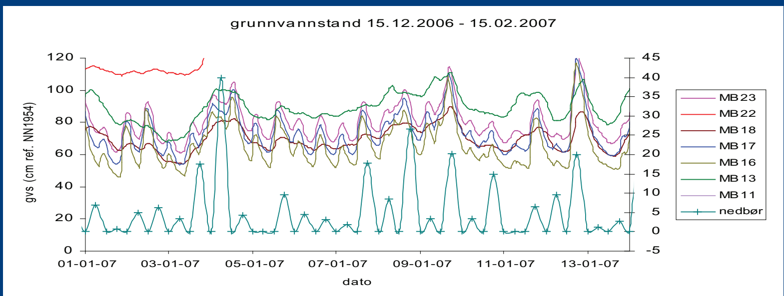
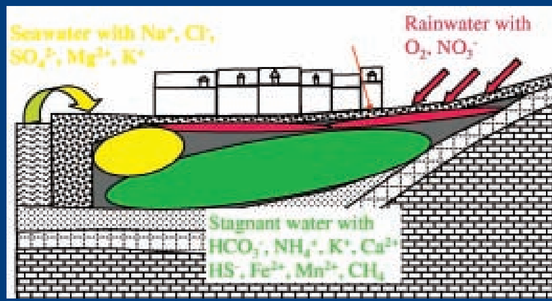
THE MONITORING MANUAL

PROCEDURES & GUIDELINES FOR THE MONITORING, RECORDING AND PRESERVATION/MANAGEMENT OF URBAN ARCHAEOLOGICAL DEPOSITS





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To Norway's Grand Old Man
of Medieval Archaeology,
Asbjørn Edmund Herteig
(1919-2006)

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Frontcover Photo/figures: Asbjørn Herteig; Bergen Museum, Middelaldersamlingen; Jann Atle Jensen, Multiconsult; Hans de Beer NGU; Henning Matthiesen, Nationalmuseet Danmark.

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FOREWORD

Urban archaeological deposits are among the more challenging phenomena confronting heritage management authorities, municipal planners, and property owners/developers alike, particularly in relation to building and infrastructure projects. The Norwegian Ministry of the Environment's stated aim is 'to preserve the "underground archives" and at the same time establish conditions for continued use of the pertinent areas and the development of vital inner cities (Parliamentary Report no. 16 (2004-2005), *Living with our Cultural Heritage*).

Through its interdisciplinary approach, the Norwegian Directorate for Cultural Heritage (Riksantikvaren) – together with the Norwegian Institute for Cultural Heritage Research (NIKU) – has been an important primus motor in what is still a relatively young field. The directorate has striven to identify the challenges and to find the expertise needed to tackle these challenges. We have come a fair way along the road but we know that there is a long stretch ahead of us yet.

Continuous and systematic monitoring of archaeological deposits, among other places at the World Heritage Site *Bryggen* in Bergen over the past five years, has added new knowledge as well as demystified some beliefs. In essence, results have shown that some causes of decay have been underestimated, while others have never been considered. Thus a major effort has been made to identify and focus on certain key parameters as early-warning indicators.

This manual represents the first milestone as regards the problems – or methods – in focus. It is the result of a collaborative effort involving employees of the following institutions: Riksantikvaren, the National Museum of Denmark, Multiconsult AS and NIKU. The latter has been responsible for sewing the patchwork together as a more or less complete quilt.

As the road winds on the manual will be updated in step with methodological advances and new findings. Work is already in progress towards the second milestone, which is to formalise the manual's methods and procedures as a Norwegian Standard in collaboration with Standards Norway.

We wish to thank all our contributors and we hope for a continuing fruitful exchange of knowledge with old and new colleagues.

Nils Marstein
Director General
Riksantikvaren

Carsten Paludan-Müller
Managing Director
NIKU

1. Introduction

The planned *in situ* preservation and the monitoring of urban archaeological deposits are relatively new areas of research. They only really came to the forefront in connection with changes regarding the granting of planning consent in York, England, in 1990. In 1995 an environmental monitoring programme was established in the city. In Norway a monitoring project designed along the same lines as the York project was initiated at Schultzgate, Trondheim, in 1996. Since then further monitoring projects have been established in Tønsberg (1999), Bergen (2000) and a second project in Trondheim in 2004.

The *Riksantikvaren*-initiated programme that is monitoring the thick cultural deposits beneath the World Heritage Site of Bryggen in Bergen has been running – and growing in extent! – for half a decade now, with the Bryggen Foundation, NIKU, the National Museum of Denmark, and Multiconsult AS as the main partners (most recently joined by NGU, the Geological Survey of Norway). Though still early days, the first results are so encouraging that it has been decided to make the work at Bryggen the basis for this manual, for a forthcoming Documentation Standard covering all kinds of archaeological deposit investigations, and for an overall preservation/monitoring strategy.

1.1 Strategy

Monitoring of sites, monuments and cultural environments [1]

Urban archaeological deposits are among the more challenging phenomena confronting heritage management authorities, municipal planners, and property owners/developers alike, particularly in relation to building (new construction, conversion, changes in loading) and infrastructure projects. The Norwegian Ministry of the Environment's stated aim is 'to preserve the "underground archives" and at the same time establish conditions for continued use of the pertinent areas and the development of vital inner cities' (Parliamentary Report no. 16, *Living with our Cultural Heritage*, p. 29 of the Norwegian version). This is also in line with the national attainment goal that *by 2020, protected and preservation-worthy cultural sites, monuments and environments are to be adequately safeguarded and in such condition that they shall not require extraordinary levels of maintenance or conservation work*, this applying equally to urban archaeological deposits. As the MOE's instrument, *Riksantikvaren* is to work out a more consistent management policy for the preservation and safeguarding of the country's automatically protected cultural heritage.

Riksantikvaren[2] is dedicated to improving the preservation conditions of the country's cultural heritage, hereunder sites, monuments, cultural environments and landscapes. It is therefore incumbent on heritage management to keep pace with modern developments, through active acquisition of knowledge, greater outreach, and a solid grasp of the principal mechanisms and consequences of the changes taking place (see *Riksantikvaren*'s strategy at:

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[1] The text is largely taken from *Riksantikvaren*'s web-site on environmental monitoring http://www.riksantikvaren.no/Norsk/Fagemner/Miljoovervaking/

[2] *Riksantikvaren* is responsible for:
- the management of all archaeological and architectural monuments and sites and cultural environments in accordance with the relevant legislation
- ensuring that a representative selection of monuments and sites of all periods is preserved for present and future generations. The selection of monuments and sites must provide an overview of historical developments, the way of life and the range of works of art and craftsmanship of each period
- ensuring that cultural heritage considerations are taken into account in all planning processes

The Directorate aims to ensure the effectiveness and quality of its heritage management work through the application of inter-disciplinary cooperation, high-quality scientific documentation, and increased use of information technology coupled with relevant geodata.

http://www.riksantikvaren.no/Norsk/Om_Riksantikvaren/Strategisk_plan/?module=Articles;action=Article.publicShow;ID=2828; – NB. in Norwegian only).

All aspects of cultural heritage have to be treated as finite and non-renewable resources, because once destroyed, they can never be replaced. Each type of heritage feature has its own unique character, which needs specific nurturing, and each is menaced by its own specific threats, which require specific counter-measures. The stated objective is to ensure that a representative selection of monuments and sites of all periods is preserved for present and future generations.

This, naturally, includes urban archaeological deposits, and the foremost threats to these are:

- direct intervention (basically, physical disturbance such as excavation)
- dessication/dewatering, hereunder:
  - o lowering of water-table (whether by artificial or natural causes)
  - o increased drainage into ditches backfilled with permeable material
- warming of deposits around piped heating systems, cellars etc
- pollution (some deposits in, for instance, Bergen's Bryggen area can be classified as bio-hazards)

These threats arise principally in connection with major construction/infrastructure projects, and in recognition of this it is now mandatory for developers to have Environmental Impact Assessments undertaken in connection with large-scale projects. No detailed survey of threats and impacts will be undertaken here, but an excerpt from Davis puts things in a nutshell: "Indirect impacts occur if the construction impact is on the…burial environment, which is promoting the continuing *in situ* preservation of the archaeological remains" (Davis, 2004).

With the current pace of development, today's society places a premium on in-depth, across-the-board knowledge. Generated through inter-disciplinary collaboration and research, knowledge about the condition of sites, monuments and cultural environments, along with the rate and causes of any changes in condition, is an essential premise for the preparation of responsible, predictable policies (see Parliamentary Report no. 16, *Living with our Cultural Heritage*).

Monitoring of sites, monuments and cultural environments forms an important component in the knowledge-based management of these historical fragments. It involves a systematic, long-term capture of data concerning the selected objects, and it allows *Riksantikvaren* to track quantitative and/or qualitative changes that may be occurring. In this way, monitoring provides an important touchstone for evaluating the extent to which the government's heritage preservation targets are being met (see national targets for sites and monuments at the Ministry of the Environment's web-site *State of the Environment Norway*:
http://www.miljostatus.no/templates/MaalNokkeltallForside____5174.aspx).

1.2 The significance of monitoring

When archaeological remains are deemed to be threatened, the knowledge acquired through monitoring is essential for making correct decisions about appropriate counter-measures. Continuous systematic monitoring and reporting of results will then show whether these measures are having the desired effect, or whether there are any unforeseen consequences. This in turn should provide a means of steering developments, and thereby allow the government's preservation targets to be attained.

Systematic monitoring also represents an important element in the formulation of standardized procedures that can guarantee genuine comparability of data and results. By means of testable, replicable methods and measures, data and results acquire increased quality and validity, and the know-how generated can be transferred with greater ease to related or different areas of scientific activity.

1.3 Clarifications

Three things need to be made quite clear from the outset:

1) An organic deposit is any deposit that contains any organic matter, however miniscule the amount. This is because the loss of such matter has two main consequences:

- loss of volume, thus contributing to settling (Matthiesen, 2004b: 21-23)
- loss of historical information potential as a result of the decomposition of the deposits' contents: timber structures, artefacts of organic material (leather, wood, textile, bone etc), botanical remains, bones, insect remains etc – in effect, the removal of an important part of the nation's historical roots

2) No distinction is made between organic deposits of cultural origin and organic deposits of natural origin (gyttja, for instance). The loss of the latter can be just as serious – certainly as regards settling problems, at any rate – as the loss of the former.

3) In Norway, the Middle Ages cover the period from AD 1030 to 1536 (incl.).

2. The medieval towns

2.1 General remarks

Riksantikvaren, NIKU, the National Museum of Denmark, Multiconsult AS, and the Bryggen Foundation are working together to devise a strategy for monitoring the archaeological deposits in the Norwegian medieval towns, as part of their overall preservation and management.

The archaeological deposits in these towns are among the most important and distinctive heritage monuments in Norway. The following towns have known medieval deposits preserved beneath them and are designated as scheduled ancient monuments: Oslo, Bergen, Trondheim, Tønsberg, Hamar, Stavanger, Sarpsborg and Skien[3]. Medieval deposits are also to be found within the settlements of Kaupanger, Borgund, Veøy and Vågan[4].

These deposits are constantly being affected by the daily functioning and development of the town – and thus are, in a very real sense, part of the public domain. The modern use of the town and the vulnerable deposits under ground must somehow find a way to interact and enter a state where the system is in maximum equilibrium and the heritage management authorities' terms concerning protection and preservation are found acceptable. It is of the utmost importance that the urban centres involved be allowed to develop and not become static and fossilized. The knife-edge to be balanced is between "the need to preserve…archaeological remains and the need to allow our towns to thrive and develop" (Wainwright, 1993: 418).

The first towns emerged around AD 1000–1100, and the oldest urban remains have thus managed to survive for up to 1,000 years. The modern settlement has developed on top of medieval and younger deposits – not forgetting prehistoric deposits (extensive traces of prehistoric settlement have been found in, particularly, Trondheim) – which means that not only are they an irreplaceable repository of historical information, but also form a significant part of the modern town's physical foundation.

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[3] Only the four major medieval towns are described in some detail in this manual (sections 2.2-2.5), partly because of the need to prioritize time, and partly because the other settlements are still relatively uncharted.

[4] This is not necessarily the full complement of settlements with medieval deposits in Norway; there may well be some unrecognized sites in addition.

Fig. 1. Medieval settlement remains at Bryggen in Bergen;
from the excavations lead by A. E. Herteig 1955-68 (Photo: Herteig).

While it is undeniable that the modern town protects the underlying deposits to a certain extent, it also intrudes into them in a variety of ways. Up to about 1900 preservation conditions for the rich organic deposits in the towns' core areas can be described as very good. Modern developments, however, have altered this situation irrevocably. Preservation conditions – and the deposits' state of preservation – can now vary considerably from area to area within each town, sometimes over surprisingly short distances, as well as from town to town. And there are of course areas where the organic deposits have deteriorated completely, or where the deposits have been removed en masse.

As just stated, preservation conditions vary within each area of archaeological deposits. This variation can be induced by a number of factors, the most obvious being "natural long-term processes", the surroundings, and the severity of direct or indirect damage that the individual area has suffered (i.e., the number, extent and depth of intrusions such as cellars and trenches). This means that the level of vulnerability to further damage varies within each area, and also varies greatly from city to city. It is clear, however, that the water content – as either groundwater or water otherwise retained in the deposits – plays a significant part in the preservation of organic deposits. Likewise it is known that the presence of oxygen is the prime decomposition accelerant. Sites where the groundwater-level has been lowered show corresponding changes in the rate and amount of decomposition of organic matter. Recent studies also show that ground-dwelling micro-organisms seem to increase in quantity due to modern changes in the surroundings (Klaassen *et al*., 2005; Senior, 1990).

The archaeological strata constitute a non-renewable resource, and direct/indirect damage to them poses a threat to the continued preservation of these heritage features. The medieval towns are protected under the provisions of Norway's Cultural Heritage Act – at the core of each town is a zone of interdiction, which entails that all intended interventions in the ground must be applied for and sanctioned by the heritage management authorities. Statutory protection is extended to all standing monuments older than 1649 and archaeological remains older than 1537. In the period 1950–1990 extensive archaeological excavations took place in most of the Norwegian medieval towns, leading to the acquisition of a great deal of new knowledge and research material. The foremost aim for the last 10 years has been to protect the archaeological remains, as recommended in the ICOMOS Charter for the Protection and Management of the Archaeological Heritage (1990), the Malta Convention (1992)[5] and the *ArcheoCode* approved in Strasbourg (2000)[6].

Knowledge regarding decay processes in the deposits – in order to secure these important remains with their immense scientific and historical source value – is assigned much higher importance today than just a few years back. It is an acknowledged fact that archaeological deposits will inevitably disappear over time, but under the right conditions organic cultural remains can be preserved for thousands of years. The concern of the authorities and the scientific community is to prevent the modern world from hastening the decay of the "old underground towns". It is therefore necessary to establish the parameters for preservation in order to maintain their future management. The protection of the archaeological heritage must be based, in order to comply with the above-mentioned charters, upon effective collaboration between professionals drawn from a variety of disciplines (chemistry, archaeology, geotechnics, etc), in cooperation with the authorities, the private sector, and the general public.

