situated at -1.3 m asl, or 2 m below the average groundwater level.

Continuous logging in a dipwell installed at the site corroborated the picture of a very dynamic system. Bergen receives as much as 2000 mm precipitation annually, and the water-level and oxygen content clearly reflect the quantity: during rainfall the water-level in the soil at this specific site increases by up to 50 cm and the oxygen content increases temporarily, probably due to fresh rainwater flushing through the deposits. These observations along with other evidence from the site confirmed that the high settling rates measured for the buildings and ground surface may be due to decomposition of organic matter in the underlying strata. The rate will be highest above the water-table, but some decomposition may also take place below the water-table due to the high concentrations of dissolved oxygen.

Future studies at Bryggen will include the establishment of a detailed hydrological model for the entire area. This is necessary in order to model the effects of different mitigation strategies and to ensure that such strategies will have no adverse effects on the cultural layers and standing buildings. Mitigation of the settling problem may include the substitution of porous stone fill along the sheet piling with less permeable clay slurry in order to raise the water-table. The future work will also include research into decomposition processes in order better to transfer the results from Bryggen to other sites with similar cultural deposits.



Mitigation strategies may include raising the water-table.... Manipulated photo from Bergens Tidende.

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