The upshot of the above is that we need baseline reference data as well as monitoring data from different parts of the deposit areas in each city. This is necessary to secure the best possible management and policy formulation regarding spatial planning, and to enable the implementation of preventive actions/mitigation strategies. Decision-making and policy implementation related to the management of these sites depend on good data. It should, however, be kept in mind that the study of the decomposition of organic archaeological deposits and the monitoring of these are still emerging fields of expertise, and these complex processes will need further study so that they can be better understood.

Summing up, in order to acquire and retain the necessary knowledge and understanding of the subterranean towns, a coherent preservation strategy – with procedures for associated monitoring – must be devised and maintained.

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[5] European Convention on the Protection of the Archaeological Heritage (Revised), Valletta, 16.1.1992. From article 2 paragraph ii: …*the creation of archaeological reserves, even where there are no visible remains on the ground or under water, for preservation of material evidence to be studied by later generations; …*

[6] European code of good practice: "ARCHAEOLOGY AND THE URBAN PROJECT" (*ArcheoCode*) ratified in Strasbourg in 2000, a code of good practice for treatment of urban archaeological remains (roles and responsibilities of public authorities and planners, architects and developers, and archaeologists). It is not legally binding, but provides guidelines for the management and preservation of the urban archaeological in accordance with the Malta Convention.
Links:
http://www.international.icomos.org/e_archae.htm (written by ICAHM, approved by ICOMOS General Assembly, Lausanne, 1990)
http://conventions.coe.int/Treaty/en/Treaties/Html/143.htm (Valletta, 1992)
http://www.coe.int/T/E/Cultural_Co-operation/Heritage/Resources/CodeArcheo.asp#TopOfPage (Strasbourg, 2000)

2.2 Bergen

Bergen grew up around the narrow bay of *Vågen*, a natural, well-sheltered harbour ideally situated to command trade along the coast and to/from the western fjord districts. The earliest settlement, dating from the latter half of the 11th century, was located towards the northwestern end of the bay's northeastern shore – the area that now contains the UNESCO World Heritage Site of *Bryggen*. The building pattern that typifies Bryggen – long, parallel tenements made up of separate but more or less contiguous wooden buildings running perpendicular to the waterfront – dates back to the town's earliest period, and was well established long before the incursion of the Hanseatic League in the 14th century. Some of the property boundaries at Bryggen have indeed remained virtually unchanged since the early medieval period. The same basic building pattern was eventually to be found along the entire harbour front.

From the original core area, settlement expanded fairly rapidly southeastwards along the shore and into the area at the head of the harbour, the quarter known today as *Vågsbunnen*. This area was originally dissected by a narrowish inlet that stretched some 300 metres southeastwards from the head of the harbour, ending at a point not far to the south of *Domkirken*, the cathedral. Bryggen and Vågsbunnen are the two main areas that constitute the medieval town of Bergen.

Even this area soon became too cramped for the needs of the thriving town, which began pushing out into the harbour area by no later than the mid-12th century. This also served to provide sufficient depth of water to the new types of cargo ships with their ever-greater draught. If we include the modern quayfront area, we find that settlement at Bryggen has advanced into the former harbour area by up to as much as 140 metres, and this is of course where the cultural deposits reach their greatest thickness – up to at least 11 metres.

The inlet running through the Vågsbunnen quarter also gradually became filled up with an enormous volume of deposits. These were mainly organic and derived from both settlement and leatherworking activities, the latter largely due to the fact that a large part of Vågsbunnen was occupied by German shoemakers/tanners from ca. 1300 to ca. 1600.

Settlement spread more gradually along the bay's southwestern shore, the area known as Strandsiden. It was well built out by around 1300, according to the written sources, and included three ecclesiastical sites, but the deposits in most of the inner part were removed after the fire of 1916. Very little remains for future research – and of what does remain, not very much has ever been properly archaeologically investigated.

Even at its maximum extent – very likely just prior to the Black Death – medieval Bergen probably covered no more than 620,000 square metres (excluding numerous satellite ecclesiastical sites). Granted, there is considerable uncertainty involved, but Bergen is nevertheless believed to have been the largest town in Scandinavia during most of the Middle Ages.

The archaeological deposits: extent and thickness

Officially delimited in 1972, the scheduled area of medieval Bergen covers about 1,600,000 m^2, and as well as the secular settlement includes the Bergenhus/Sverresborg complex, the bay of Vågen (ca. 200,000 m^2), the large pond called Lille Lungegårdsvannet, and the whole of the Nordnes peninsula (the table below provides quick-reference estimates of principal extents).

Area	Area in ha. (ca.)	Comments
A. Scheduled area	1600	Covers areas outside the settlement too
B. Probable extent of medieval town	620	Maximum extent around 1350
C. Harbour	200	Uncertain extent and volume of deposits
D. Dry-land area with all deposits removed	170	Mostly removed since ca. 1800-50
E. Dry-land medieval area	450	Incl. areas with partly removed deposits

The thickness of the cultural deposits varies considerably within the area, and for sake of brevity it is intended to let the accompanying map (fig. 3), which shows the extent and variation in thickness of the deposits within the principal medieval urban area, speak for itself. It is, however, worth stressing that the thickness values shown in the map include **all** the archaeological deposits – from prehistoric to recent (i.e., up to ca. 1900). Along with the map, there is a schematic transect to illustrate the situation both above and below ground in the Bryggen World Heritage Site (fig. 2).

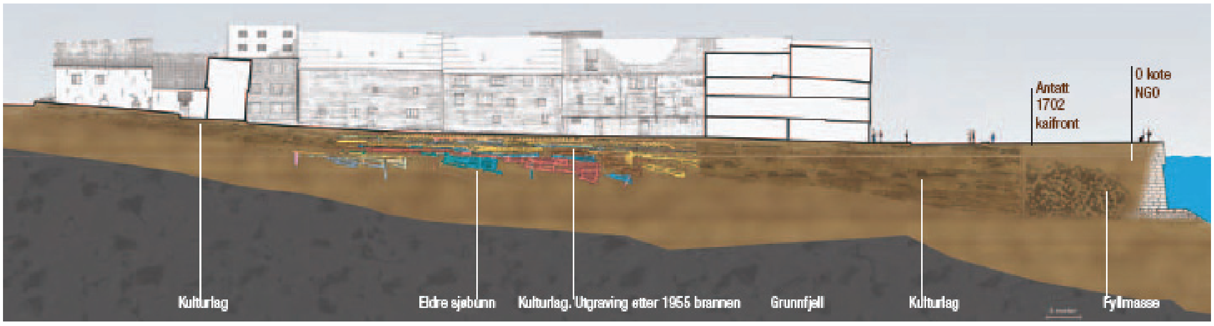


Fig. 2. Schematic transect through the Bryggen area.

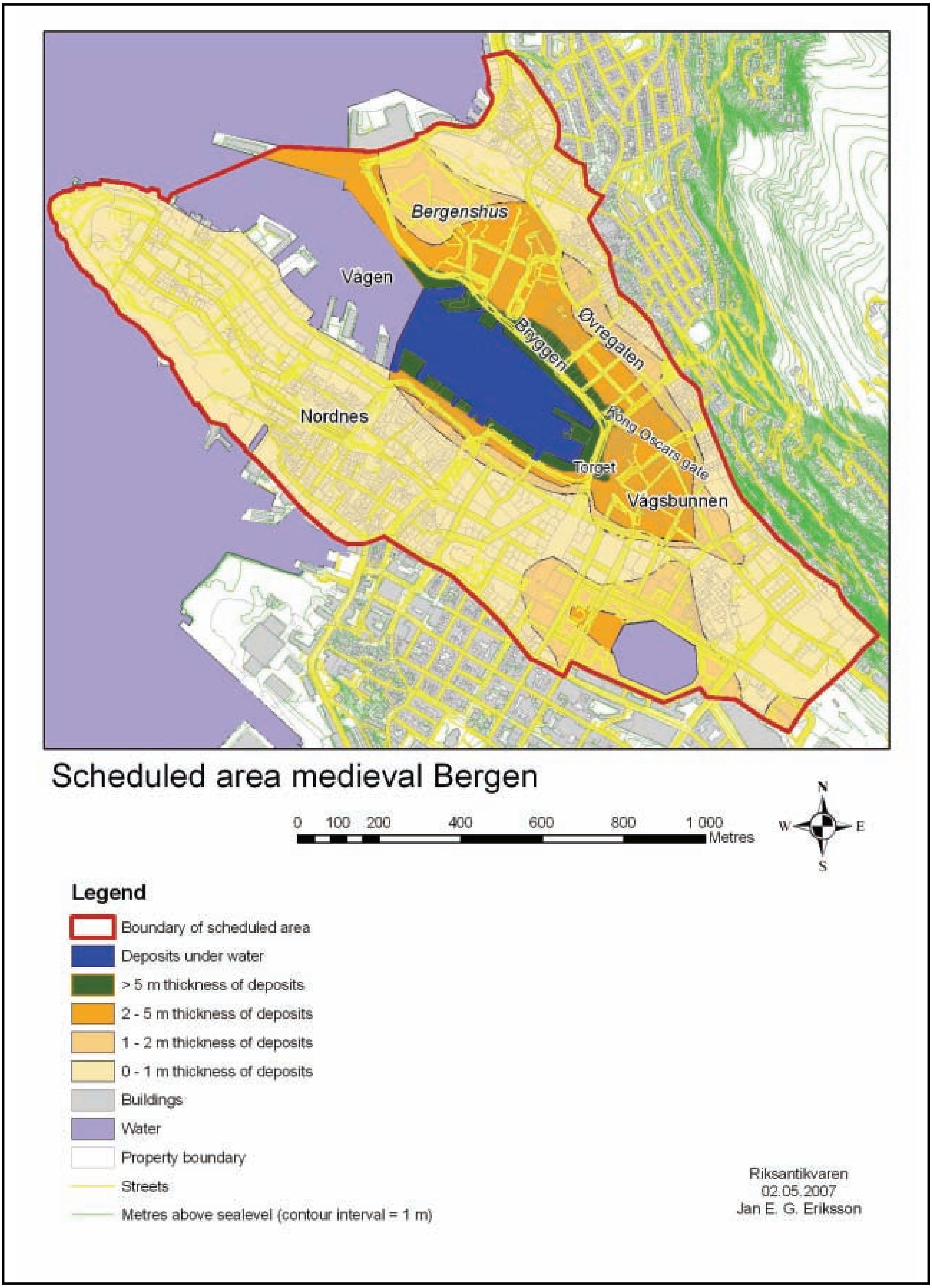


Fig. 3. Variation in deposit thickness within the scheduled area *Medieval Bergen*.

Attention should also be drawn to the fact that there are some major reservoirs of archaeological deposits in addition to the areas mentioned previously, but whose extent and thickness are comparatively uncertain. These areas include the Bergenhus area, situated on the former promontory of Holmen to the northwest of the secular medieval settlement, and the Koengen/Kroken area, which lies between Bergenhus and the secular medieval settlement. A large part of the Koengen/Kroken area was occupied – up to about AD 1200 – by a brackwater, relatively shallow lagoon called *Veisan*. Only a very small portion of this area was ever “colonized” by ordinary settlement, and there is every reason to suppose that the bulk of the deposits that accumulated in and around the lagoon have remained intact, and that conditions for the preservation of their organic content are generally good.

At a rough – and perhaps conservative – estimate, the total volume of archaeological deposits within Bergen’s scheduled area may well be upwards of 2 million cubic metres.

State of preservation and vulnerability

Situated on Norway’s west coast, Bergen “enjoys” an annual precipitation that averages around 2,500 mm/year. Since most of the area containing cultural deposits is backed by hillsides, the water-table is generally not far below the surface and fluctuates relatively little. This applies in particular to the low-lying areas surrounding the harbour.

The deposits’ state of preservation and their vulnerability to attack vary considerably within the scheduled area. Optimal preservation conditions are to be found in the area where deposition took place along the foreshore or, subsequently, in the harbour bay. This largely corresponds to the area where the deposits are permanently saturated, and where they achieve their greatest thicknesses.

Archaeological investigation and documentation

Systematic archaeological excavations were in progress in Bergen more or less annually from 1955 to 1974, and it has been said that Herteig’s Bryggen excavations from 1955 to 1968 saw the birth of modern urban archaeology in Norway. Since 1974, major excavations have been carried out relatively sporadically – but smaller excavations and other investigations have nevertheless yielded much fruitful information and research material.

In 1980 *Riksantikvarens Utgravningskontor for Bergen* – the Bergen Excavation Unit under the Central Office for Monuments and Sites – was established in response to the recently revised Cultural Heritage Act. The office’s first director was Siri Myrvoll. Its principal purpose was to handle rescue excavations in (mainly) the town centre, at least to begin with. With the establishment of the Norwegian Institute for Cultural Heritage Research (NIKU) in 1994, the unit became one of NIKU’s regional offices.[7]

The Bergen Unit’s main focus was on the use of standardized systems to document the stratigraphy of the sites. The stratigraphic method was employed right from the start, and the checkerboard excavation system has been used on a number of major sites, partly to avoid baulks. The unit employed much of the existing documentation system from Herteig’s Bryggen excavations, but adapted it in the light of newer methods. A much greater emphasis was placed on the *layer* as the primary source of urban archaeological information – thanks largely to the arrival of Andrzej Gołembnik and his layer recording sheet in 1982.

The unit also focused keenly on chronology – a topic that is, of course, intimately connected with the interest in layers – in continuance of a tradition begun by the Bergen scholar Christian Koren Wiberg and developed by Herteig, and more recently by Christensson, Dunlop, and Dunlop/Sigurdsson.

In 1972, a comprehensive Archaeological Survey of Bergen was carried out – coinciding more or less with the completion of Herteig excavations – and it was only natural to continue

[7] The same change in status took place in Oslo, Trondheim and Tønsberg.

to collate topographic and historical information from subsequent investigations. This information was written down on special recording forms to begin with, but with the advent of the office computer in the mid-1980s the archive was transferred to a database. Thus was born *Bergensbasen* (the Bergen Archaeological Record: Dunlop & Molaug, 2002), and it has been kept updated ever since.

2.3 Oslo

It is believed that the oldest settlement in Oslo can be dated to around 1000. It was situated on the southernmost parts of the peninsula between the lower part of Alnaelva (the River Alna) and Bjørvika bay, in the area between Clemenskirken (St. Clement's Church) and the royal castle. The oldest remains of ordinary urban habitation, in the area north of Clemenskirken, are dated to around 1030. The area south of the present street of Bispegata has been dominated by brush vegetation and trees before the town emerged, whereas in the area to the north there have been found ploughmarks from fields dated to the 10th century and earlier. Regarding both areas, the natural ground consists of a top layer of sand, between 50 and 100cm thick, with marine clay beneath. In some areas there are fluvial sediments from older courses of the Alnaelva, consisting of sloping layers of sand, gravel, clay and organic material.

The habitation area of Oslo expanded in the 11th and 12th centuries to Hovinbekken (the Hovin brook) in the north and Alnaelva in the southeast. To the northeast there were probably some houses standing along the main street leading out of the town. Very few traces of such habitation have been found, just parts of the churchyard of the St. Lawrence's Hospital lying outside the habitation. From the 13th century on, some habitation was to be found east of Alnaelva, by the Franciscan friary and the bridge crossing the river. North of Hovinbekken a nunnery was established in the 12th century. These monasteries, at least their churches along with most of the other churches in Oslo, were of stone. The ordinary habitation was wooden, the houses as well as the fences, the yards and the streets. From the mid or late 16th century several stone cellars and some stone buildings were erected and cobblestones were used for paving streets and yards. The royal and episcopal castles were originally of wood, but stone buildings and protecting walls were erected from around sometime in the 13th century.

After the major fire in 1624 the inhabitants of Oslo were not allowed to rebuild their houses, but were forced to settle on the other side of Bjørvika bay, in the new town named Christiania. Some of the monumental stone buildings remained standing, however, and continued in use. Some new buildings were erected. Most of the area of the old town was turned into agricultural land until the last quarter of the 19th century, when the railway company took over large areas to establish new tracks and buildings. In the same period a number of tenement houses with cellars were built and by the sea large quays and terminals for goods handling were established. From the 1950s to 1995 the area was dominated by an expanding traffic scheme. The road tunnel through the Ekeberg Hill represented the start of a wave of new development in the medieval settlement area, but went hand in hand with protection of the inherent heritage, the reconstruction of medieval structures, and the laying out of extensive green areas for the public.

Extent of cultural deposits

The area covered by the medieval town at its largest is believed to be around 270,000 m^2, though the scheduled area of medieval Oslo is much larger. In the northeastern part of this area there are few or no cultural deposits. Then again, there are medieval remains in the harbour area lying outside the scheduled area. Most of the 270,000 m^2 has no culture-layers left, and in parts of the original urban area there were probably only ever very thin cultural deposits. Many layers have been removed in modern times, the most obvious agents being:

1. Railway yards, tunnels
2. Buildings of the railway company
3. Late 19th C dwellings with cellars
4. Foundations for streets, including pillars for bridges
5. Trenches and pits for sewers, water, gas, electricity etc.
6. 16th and 17th C cellars, wells etc.

These have been responsible for either total removal (1-5) or partial removal (4-6) of the archaeological deposits. The table below provides quick-reference estimates of principal extents, and is a reflection of how the medieval town has gradually been whittled down. The situation in medieval Oslo is illustrated by figs. 4, 5 and 6.

Area	Area in ha. (ca.)	Comments
A. Scheduled area	480	Covers areas outside the settlement too
B. Probable extent of medieval town	270	Maximum extent around 1300
C. Medieval area after railway construction	135	Mostly destroyed ca. 1880-1925
D. Medieval area not destroyed, incl. bay	90	Mostly destroyed ca. 1880-1900, 1960→
E. Medieval dry-land area not destroyed	40	Including partly destroyed areas

The average thickness of the various types of deposit is as follows:
- post-medieval and modern layers make up at least 50 cm, often 1 m thick
- medieval layers vary in thickness between 5 cm and 3 m

Vulnerability of the cultural deposits
Conditions for the preservation of the cultural deposits vary considerably, from excellent to very bad. The variation is largest between different areas, but considerable variation can often be observed as well. The upper layers are generally badly preserved. The lowest layers are often less well preserved than the layers in the middle, probably because of drainage and the effect of oxygenated water flowing through the uppermost natural strata in the sloping terrain that the medieval town was situated in.

Areas defined according to preservation conditions, from south to north (see fig. 4)
<u>1. Area southeast of the former Alnaelva:</u>
Generally few cultural remains and poor preservation conditions
0–0.3m-thick medieval layers
<u>2. *Øra*-area with Mariakirken (St. Mary's Church), the royal castle, and including Clemenskirken and the area to the east:</u>
Partly poor preservation conditions due to railway cuttings on both sides. The perhaps most important area for knowledge about the early medieval town is suffering from continuous deterioration.
0.8–1.8m-thick medieval layers
<u>3. The harbour area and Sørenga, from Bispegata to the south and up to a little way north of Mariakirken:</u>
Very good preservation conditions because of high water-table. Remains covered by clay deposits under water. Not very vulnerable, except for the top layers.
1.5–4.5m-thick layers, mostly natural clay with medieval remains.
North of Bispegata most deposits have probably been removed.
<u>4. The area east of Sørenga and the railway cutting, under and south of Bispegata, north of Clemenskirken:</u>
Generally very good preservation, excepting the top layers, but locally not always so good. Probably a drainage problem in the area underneath the former Sørenga Bridge towards west and the railway cutting. The deterioration will probably continue because of the sloping natural terrain. Local drainage problems caused by the buildings east of Oslogate and the slope towards the railway cutting here.
1.0–2.0m-thick medieval layers
<u>5. Along Oslogate from Bispegata, including the bishop's castle and Olavsklosteret (St. Olaf's Friary), up to Schweigaardsgate.</u>
Generally good preservation conditions, except in the upper layers. Preservation conditions decrease on both sides of the street, to the west because of the railway area.
1.0–2.0m-thick medieval layers

<u>6. Hallvardskirken (St. Hallvard's Cathedral), Olavsklosteret, the area south and north of Korskirken (Holy Cross Church), east of area 5.</u>

Generally poor preservation, but in some places well-preserved remains, especially churchyard burials, wells etc. The layers in the outskirts of the town are very vulnerable to water-table variation and drainage.

0–1.5m-thick culture-layers, churchyard layers, decomposed ordinary habitation layers

<u>7. Area north of Hovinbekken.</u>

Generally few cultural remains and poor preservation conditions.

0–1.0m-thick culture-layers, churchyard layers, slag dumps.

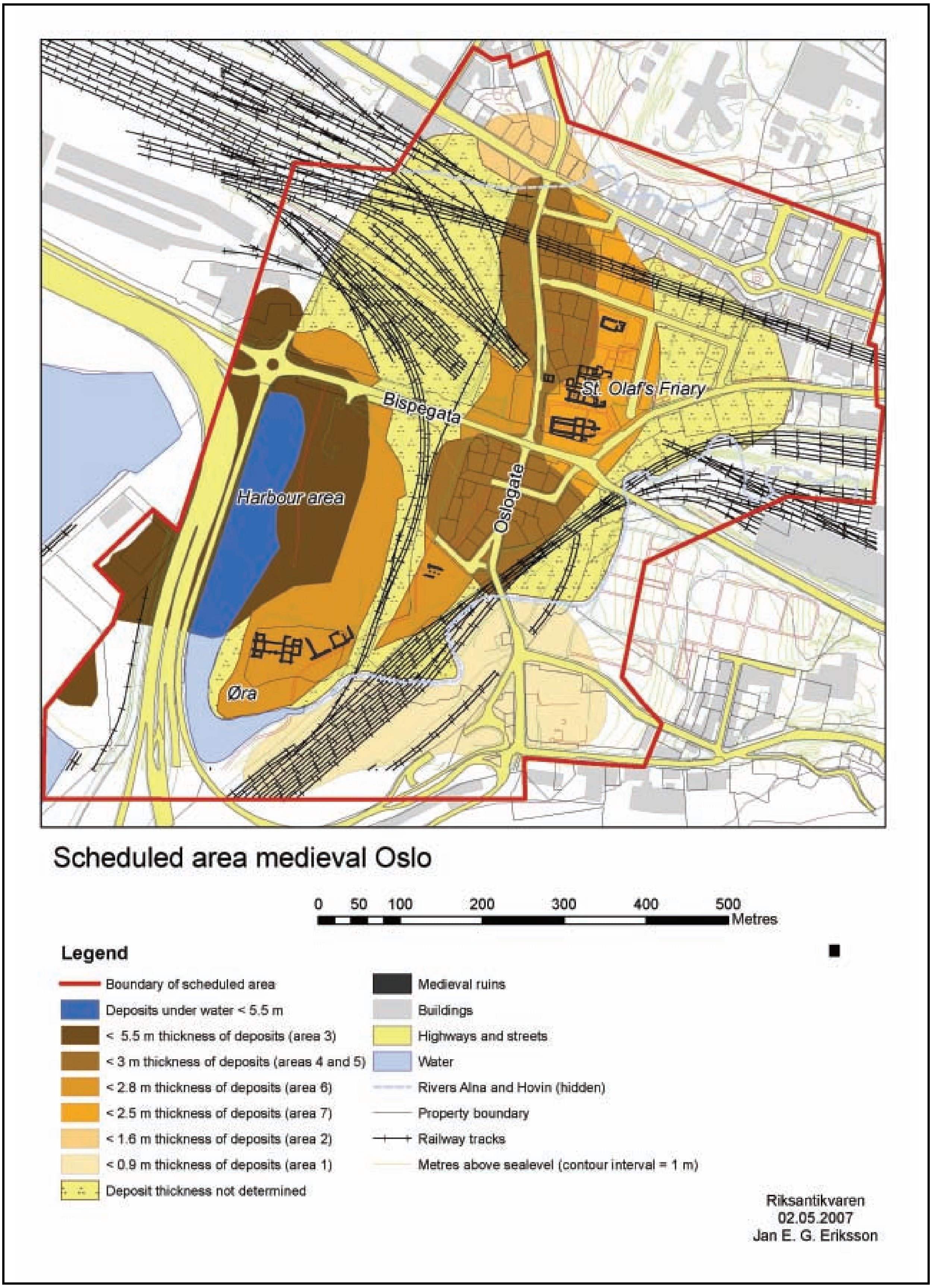


Fig. 4. Medieval Oslo. The area containing cultural deposits is divided into seven zones according to thickness and state of preservation of the deposits.

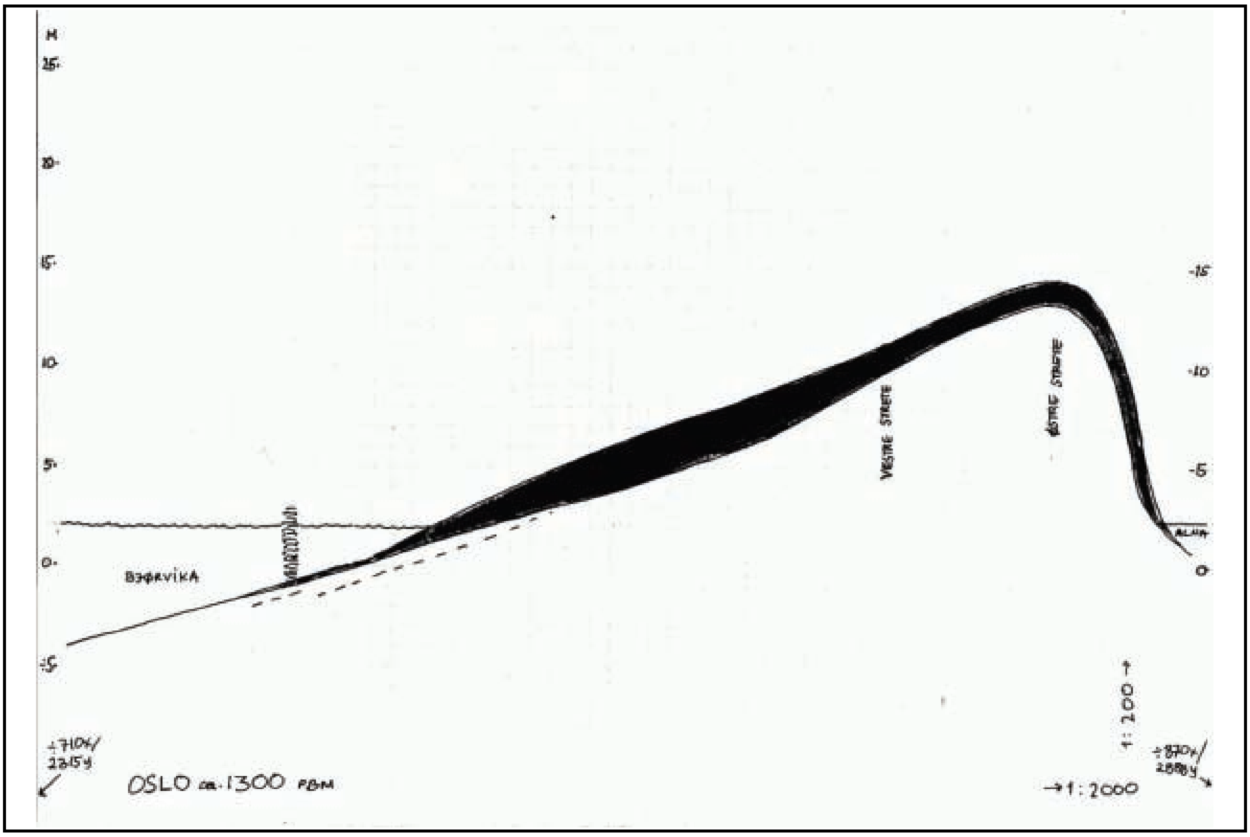


Fig. 5. Reconstructed schematic transect through medieval Oslo at about 1300.

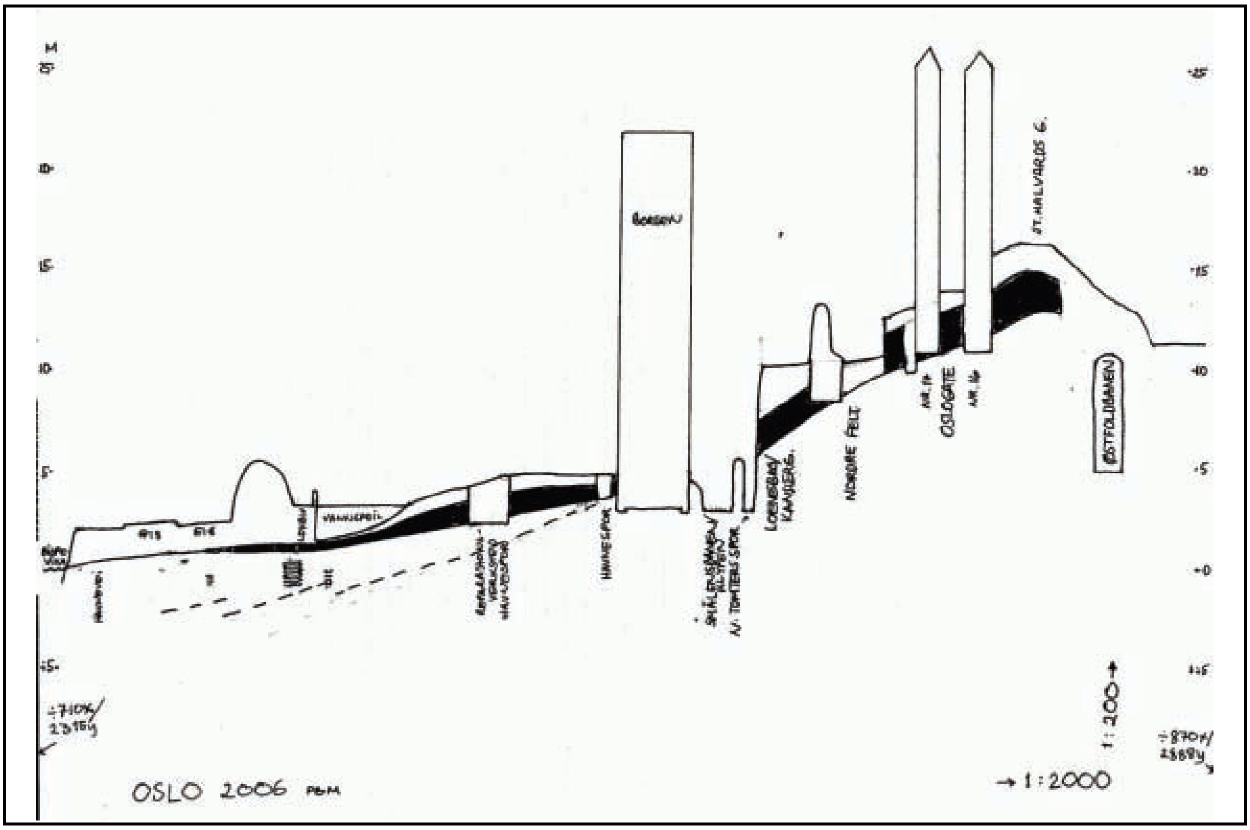


Fig. 6. Reconstructed schematic transect through medieval Oslo at about 2000.

2.4 Trondheim

The earliest human activity, dated to the period around the year AD 0, has been uncovered in the western part of the town, while the earliest building remains so far recorded have been found on the high ground in the vicinity of the cathedral. The medieval town grew up along the west bank of Nidelva (the River Nid), the western limit of the town being established already in the late 11th century. It was only in the 16th century that the town began to grow beyond this point.

The archaeological deposits: extent and thickness

The scheduled area of the medieval town of Trondheim was officially delimited in 1971 with modifications in 1984. The main area covers approximately 560,000 m² and in addition there are satellite scheduled areas around the medieval hospital to the west and around the monastic establishments at Elgeseter, Bakkegård and on the island of Munkholmen (the table below provides quick-reference estimates of principal extents).

Area	Area in ha. (ca.)	Comments
A. Scheduled area	560	Excluding satellite areas
B. Probable extent of medieval town	863	Maximum extent around 1200, includes town fields and medieval hospital
C. River/estuary	0	
D. Dry-land area with all deposits removed	253	Within the scheduled area. Mostly removed since ca. 1840
E. Dry-land medieval built-up area	296	Incl. areas with partly removed deposits

Fig. 7. The medieval town of Trondheim: variation in the deposits' state of preservation (red = very high organic content).

The thickness of the archaeological deposits varies considerably within the main area, as shown in fig. 8.

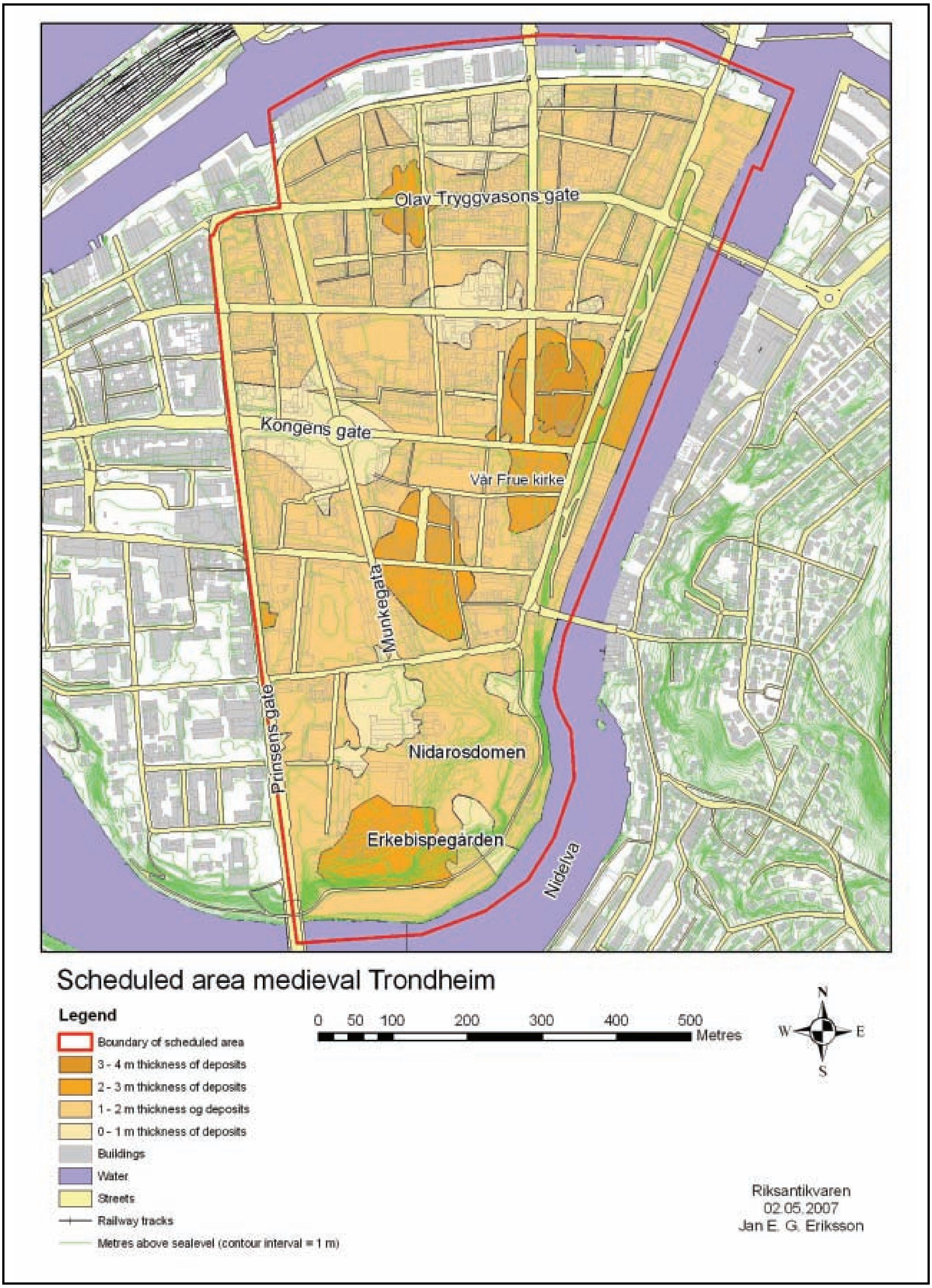


Fig. 8. Variation in deposit thickness within the scheduled area *Medieval Trondheim*.

- The area at the junction of the southern end of Søndre gate and the eastern end of Kongens gate has deposits in excess of 3 m. Coring undertaken along the southern side of Kongens gate indicates stratified archaeological deposits down to 6.2 m below the present ground surface.
- South of Vår Frue kirke (the Church of Our Lady) in Schultzgate the deposits are between 2 m and 3.5 m with well-preserved building remains from the early 12th century.
- In the western part of the town, mainly from Munkegata and westwards, the main activity has been agricultural until the early 17th century. The deposits here are generally around 1 m thick, while on the market-place and at the southern end of Munkegata they are 0.6 m or less.
- In the satellite areas the nature of the deposits is less well documented. Where information is available the deposits are similar to those on the western edge of the medieval town, with little or no organic remains preserved.

State of preservation and vulnerability

The state of preservation of the deposits varies considerably. The area with thick deposits is characterized by well-preserved organic remains, whereas the areas with thinner deposits (around 1 m) are generally on well-drained sandy soils and are themselves dry with little or no organic remains preserved.

The digging of cellars from the late 17th century onwards and full basements from around 1900 has effectively removed the bulk of the archaeological deposits, particularly in the northern part of the town. Until the late 1960s large areas of archaeological deposits were preserved under the streets themselves, though of course partly removed by ditches for waterpipes, sewers, and telephone and power cables. But with the increase in the volume of traffic during the 1960s and early 1970s it was necessary to increase the load-bearing capability of the roads. This was done by mechanically removing the archaeological deposits in a number of the main streets and replacing them with more stable materials. This work was halted in 1970, when *Riksantikvaren* intervened to rescue 11th century building remains in Søndre gate.

In recent years the main threat has been the redevelopment of parts of the city centre together with the renewal of the various services (some of the waterpipes still in use were laid during the 1860s). In addition the laying of a piped heating system in the town centre has from the early 1990s also resulted in a number of interventions.

Archaeological investigation and documentation

Archaeological excavations of one form or another have taken place every year since 1971, although with periods of relatively little activity in the 1980s. The majority of large-scale excavations in the central part of the medieval town took place during the 1970s.

The collection of archaeological data from the various archives and the creation of a new urban archaeological archive took place between 1971 and 1972, and the overview of all archaeological data up to 1970 was completed in 1973.

From 1971 to 1978 the stratigraphy was documented by means of daybooks, plans, drawings and photographs, all based on a set of standards. Standards as to how this documentation should be carried out were formalized in 1976. In 1979 a context card system was introduced together with standards for how this system was to be used. In connection with the excavations at Erkebispegården (the Archbishop's Palace), the context cards were further refined (see Appendix 3) and the system developed into a single-context recording system.

2.5 Tønsberg

The remains of the medieval town of Tønsberg are situated in the central part of the modern city that faces the sea (*Byfjorden*). The hitherto earliest structural remains were found on the then foreshore in the northern part of the medieval settlement area, where today's main street (Storgaten) runs. By the early 12th century the settlement started expanding eastwards, followed by an expansion southwards along the foreshore. Parallel to this there was an ongoing expansion southwestwards into the sea.

The archaeological deposits: extent and thickness

Officially delimited in 1974, the scheduled area of medieval Tønsberg covers about 560,000 m², and in addition to the secular settlement comprises Tunsberghus castle and the Slottsfjellet area, the *Thing* area of Haugar, and the episcopal estate at Teie on the opposite side of Byfjorden (the table below provides quick-reference estimates of principal extents).

Area	Area in ha. (ca.)	Comments
A. Scheduled area	560	
B. Probable extent of medieval town	516	Maximum extent around 1350
C. Harbour/fjord	Unsure	Uncertain extent and volume of deposits
D. Dry-land area with all deposits removed	63	Mostly removed since ca. 1837
E. Dry-land medieval built-up area	220	Incl. areas with partly removed deposits

The thickness of the cultural deposits varies considerably within the medieval urban area, and this is illustrated by the accompanying map (fig. 9).

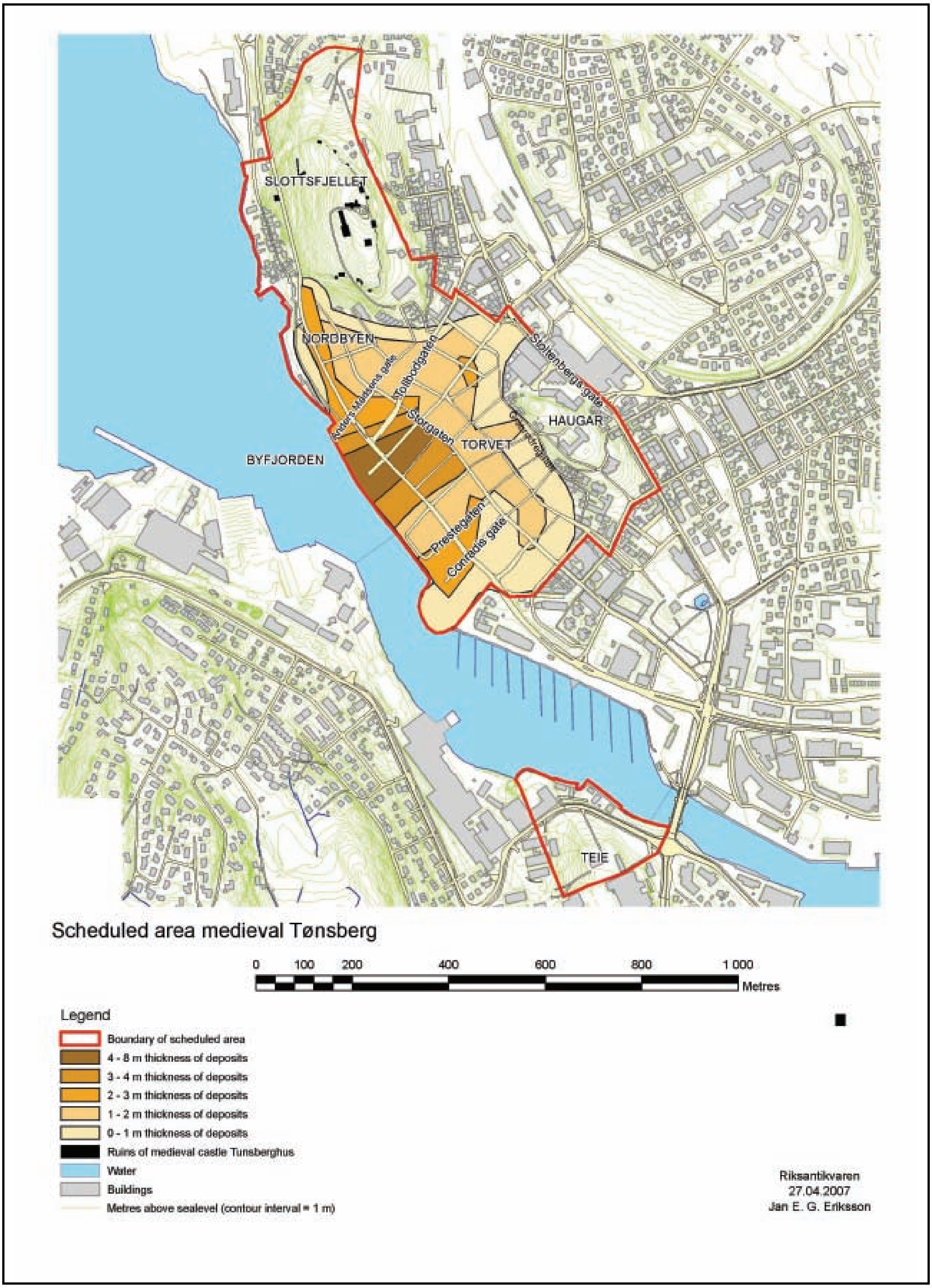


Fig. 9. Variation in deposit thickness within the scheduled area *Medieval Tønsberg*.

The following main zones of deposit thickness can be defined at present:

- In a smaller area bordering Møllegaten, below Storgaten, deposit thickness averages out at 4-5 m. However, coring in the same area has shown that there are stratified cultural deposits down to 8.5 m below the present ground-level.
- In a zone limited by Storgaten and the existing wharf, and by Anders Madsens gate to the north down to the block between Prestegaten and Conradis gate to the south, deposit thickness is estimated to be about 3.5 m. The deposits here derive mainly from systematic deposition of rubbish to reclaim land for the wharf.
- In the area from Nordbyen along the foot of Slottsfjellet northeastwards to Stoltenbergsgate and further along to Gråbrødregaten, deposit thickness is 1 m or less.
- Our knowledge about deposition of cultural deposits in and around the castle, the episcopal estate and the *Thing* area is limited, and the culture-layers in these areas can hardly be compared with those deposited as a result of activities in the town core.

State of preservation and vulnerability

The state of preservation of the medieval deposits and their vulnerability varies within the cultural layer area as a whole. The best conditions for preservation are found in those areas where deposition took place on the foreshore or in the sea. This area coincides to some extent to the area where the deposits are directly in contact with the water-table.

The greatest threats to the preservation of the (medieval) deposits during the last 30 years have been new construction projects and the piecemeal renovation of the public services infrastructure, and these will remain the principal <u>direct</u> threats. On the whole, however, perhaps the greatest overall, long-term threat will come from the large-scale road and tunnel projects that are now on the drawing board. While these do not themselves involve direct intervention in the archaeological deposits, there is a significant risk that they will adversely affect preservation conditions throughout the whole of the scheduled area in the long run.

Archaeological investigation and documentation

Systematic archaeological investigations in the medieval town of Tønsberg were in progress more or less annually from 1971 to 1991. After that only watching briefs combined with smaller archaeological excavations have been carried out, with the exception of one major excavation in 1999. The latter was followed up with a monitoring programme to record possible effects of the new building on the archaeological deposits left intact around and under the building.

Archaeological mapping of medieval Tønsberg started in 1973. To begin with, work focused on establishing the extent of medieval deposits and to define where deposits had already been destroyed (cf. fig. 10 below). This resulted in the production of a map delimiting the scheduled area. At the same time it became compulsory to notify *Riksantikvaren* of any intended excavation work within this area. All archaeological information collected in the period 1973-1994 was published in a special report in 1994.

In 1978 a local standard for archaeological documentation was devised: *Dokumentasjon – Tønsbergstandard* (with later revisions, the latest in 1999). The standard's main purpose was to provide an introduction to the local principles of documentation and finds treatment, and includes standards for site drawing, photography, surveying, and written documentation. Layer documentation proceeded along the following lines:

- Definition of the individual layer was based on principal constituents together with other components according to a trisect scale of occurrence.
- For recording, there were specially designed forms divided into two main sections, one for factual information and one for description and interpretation.

In 1999, during the excavations at Nedre Langgate 40, two new methodological aids were introduced: single-context recording; and PenMap, a digital surveying and drawing system.

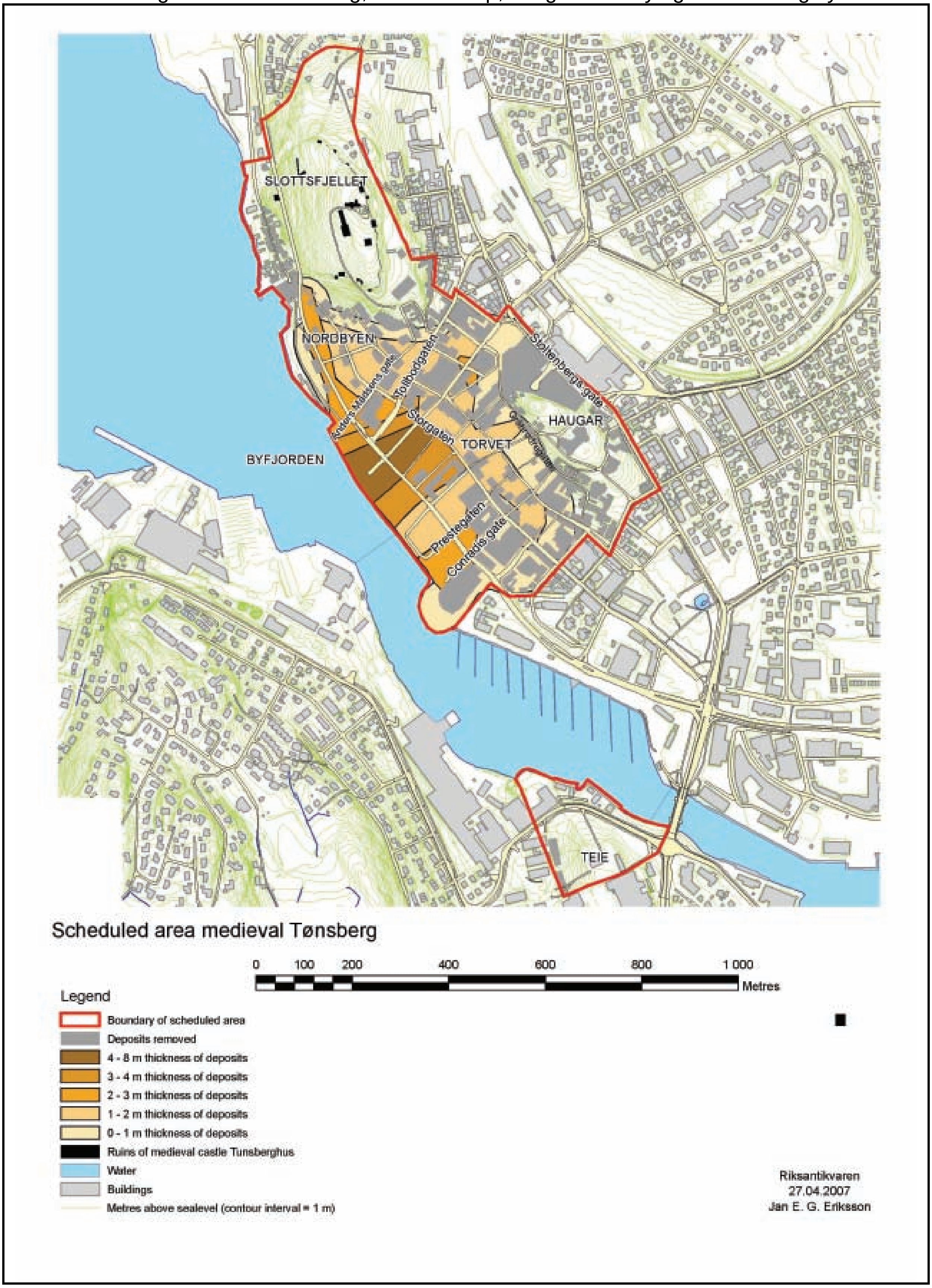


Fig. 10. Areas where archaeological deposits have been partially or entirely removed within the scheduled area *Medieval Tønsberg*.

3. Methods

3.1 Archaeological methods

3.1.1 Re-examination and recording of sections in existing trenches/pits

Cases where an existing trench or pit is to be re-opened afford archaeologists with a good opportunity to compare then and now situations – always provided that sections in the trench or pit were recorded in the first place. If one can re-locate and redraw the exact same section, then it is easy to compare by means of overlay. This enables the archaeologist to a) ascertain whether the organic deposits have undergone any significant loss of volume, and b) detect any marked differences in state of preservation. The amount and quality of information that can be gleaned will of course be dependent on the accuracy of both sets of drawings.

One should, in addition, endeavour to record – at one point, at the very least – an "outer" and an "inner" section. That is to say, the section that emerges after cleaning away the disturbed material represents the outer section, which is naturally recorded in its entirety. One can subsequently excavate a column (5-10 cm deep and up to 50 cm wide can be suggested) running from top to bottom, and record the exposed "inner" section – i.e., the section that lies 5-10 cm behind the original section. This will allow detection of any significant differences in state of preservation, and provide some indication regarding the organic deposits' "natural resistance" to decomposition. It can also provide a basis for overall evaluation of how different types of backfill may affect preservation conditions.

As regards previous experience of this procedure in Norway to date, there are really only two instances that qualify – one in Trondheim, and one in Tønsberg. In Trondheim a trench excavated in 1985 was re-opened in 2004; this had been backfilled with a sand and gravel mixture. The archaeological deposits appeared to be well preserved, were moist, and had a smell typical of anaerobic conditions. In Tønsberg a trench excavated in 1976 was re-opened during a large-scale archaeological excavation in 1999; this trench had been backfilled with material excavated from the trench. When the section drawings were compared, no significant difference in the layer boundaries could be found.

3.1.2 Layer(/context) recording

For monitoring purposes, layer/context recording methods can be divided into two main areas: in connection with systematic excavation; and in connection with drilling.

Excavation

For layer(/context) recording in connection with systematic excavations, *Riksantikvaren* and NIKU's regional offices are agreed upon using a modified and upgraded version[8] of the original recording sheet used in Bergen[9]. This arose in recognition of the fact that comparative studies – whether of preservation conditions or more traditional archaeological aspects – between the towns depend on congruent data, and that such data can only really be achieved through uniformity of documentation.

The philosophy behind the layer(/context) recording system is quite simple. Put bluntly, archaeology occurs when heritage management and preservation fail. Archaeology then

[8] The amendments were undertaken partly with a view to the adoption of digital documentation for all kinds of archaeological investigations, and partly to incorporate new aspects/factors. Upgrading stemmed to a great extent from an in-house seminar held by NIKU's Archaeological Investigations group on January 19th 2006.

[9] For a brief history of the original version, see Appendix 5.

becomes "Preservation by Record", and the state of preservation of the investigated and removed deposits is then dependent on the quality of the documentation – as is, of course, the quality of the historical information that can be extracted from the documentation material. The layer(/context) recording system therefore strives to maximize both sets of information.

The whole point of the layer(/context) recording sheet is to lead the recorder step by step to a conclusion about the layer in question's depositional and post-depositional/taphonomic history: in short, its formation. The guiding premise behind this is that a layer's physical attributes, cultural contents and stratigraphic context/relationship to other layers and/or structures – in short, an assessment of the whole situation – will reflect the nature, conditions and approximate duration of its formation, together with any subsequent transformations.

Each layer is therefore recorded separately on a special sheet, which contains a detailed description of its stratigraphic context, its physical characteristics/attributes and its contents (supplemented where possible by laboratory analysis of soil samples). And it culminates with an interpretation of its formation – i.e., whether it represents a natural deposit, an *in situ* accumulation, redeposited material, etc.

For presentation purposes here, the sheet has been divided into six sections, and each section is described briefly. Appendix 4 presents the accompanying sheet that provides more detailed instructions for completion of the layer/context recording sheet.

Section 1 contains basic information (site identification, name of recorder, date of recording, etc).

Section 2 contains information on the layer's context in relation to surrounding layers and constructions. Once surveying by total station becomes the norm, there will no longer be any need for traditional locational data, since this will be supplied in the form of geodata.

Section 3 contains information on the layer's physical attributes/properties. In most cases the variables can be numbered from 1 to 5, making them easier to work with.

Section 4 is devoted to the four categories of components: botanical, zoological, mineral and artefactual.

Section 5 contains Preservation Category, where the state of preservation of the layer as a whole is specified in accordance with the State of Preservation Scale (see section 3.1.3). For some organic layers – peat, basically – degree of decomposition can be scaled using the Von Post test. This can be supplemented by moisture content readings derived from, for example, Theta probes, and by other measurements (oxygen, temperature, pH etc) as applicable.

Finally, Section 6 contains the overall interpretation of the layer's formation.

Section 1
BASIC DATA (administrative/archival, e.g. site identification)

NIKU PROJECT NO.
MUSEUM'S NO. (e.g., BRMxxx)
SITE NAME
DATE
SIGNATURE
LAYER(/CONTEXT) NO.

LOCALIZATION: Geodata from total station etc (with supplementary field for section drawing number/numbers)

Section 2
POSITION

STRATIGRAPHIC RELATIONSHIPS	cuts, cut by, above, below, inside

Section 3
PHYSICAL ATTRIBUTES

COLOUR	basic, additional, shade
COLOUR CHANGE	light to dark
CHANGE RATE	none slow (several minutes) medium (up to 1 min.) fast (seconds)
ODOUR TYPE	just plain earthy H_2S pollution (i.e., diesel/oil) freshly cut wood salt dung/excrement
ODOUR STRENGTH	absent faint medium strong overpowering
SURFACE	1 – 5 (see completion sheet)
LIMES	1 – 5 (see completion sheet)
HOMOGENEITY	1 – 5 (see completion sheet)
LAMINATION	1 – 5 (see completion sheet)
COMPACTNESS	1 – 5 (see completion sheet) *
ELASTICITY	1 – 5 (see completion sheet)

Section 4 – Components

BOTANICAL COMPONENTS	
PRESERVATION*	1 – 5 (see completion sheet)
INCLINATION	1 – 5 (see completion sheet)
DISTRIBUTION	1 – 5 (see completion sheet)
MECH. FACTORS	1 – 5 (see completion sheet)
SUPPLEMENTARY FREE-TEXT DESCRIPTION	

- Cf. separate list in 3.1.3 of specific indicators/criteria for archaeological assessment of state of preservation; and in some situations – notably, peat bogs and the like – the Von Post scale (see section 5 below) will also be applicable
- It is possible that state of preservation should be specified separately for the different types of organic components present in the individual layer (cf. Specification of Components)
- Knife-point test for large pieces of wood
- For smaller pieces of wood, thinnish woodchips or twigs should be chosen, not naturally hard pieces like knots

ZOOLOGICAL COMPONENTS	
PRESERVATION	1 – 5 (see completion sheet)
INCLINATION	1 – 5 (see completion sheet)
DISTRIBUTION	1 – 5 (see completion sheet)
MECH. FACTORS	1 – 5 (see completion sheet)
MINERAL COMPONENTS	
INCLINATION	1 – 5 (see completion sheet)
DISTRIBUTION	1 – 5 (see completion sheet)
MECH. FACTORS	1 – 5 (see completion sheet)
MECH. FACTORS	1 – 5 (see completion sheet)
ARTEFACTS	
INCLINATION	1 – 5 (see completion sheet)
DISTRIBUTION	1 – 5 (see completion sheet)
MECH. FACTORS	1 – 5 (see completion sheet)
SUPPLEMENTARY FREE-TEXT DESCRIPTION	

PROPORTION (as a percentage of total volume of layer/context)							
BOTANICAL		ZOOLOGICAL		MINERAL		ARTEFACTS	

SPECIFICATION OF COMPONENTS										
Type	amount	preserv	Type	amount	preserv	Type	amount	Type	amount	preserv
Detritus Lignosus:			Human bones			Stones > 5 cm		Stone		
- woodchips			Animal bones			Pebbles 2 - 5 cm		Brick/tile		
- (hazel)nut shells			Fish bones			Gravel 2 mm - 2 cm		Pottery		
- leaves			Bird bones			Sand 1 - 2 mm		Glass		
- bark			Antler			Sand 0,2 - 1 mm		Iron		
Detritus Herbosus:			Scales			Sand 0,06 - 0,2 mm		Non-ferrous metal		
- grasses			Shells (marine)			Silt 0,002-0,006 mm		Wood		
- cereals			Chitin			Clay < 0,002 mm		Leather		
- herbs			Hair			Lime		Textile/rope		
Detritus Granosus (mosses, etc)			Insects			Other:		Bone/antler		
Turfa (turf, peat)			Egg cases					Composite artefacts		
Substantia Humosa			Other:					Other:		
Charcoal										
Ash/soot										
Dung										
Excrement										
Other:										

Section 5
PRESERVATION CATEGORY (of whole layer; in accordance with State of Preservation Scale: e.g., A1, C4, etc – see section 3.1.3)

Degree of decomposition
Von Post scale, from H1 to H10
(H1 = not decomposed,
H10 = fully decomposed)

MOISTURE CONTENT (from e.g. Theta probe)
READING No.:
READING:
WHERE MEASURED:
SOIL TYPE SETTING:

OTHER MEASUREMENTS (O_2, pH, %organic content)

Section 6
CHARACTERIZATION OF THE LAYER

ACCUMULATION RATE		**MECHANICAL FACTORS**		**CHARACTER**	
1 – 5 (see completion sheet)		1 – 5 (see completion sheet)		1 – 5 (see completion sheet)	

ADDITIONAL COMMENTS (text)
It has been pointed out that provision should be made for a “history of recording”, i.e., to accommodate lengthy screeds written by fieldworkers who did the original excavation of the layer, but with a condensed/revised version written by the supervisor.

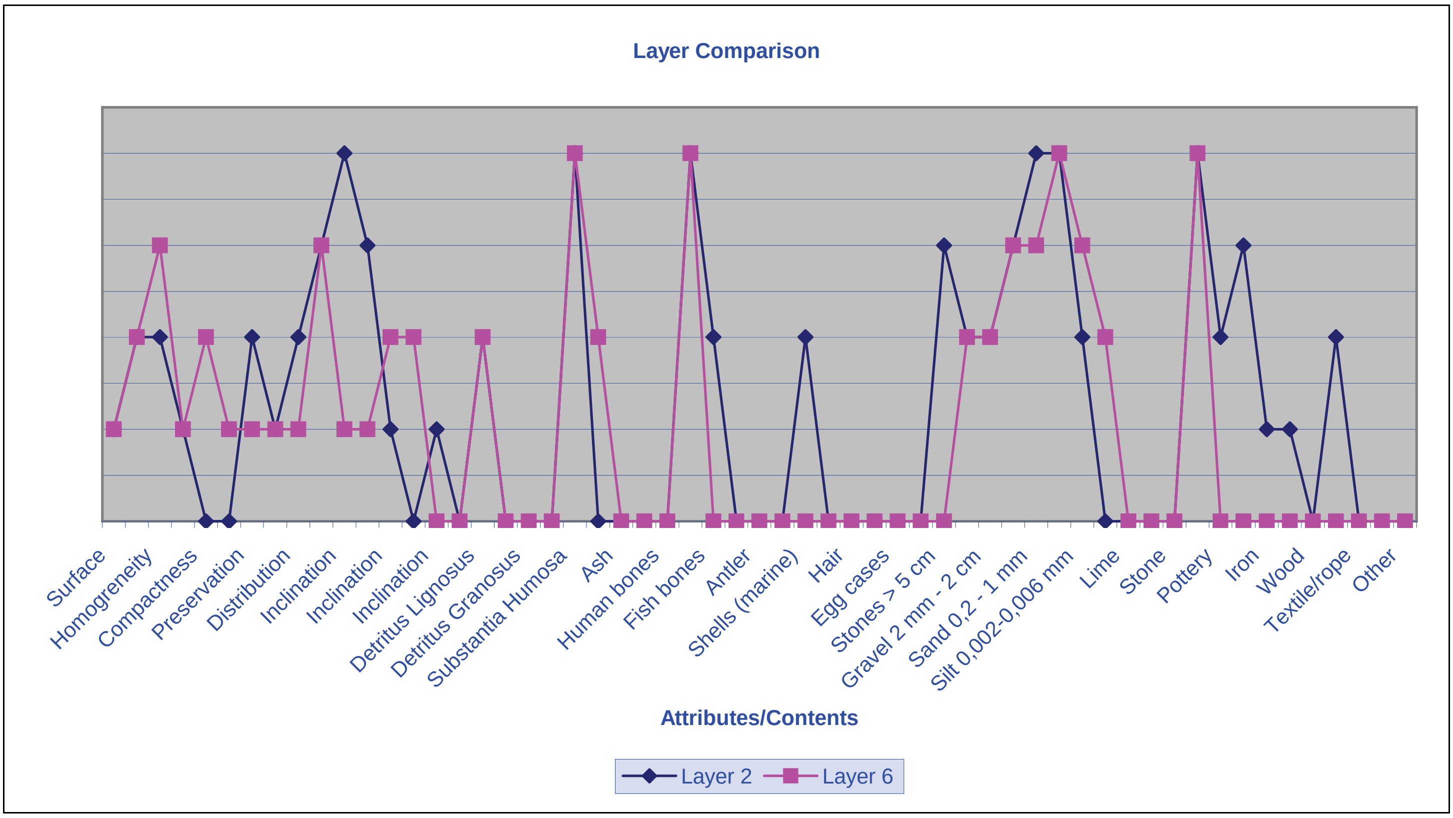
Photos (list: text)
Samples (list: text)

It has been objected that, when using the sheet, things have to be forced into a pre-existing mould, leaving little leeway for improvization. However, it has yet to be demonstrated that there are layers – no matter whether situated above or below the water-table, or however old or recent they may be, etc – that cannot be described according to the four categories (after all, a cultural deposit is, in a very real sense, itself an artefact).

There will, of course, be holes that require plugging: for instance, it is at present still difficult to express differences in preservation between, for sake of argument, large and small woodchips. However, it can be pointed out that the “Additional comments” field makes it possible to supplement the standardized description by means of free text.

As mentioned in the Foreword, nothing stands still for very long, not even a discipline like archaeology, and the planned introduction of all-embracing digital documentation systems for archaeological recording in Norway will undoubtedly bring major changes. The digital version of the recording sheet may very well end up looking nothing like the original – among other things it will probably be colour-coded to indicate what fields “must be filled out”, “should be filled out”, and “fill out as applicable” – but the underlying principles will continue to apply in some form.

Turning to the plus side, one of the sheet’s major advantages is the facility of assigning a number to the various options within each attribute or material category. These numbers can be presented in the form of a graph – and one obtains, in effect, a fingerprint of the layer. An inspired arrangement, it enables comparison of two or more layers (see Microsoft Excel example diagram below), or even the same layer recorded on two or more separate occasions.



Comparison of archaeological state-of-preservation assessments with the measured loss-on-ignition values indicates that there is a fairly satisfactory degree of correspondence (Matthiesen 2004b: 23-25). This means two things:

- that archaeological assessments can stand alone (i.e., in those cases where no results of geochemical analysis are available)
- that the preservation information contained in former versions of the Bergen layer recording sheets – even though radically different in layout – is still valid, thus enabling data from more than 20 years ago to make a contribution. In other words, it means that documentation from earlier archaeological investigations, at least those that employed layer recording sheets with some provision for indicating state of preservation, can be activated in order to provide data for the mapping of preservation conditions in adjacent areas.

Drilling
As described later on in section 3.2, drilling is frequently done using a rotary drill (auger) whose total "thread" height is normally one metre. The drill is driven down under rotation one metre at a time, and then retracted without rotation so that the adhering soil can be inspected (after having carefully scraped off the outermost material, which may readily become contaminated as a result of contact with higher strata).

Different strata are identified on much the same basis as in an excavation section. The method of recording is a relatively uncomplicated process (NB.: the layer recording sheet used on excavations is not normally used in connection with drillings). Each stratum's detailed description – including an overall assessment of its state of preservation – is written down in a logbook, along with the stratum's depth below the surface, and the depth of any soil samples, finds and dating samples. The recommended way of recording is exemplified in the table below (stratigraphic sequence in a dipwell designated MB14 installed at Bryggen in Bergen):

Depth (m)		
From	**To**	**Description**
0	0.10	Shingle
0.10	0.20	Smashed pantiles and some stones
0.20	0.50	Grey, sticky soil with pieces of brick and stones
0.50	0.60	Firelayer, but only charcoal visible
0.60	1.75	Dark-grey/brown sticky, sandy humus, some half-rotted woodchips, birch-bark pieces and hazelnut shells 1 piece of post-medieval windowpane (<u>not retained</u>) Relatively dry soil Groundwater at ca. 1.00 m Sample 1: 0.70-0.90 m; Sample 2: 1.50-1.60 m Poor preservation
1.75	2.00?	Probably in situ firelayer: patches of reddish ash/-sand present in amongst charcoal Preservation indefinable
2.00?	2.60	Most of the material was washed off the drill on its retraction up through the groundwater Some larger pieces of medium-preserved wood at 2.10-2.20 m; possible foundation timber
2.60	3.50	Very organic, but practically no humus: fine pieces of plant remains with a great quantity of laminated moss, and probably some excrement too, along with hazelnut shells and fresh-looking woodchips Strong rotten-egg stench Good preservation
3.50	6.35	Very organic, but very little humus: mostly plant remains, dung/straw, a considerable quantity of fresh woodchips along with some twigs and hazelnut shells; very few fragments of animal bone Surprisingly soft and runny, and a lot of material was washed off the drill, especially down to 5.00 m, but then very compact on downwards Some differentiation, as follows: 4.00 to 5.00 m: probably more laminated moss than dung/straw, and varying quantities of woodchips, twigs and hazelnut shells

		5.00 to 6.35 masl: definitely laminated moss, and varying quantities of woodchips, twigs and hazelnut shells 1 piece of metallic slag(?) from 4.60 m Sample 3: from 3.70-3.90 m; Sample 4: from 5.50 to 5.70 m; Sample 5: from 6.10 to 6.30 m Radiocarbon dating sample taken from Sample 5 Excellent preservation in deposit’s lower half especially
6.35	6.45	Transition to light-grey/-brown sand with sea shell fragments
6.45	↓	Seabed deposit: grey, relatively coarse sand with sea shell fragments
		Rotary drilling abandoned at ca. 7.00 m

For report purposes, this field documentation can be cleaned up, supplemented, and presented in the following way (it has since been suggested that the table should include a column for, amongst others, loss-on-ignition data):

MB14: sediment sequence (visual inspection) This hole was towards the northeastern end of the extensive unbuilt area in the middle of Holmedalsgården’s southern building-row. Multiconsult determined its coordinates as X59919.550/Y67171.655, and the modern shingle surface was at an elevation of ca. 2.30 metres above sea-level (masl). PC = Preservation Category (in accordance with SOPS – State Of Preservation Scale)								
Masl		**Stratum number**	**Same as stratum no.**	**^{14}C-dating /finds**	**Accession number**	**Period**	**PC**	**Description**
From	**To**							
2.30	2.20	MB14-01				Mod	E0	Shingle
2.20	2.10	MB14-02				Mod	E0	Smashed pantiles and some stones
2.10	1.80	MB14-03				Mod	A0	Grey, sticky soil with pieces of brick and stones Preservation indefinable
1.80	1.70	MB14-04				1702 (?)	A0	Firelayer, but only charcoal visible Preservation indefinable
1.70	0.55	MB14-05		1 piece of post-medieval window-pane (<u>not retained</u>)		Post-med.	B2	Dark-grey/brown sticky, sandy humus, some half-rotted woodchips, birch-bark pieces and hazelnut shells Relatively dry soil Groundwater at ca. 1.30 masl (?) Sample 1: 1.60-1.40 masl Sample 2: 0.80-0.60 masl Poor preservation
0.55	0.30?	MB14-06					C0	Probably in situ firelayer: patches of reddish ash/sand present in amongst charcoal Preservation indefinable
0.30?	-0.30	MB14-07					C3	Most of the material was washed off the drill on its retraction up through the groundwater

								Some larger pieces of medium-preserved wood at 0.20-0.00 masl; possible foundation timber
-0.30	-1.00	MB14-08					C4	Very organic, but practically no humus: fine pieces of plant remains with a great quantity of laminated moss, and probably some excrement too, along with hazelnut shells and fresh-looking woodchips Strong rotten-egg stench Good preservation
-1.00	-1.20	MB14-09					C4	Timber pieces, solid and fresh-looking
-1.20	-4.05	MB14-10		AD 1035-1185 1 piece of metallic slag (?) from -2.30 masl	603/1 603/2	Med. *up to at least -3.80 masl*	C4/-C5	Very organic, but very little humus: mostly plant remains, dung/straw, a considerable quantity of fresh woodchips along with some twigs and hazelnut shells; very few fragments of animal bone Surprisingly soft and runny, and a lot of material was washed off the drill, especially down to -2.70 masl, but then very compact on downwards Some differentiation, as follows: -1.70 to -2.70 masl: probably more laminated moss than dung/straw, and varying quantities of woodchips, twigs and hazelnut shells -2.70 to -4.05 masl: definitely laminated moss, and varying quantities of woodchips, twigs and hazelnut shells Sample 3: from -1.40 to -1.60 masl Sample 4: from -3.20 to -3.40 masl Sample 5: from -3.80 to -4.00 masl Radiocarbon dating sample (birch-bark) taken from Sample 5 (-3.80/-4.00 masl) Excellent preservation in deposit’s lower half especially

-4.05	-4.15	MB14-11						C0	Transition to light-grey/-brown sand with sea shell fragments
-4.15	↓	MB14-12						C0	Seabed deposit: grey, relatively coarse sand with sea shell fragments
									Rotary drilling abandoned at ca. -4.70 masl

It is very important that the strata in each drilling be numbered in accordance with a consistent system, with a view to ensuring unique identity in connection with eventual database work. It is best not to use the same numbering as for layers/contexts, but rather a separate stratum numbering. Strata sequences in dipwells installed at Bryggen in Bergen, by way of example, are numbered using a letter/number combination that starts with MB (derived from ***miljøbrønn***, the Norwegian for dipwell), followed by the individual dipwell's sequential number, and ending with the stratum number (numerical sequence from top to bottom). Obstructions and missing parts of sequences are not normally assigned a stratum number.

The state of preservation of each stratum is assessed archaeologically, either in the field (where augering is concerned, at least in most cases) or in the laboratory (coring). This assessment should be based on the criteria/indicators presented in section 3.1.3. The state of preservation assessment for each stratum can then be noted down in the column PC in the table shown above, PC standing for Preservation Category (in accordance with the State Of Preservation Scale: see section 3.1.3).

There is one major drawback with regard to the archaeological recording of stratigraphy in drillings/corings. Though it is reassuring to find that, as indicated elsewhere, archaeological state-of-preservation assessments are not way off the mark, it must be pointed out that in the case of layers exhibiting poor preservation archaeological assessments cannot really reveal whether the observed decomposition is due to ongoing processes, or rather took place at the time of the layer's deposition, or even at some time in between. If, however, one is fortunate enough to recover larger pieces of wood, these can be inspected to see whether they display remains of fungal growth/attack (which will not normally occur in undisturbed deposits, at least not in the deeper-lying ones).

Additional aspects

W.E.T sensor/Theta-probe readings of water content

- water content measurement can be carried out by taking ca. 0.5 litres of soil directly from the drill and placing it in a plastic bag. By compressing the soil in the bag so as to ensure good contact with the sensor's prongs, a relatively reliable reading can be achieved.

Test-pit

It is very useful – and highly recommended – to excavate a small test-pit (1m^2 or so) either around or close to the borehole, in order to obtain baseline archaeological and geochemical data – e.g., dating material and soil samples – from the upper strata.

Dating

The number of ^{14}C-datings per drilling must be evaluated under way, depending to a certain extent on the amount and position of chronologically diagnostic archaeological finds. Ideally, one should take dating samples from somewhere near the top and the bottom of each sequence, but this will also depend on how generous the project budget is.

3.1.3 State Of Preservation Scale

For layer(/context) recording in connection with both excavation and drilling, and particularly with a view to subsequent monitoring and mapping work, one of the most important fields to be completed is Preservation Category. The correct preservation category for the individual deposit can be determined by reference to the table below – the State Of Preservation Scale (SOPS) – provided one has established the groundwater-level, along with any possible fluctuation range of significance.

Apart from this, the scale should be fairly self-explanatory. It can be applied universally and thus will facilitate comparison between archaeological and geochemical (or other laboratory based) state-of-preservation assessments wherever such investigations may be undertaken.

STATE OF PRESERVATION SCALE (SOPS)

PRESERVATION SCALE		DEGREE OF PRESERVATION						
		NULL-VALUE	LOUSY	POOR	MED-IUM	GOOD	EXCEL-LENT	
POSITION IN RELATION TO GROUNDWATER	OVER	A0	A1	A2	A3	A4	A5	A
	OVER/IN	B0	B1	B2	B3	B4	B5	B
	IN	C0	C1	C2	C3	C4	C5	C
		0	1	2	3	4	5	
"Extreme situations/cases"		D0	D1	D2	D3	D4	D5	D
Fill etc later than ca. 1900		E0	E1	E2	E3	E4	E5	E

The assessment of state of preservation should be based on the following principal criteria/indicators:

- Odour:
  - for <u>organic</u> deposits: presence and strength of "rotten-egg" smell
  - for wood: presence and strength of "freshly cut" smell
- Colour/colour change (the brighter the soil's colour when first exposed and the faster the colour change after exposure, the better the preservation)
- Amount of force required to snap pieces of wood (the more force, the better the preservation – for this purpose, relatively thin woodchips or twigs should be chosen, not naturally hard pieces like knots)
- Amount of force required to pull apart a strand of moss
- Sponge reaction of soil block; squashiness of woodchips; springiness of strands of moss or hair/fur
- General appearance (colour, visibility of structure) of macroscopic organic components.

The State Of Preservation Scale gives the impression of being an absolute scale – and possibly it should be, in theory. However, it has been noticed that it is hard for the recording archaeologist to make assessments in relation to an absolute scale of state of preservation. Obviously, it is not possible for all archaeologists to have precisely the same notion of what represents optimal state of preservation. Moreover, perhaps the question is whether there can be such a thing as an optimal state of preservation in absolute terms. We may point to a certain deposit now and characterize its state of preservation as excellent, but if all organic deposits are undergoing decomposition, however gradual, then how much better must not its state of preservation have been 100 years ago. And anyway, what situation are we to hold up as a yardstick? How could we ever be sure that we have encountered deposits exhibiting optimal state of preservation?

This problem is even more apparent when one moves from one town to another, and there is an inevitable tendency to see the individual sequences in isolation from each other. The Piling Project drillings carried out in Bergen, Copenhagen and Lund in 2005 provide a concrete example. A certain deposit in one of the Copenhagen drillings was assessed as well preserved, but this was largely relative to the state of the other deposits in that particular sequence. Had it appeared in a drilling in the Bryggen area, for sake of argument, it might very well not have achieved a similarly high score.

It has therefore been argued that the results of geochemical analysis methods such as loss-on-ignition must be used to “calibrate” the archaeological assessments, enabling the latter to be tied more reliably into an absolute scale.

3.2 Geotechnical methods

3.2.1 Geotechnical boreholes and the analysis of soil samples

Boreholes are a relatively cheap and easy way to obtain soil samples, particularly in cases where excavation is out of the question. Boreholes are normally made using two different methods: augering, and drilling with samplers (coring). Where appropriate, it is strongly recommended that the borehole be used for the installation of a dipwell for groundwater monitoring.

Augering

This can either be carried out using a hand drill, a lightweight vibro-hammer corer unit, or a drilling rig; today, most drilling firms use the latter. The augers normally used have an external diameter of 75-100 mm. The auger is drilled down under rotation 0.5 m or 1.0 m at a time (depending on the type) and then withdrawn from the borehole without rotation. Samples are taken from the soil that adheres to the retracted auger, after having first cleaned off any contaminated material.

Sampling with 100 mm auger on rig inside building IVe,
Svensgården tenement, Bryggen, Bergen (photo: Jensen, Multiconsult AS).

There are some problems with this method of sampling:

- in dry sandy, gravelly and stony soils and in very moist soils it is often impossible to retrieve samples
- the auger can be deflected or stopped by large stones, well-preserved massive timbers, and even some compact/firm deposits

As regards obstructions, most can be jackhammered through – though this can cause greater local damage to the surrounding deposits. And as regards dry, sandy soils, these are hardly relevant in the present context.

In boreholes with diameter equal to or larger than 100 mm, groundwater sample wells (dipwells) can be installed. To prevent infiltration of surface water into the wells, the surface around the crown should be sealed with swelling bentonite clay. If boreholes in archaeological deposits are not to be used for the installation of monitoring devices, they should be completely sealed with bentonite (in pellet form) to avoid increased decay rate.

Drilling with samplers

This type of sampling is normally carried out using a drilling rig, but when using a window-sampler (basically, a cylinder with a narrow slit running the full length) can also be carried out using a vibro-hammer. The standard diameter of samplers used is 54 mm but larger samplers are available; in Bergen cores were extracted using a 76 mm diameter sampler and in Tønsberg a 97 mm diameter sampler was used. The larger-sized samplers demand the use of either a heavyweight well-drilling rig, which is difficult to use in confined spaces, or a smaller rig that is anchored – which may itself cause damage to the deposits. Furthermore, the risk of sample loss increases with the sampler diameter and the weight of the core.

The sampling methods are the same for all sizes of samplers, but the length of the sampler can vary. For the 54 mm samplers the length of the cylinders is normally 0.8 m, but samplers of 0.4 m are also available. The 76 mm samplers have a cylinder length of 1.0 m, and the 97 mm samplers used have had a length of 0.6 m.

As the cores are retrieved the cylinders are sealed at both ends to hinder drying out during transport to the laboratory and prior to their analysis. At the laboratory the cores are removed from the cylinders using a hydraulic or compressed air-driven ram. Once removed from the cylinder the core can be described and sampled for analysis.

This method of sampling has its problems too:

- it has been difficult to use all the above-mentioned sampler diameters in the urban deposits because stone, wood etc can block the cylinder and prevent the acquisition of full-length samples
- all samplers have difficulty in cutting through well-preserved timbers, so that it is almost always necessary to drill through the obstruction without sampling (Odex drilling)
- when the cores are removed from the sampler, they may be compressed or deformed by the equipment used
- relatively few laboratories are equipped to deal with large diameter cores.

Lower end of 54 mm core sampler damaged on encounter with well-preserved timbers in archaeological deposits (photo: Dunlop, NIKU).

Analysis of samples

The diameter of the sampler dictates the size of the sample that can be taken from individual layers within a core. Experience has shown that the sample sizes obtained from cores retrieved with the 54 mm sampler are often too small to do anything other than a basic geotechnical analysis, the basic parameters being water content and organic content. However, even with small samples it is normally possible to test for pH and conductivity as well.

- Water content is normally expressed as a percentage of sample weight after drying at 110ºC.
- The organic content is usually estimated by loss-on-ignition, where the sample is heated to 450-550ºC over a given length of time (normally 24 hours). This consumes the organic matter, and the organic content can then be expressed as a percentage of the weight of the dry matter. Other methods of estimating the organic content include chemical treatment with permanganate, dichromate or hydrogen peroxide.
- The pH-value gives an indication of the acidity or alkalinity. It is measured using a standard electronic pH-meter placed in a solution of the sample material dispersed in de-ionized water.
- The electrical conductivity of soil is its ability to conduct an electric current and is normally expressed in milliSiemens per metre (mS/m). De-ionized water is added to the sample, which is left to stand for at least 1 hour before it is filtered, with the aid of a vacuum pump, through filter paper. The filtrate's ability to conduct an electric current is measured using a conductivity meter. In soils, the conductivity gives an indication of the level of ionic species in the water and thus an indication of the origins of the water within the archaeological deposits.[10]
- The texture of the sample includes a particle size analysis and – where possible – a porosity measurement. The latter requires a relatively undisturbed sample and is necessary for interpretation of measured water contents.

If the samples are sealed in such a way that no oxygen is allowed into the sample, a wider range of parameters can be analysed. This demands specialist assistance both on site and in the laboratory. In the laboratory the samples have to be opened in a nitrogen tent, and certain of the measurements need to be carried out in this nitrogen atmosphere. Samples

[10] Matthiesen suggests that measurement of chloride levels provides a sufficient indication of conductivity.

from one investigation where this method was used (Skostredet in Bergen) were analysed for dissolved oxygen, redox, and sulphide content, all of which are indicators of whether an anoxic environment is present or not.

3.2.2 Methods and devices used in environmental monitoring projects

By environmental monitoring is meant a periodic or continuous systematic measurement of the burial environment (with parameters such as water content, groundwater-level, microbiology, chemical composition, subsidence/compression etc) in order to document the effect of external influences. This is done with the use of geotechnical methods of analysis. Relatively new as an archaeological method, much is therefore still at an experimental stage.

Much of the equipment used for this type of monitoring was not developed with the archaeological community in mind but rather in connection with agriculture and/or soil pollution. It has, however, been shown that the equipment works equally well on archaeological deposits. In recent years, research has been carried out into the development of specific types of instruments for the archaeological community. This work has taken place in Denmark, the Netherlands and England.

Groundwater monitoring

Groundwater-levels are extremely important in providing information about the overall groundwater flow regime and the water budget within an area. Generally, water-level data is recorded as X/Y (global coordinates) and Z (elevation) format, providing the key data-set for contouring and mapping water-tables.

Groundwater-level monitoring has numerous purposes. In relation to preservation of subsurface archaeological deposits below the water-table within any given area, the key objectives are:

- Mapping of the local and/or regional groundwater flow pattern, including temporal variations, in order to establish the area’s water budget and identify factors influencing preservation conditions at the site.
- Compare historical data to establish trends in water-table elevations resulting from human interference or climatic changes.
- Provide a source of “real” data for model calibration.
- Calculate groundwater flow vectors and velocities for risk assessment.
- Identify groundwater boundary conditions for modelling purposes.

Another parameter that may be of importance for archaeological preservation purposes is the temperature of the groundwater, as it plays an important role in the aqueous geochemical make-up of groundwater. As groundwater flows through porous media, it attracts unique elements directly from the aquifer, and thereby becomes endowed with distinctive characteristics. However, as groundwater temperature fluctuates, so does the ionic balance of the elements suspended in the fluid media. Furthermore, increased temperature may indicate pollution by sewage water, and a fluctuating temperature may indicate a dynamic environment with a fast through-flow of (rain) water.

For long-term, continuous monitoring, automatic measurement and recording of both groundwater-level and temperature is necessary. Groundwater dataloggers are nowadays designed to achieve accurate and reliable, longer-term monitoring, maximizing the monitoring network.

The TD-diver (http://www.vanessen.com./release/en/index.php) by Van Essen Instruments (Schlumberger) is the most frequently utilized logger in the world. A new series of dataloggers (http://www.vanessen.com./release/en/pdf/brochure_divers.pdf) has recently been introduced. As an alternative technically equal to the TD-diver, Keller AG (http://www.keller-druck.com/english/homee/hmprode.html) produces a series of autonomous dataloggers (DCX22) that measure both temperature and pressure, including atmospheric correction. Both products can be extended with telemetry, using GSM.

Equipment for acquisition of water samples

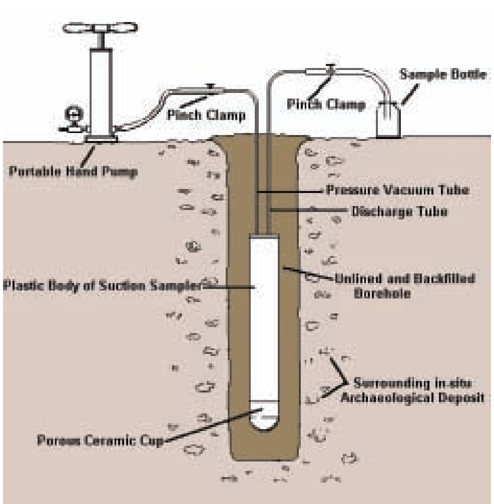
Dipwell

This is a plastic tube that is installed vertically in the deposits. It is equipped with a filter at the depth from which samples of the groundwater are to be drawn off. Multi-level dipwells do exist, but otherwise multiple boreholes with one dipwell/piezometer each may be used to obtain knowledge about depth-specific variations in water chemistry. Dipwells are normally installed with a drilling rig, and the drilling also provides soil samples that can be subjected to different types of analysis.

Left: installation of a dipwell, using a manual drilling rig;
right: taking a water sample from a dipwell (photos: NIKU).

Suction samplers

These are a permanently installed system that consists of a porous sampler placed in an unlined borehole and connected to the surface by two plastic tubes. These are used in deposits that are above the groundwater-level, and where the porewater must be drawn into the tube. The usual way of doing this is with the aid of pressure/vacuum, both to get the water into the tube and to draw off samples for analysis.

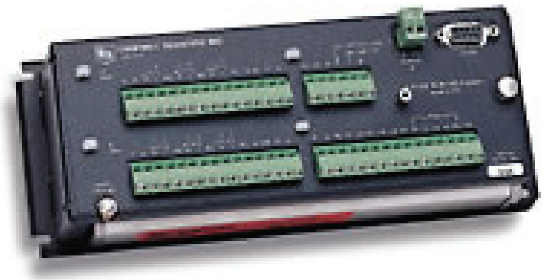


Groundwater loggers
At Bryggen, groundwater loggers of the following two types have been installed so far: MiniDiver, and BaroDiver (both manufactured by Schlumberger Water Services). These measure pressure and temperature at hourly intervals, and each logger has a capacity of 24,000 separate readings. The software goes by the name of Logger Data Manager. Minidiver is unsuitable for use in anything but freshwater, but there is a third logger type – named CeraDiver – that can be installed in dipwells in areas affected by the sea.

Monitoring of water content in the unsaturated zone
The water content in the unsaturated zone is a relevant monitoring parameter, as a change in the content may indicate changed preservation conditions. Several types of equipment are available that detect such changes. However, when it comes to the absolute value of the water content it will often be necessary to make a soil-specific calibration of the equipment to obtain sufficient accuracy. Furthermore, it is highly relevant to know the porosity of the soil in order to interpret the water content readings. The porosity is equal to the pore volume in the soil, and varies between approximately 30 vol% in sand and up to 95 vol% in peat. This means that a measured water content of 30% in sand indicates water-logged conditions, whereas the same value in peat implies drained, almost dry conditions.

Neutron probe
This is a portable unit containing a radioactive source that reacts when emitted electrons strike hydrogen atoms in water. An aluminium access tube is permanently installed in the archaeological deposits, while the probe is only connected to this when measurements are to be taken. Measurements are taken at different depths down the tube, and are converted with the aid of a calibration curve to data concerning the volumetric water content.


Soil moisture cells
These are installed at different depths in the archaeological deposits and measure the dielectric properties of the soil; the varying output of each sensor is used as an indicator of moisture change and after calibration is converted to moisture content values. Some models, such as those used in York, also give the possibility of measuring the temperature; otherwise, separate sensors are required for this. These can be either connected to a permanent datalogger that continually records the data, or to a portable unit that can be connected when necessary.

http://www.delta-t.co.uk/products.html?product2005092818876

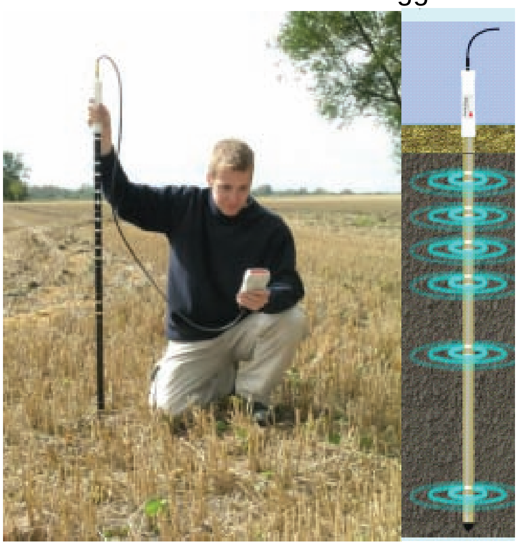
W.E.T. sensor

This is a multi-sensor that measures water content, electrical conductivity and temperature. At the moment it can only be used for one-off measurements in conjunction with a handheld moisture meter – which, when used during excavations, has provided good results. However, it has so far not been tested for continuous monitoring in conjunction with a data-logger.

http://www.delta-t.co.uk/products.html?product2005092818929

Profile Probe

This instrument measures the water content in the deposits. Fibreglass access tubes are permanently installed in the archaeological deposits, the probe itself being inserted only when measurements are to be taken. The probe can have a maximum length of 1 metre with up to 6 sensor rings placed at 10 cm, 20 cm, 30 cm, 40 cm, 60 cm and 1 m. The data from the sensor rings is simultaneously read by a handheld moisture meter, but the probe can also be connected to a data-logger.



http://www.delta-t.co.uk/products.html?product2005092818887

Measurement/monitoring of soil pore-gas in the unsaturated zone
The composition of soil pore-gas can provide a good indication of prevailing redox and microbial activity in the unsaturated zone. The sampling can be easily performed by hammering or vibrating steel pipes to a depth of 1-2 metres, or more if the soil type permits. Before insertion, the pipe is fitted with a loose cone to help penetrate the soil and to avoid clogging. When the desired depth is reached, the pipe is withdrawn approximately 0.1 metres to leave a space in the ground above the cone, which is sacrificed.

To sample the gas in the soil a Teflon tube is mounted down the steel pipe through a rubber stopper at the top. The tube is connected to an in-line chamber and to a vacuum pump, or directly to the vacuum pump, where a Tedlar bag is mounted on exit. The pump must have a manometer to register the counter-pressure. If counter-pressure exceeds 1 bar there may be a risk of leakage in the system and pumping strength should be adjusted accordingly. Prior to sampling, the system should be flushed by pumping out at least five times the volume of the pipe.

The soil pore-gas content of H_2O, CO_2, O_2, CH_4 and H_2S is recorded on an instrument based on IR absorbance or an electrochemical device with direct reading.

Barometric pressure, wind speed and direction, amount of precipitation, and temperature of the soil and air at ground-level are to be measured and noted in the sampling report.

Equipment for monitoring of other parameters in unsaturated or saturated zones
Oxygen probe
Oxygen has normally been measured in water samples, but an oxygen probe for continuous measuring in water has been tested in Holland and by the National Museum of Denmark, Copenhagen. The actual logger tested (OTD diver from Van Essen) has unfortunately gone out of production, but other products are available, for instance from Aanderaa. Only sensors that do not consume oxygen during the measurement can be used. Sensors for taking measurements directly in soil are currently being tested at Bryggen.

Optical oxygen sensor (oxygen optode) from Aanderaa AS, Bergen, Norway.
http://www.aanderaa.com/docs/Oxygen_Optodes_3835_4130_4175.pdf

Conductivity probe
For sites close to the sea, where flooding or sub-surface ingress of seawater may occur, monitoring the conductivity in the dipwells can be relevant, to study the temporal variation in

the salt content. Several products exist, and it is advantageous to combine probes and water loggers from the same manufacturer.

CTD diver from Van Essen
http://www.vanessen.com/en/products/ctd-diver/default.php

Redox probe
The redox potential has generally been measured in water samples, but the need to be able to measure redox in solids has been identified. This has lead to the development in the Netherlands, by the Dutch Ministry of Economic Affairs and the State Service for Archaeological Investigations (ROB: www.archis.nl), of a redox (and acidity) monitoring instrument for archaeological use. The redox electrode is 8 mm thick with a variable length of up to three metres. The electrode is installed using a special foot-operated apparatus to push it down to the depth desired. The electrodes can be connected to a hand-held high-resistance volt meter, but are preferably used in combination with a data-logger. Other probes are available as well, all working on the same principle. The correct measurement and interpretation of redox values is notoriously difficult and still a matter of debate (even if the principle is very simple), and its value in urban deposits should be thoroughly tested before making it a standard parameter in monitoring projects. If used, it is important to report all results on the same scale (mV versus the Standard Hydrogen Electrode).

Thermistor
This instrument is used to measure temperature and is usually connected to a data logger. It is general purpose and suitable for burial in connection with measurement of soil temperature. Logging of soil temperature normally gives good value for money, as this parameter can for instance provide an indication of water flow in the soil, leakage from drains/waterpipes, or temperature increase due to building activity.

General requirements
The use of soil moisture and temperature sensors is conditional on installation in an excavated section through the archaeological deposits, while the neutron probe, dipwells and suction samplers can be installed from the surface without need of any excavation. Even if some of this equipment seems very simple, there are numerous possible pitfalls, and the installation, calibration and use of such equipment should involve specialist instruction at least.

Experiences to date in Norway
In Trondheim a neutron probe has been used together with suction samplers, while in Tønsberg individual soil moisture sensors and temperature sensor were installed together with dipwells.

The methods used in Tønsberg – soil moisture and temperature sensors, and dipwells – have proved to function relatively well. There have, however, been some problems with the instrument used to measure various parameters of the groundwater chemistry, and analysis of water samples at a commercial laboratory may thus be preferable. In Trondheim the neutron probe appears to have worked satisfactorily, but there have been problems with the suction samplers – it has proven difficult, in some cases almost impossible, to draw porewater from the archaeological deposits.

Instrument/Device	Performance/suitability (relative to monitoring in urban deposits)	Optimal sphere of use/ Requirements
Groundwater loggers	Relatively untested	Areas with groundwater Dipwell
Neutron probe	Satisfactory	Areas with porewater Aluminium access tube
Soil moisture cells	Satisfactory	Section excavated beforehand
W.E.T. sensor	Handy	Excavated surface/section
Profile probe	Untested	Fibreglass access tube
Oxygen probe	Relatively untested Teething troubles	Dipwell/ Other sensors directly in soil
Conductivity probe	Untested	Coastal sites Dipwell
Redox probe	Relatively untested	
Thermistor	?	Section excavated beforehand
Dipwell	Good Mostly positive experiences to date	Areas with groundwater Drilling
Suction samplers	Relatively untested Water samples difficult to obtain sometimes	Areas with porewater Drilling

3.2.3 Monitoring of settlement: fixed measuring points

Settlement of the ground surface and/or buildings within an area containing archaeological deposits may be an important indicator of problems in the ground, as demonstrated at Bryggen (Jensen 2003b). It is measured by non-invasive methods and can give a good overview of the extent of the problems. One particularly appropriate method of monitoring the extent and rate of settling is to establish a grid of fixed points on the ground surface and/or buildings within the area being monitored. The elevation of the points is then measured by total-station or precision levelling instruments – both of which ensure millimetre accuracy – at regular intervals over a period lasting at least 1-2 years. The measured points must be protected against damage or other movements. Levelling points fixed on the ground give the most reliable measurements of settlement. Points on buildings, when measured by total-station, can also be used to monitor horizontal displacements. If there exist sets of elevation data series for fixed points (such as Ordnance Survey points) in the study area, it may be possible to estimate previous settlement (Ribe Amt & Ribe Kommune, 2005; Matthiesen, 2006c). It may also be possible to use measurements from satellites, as there exists data to analyse the settling in all European towns retrospectively from 1992 until today (www.terrafirma.eu.com).

However, these measurements cannot stand alone, as settlement may have other causes than the decomposition of archaeological deposits. Neither will decomposition of deposits necessarily cause a measurable amount of settlement in all cases, so zero settlement does not constitute proof of good preservation conditions. Supplementary measurements in the ground are thus necessary.

3.3 Geochemical methods

3.3.1 Geochemical sampling and analysis

The decomposition of (organic) archaeological deposits is brought about by chemical and microbiological processes, where the microbes and their activity are dependent on a number of chemical compounds, especially nutrients and different oxidants. Process identification and quantification therefore require detailed geochemical fingerprinting of the individual strata. At the same time, the extensive research into decay processes conducted in related fields, notably soil pollution and waste disposal, has produced a great body of data, methods and theories that can be applied to the archaeological situations. In this connection, geochemical analysis constitutes an indispensable *lingua franca* when it comes to describing cultural deposits and placing them within the framework of existing models of decay processes.

Soil sampling
The following can be proposed as an ideal procedure.

Samples for chemical analysis are to be taken from each identified stratum, at least the organic ones, with an "identical" set for freezer storage. If a stratum is more than 0.5 metres thick, then samples should be taken at half-metre intervals (this will normally apply mostly to drilling). Sample size should be 100-250 grams, and the soil should be collected in an airtight bag (e.g., Rilsan *miljøpose*) or a glass container with an airtight screw-cap. It may often be convenient to take a small sample (100g) for basic analysis S1 (see below), where a zippered plastic bag will suffice. For taking samples for porosity measurements, there are special soil sampling rings with a volume of exactly 100 cm^3, which are carefully pressed into the undisturbed soil.

Samples should be marked with indelible marker noting locality and project name, date, drilling number, consecutive sample number, and depth in metres or height above sea-level. There may, however, be variations in marking requirements from one laboratory to another. Samples must be kept cool, dark and dry until examination, and should preferably be sent to the laboratory as soon as possible after collection.

Chemical analyses of soil samples
Chemical analysis of soil samples has a two-fold objective. One purpose is to distinguish different soil layers, thereby supporting, verifying or correcting layer descriptions made in the field by the archaeologist, geologist or pedologist. The main purpose is of course to characterise and quantify the physical and chemical environment in the soil.

Four analysis programmes or packages – designated S (for soil) 1, S2, S3 and S4, with S1 as the most basic – have been defined.

S1
For all soil samples – regardless of what kind of investigation they come from – the following parameters must be determined:
- Water content (dry weight)
- Loss-on-ignition
- Chloride, water soluble
- pH

These are the basic parameters needed in connection with modelling of the area and/or site's hydrogeology, and give an indication of settling potential and water flow. Ideally, pH should be measured in the field with a solid-state pH electrode inserted directly in the soil, thereby obviating the need for measurement in the laboratory. Some of the parameters and methods have already been described in connection with geotechnical procedures (section 3.2).

S2
Selected samples are analysed for total amounts of the following elements:
- Phosphorus

- Nitrogen
- Sulphur
- Iron
- Manganese

This package provides a first indication of the content of nutrients and redox-active species – and at a reasonable cost.

S3

For more detailed study of redox conditions, the S2 analysis package can be expanded with the following speciations. These analyses require that the sample is kept cool or frozen and sent to the laboratory at once.

- Ammonium
- Sulphide and sulphate
- Ferro- and ferri-iron
- Total organic carbon (TOC)

This package provides a comprehensive picture of the total availability of redox-active species – and thereby the potential deterioration – in each of the investigated deposits. The ratio between TOC and the loss-on-ignition may indicate the actual oxidation level of the organic material. It is important to select samples from the saturated as well as the unsaturated zone, and ideally from different locations that form a line more or less parallel with the direction of groundwater flow.

S4

In areas or on sites not previously checked for pollution, it is suggested that the level of pollution in selected samples be determined using the following parameters:

- ICP screening of metals (Lead, Cadmium, Nickel, Copper, Chrome and Zinc)
- Total hydrocarbons
- Polyaromatic hydrocarbons (tar components)
- Mercury
- Arsenic

The relative distribution of the metals also represents an efficient way of fingerprinting different layers, and can even help to support the archaeological dating of the layers.

Groundwater sampling

If at all feasible, groundwater sampling should be undertaken by specialists, and preferably by personnel from the laboratory responsible for analysing the samples or the drilling firm that installed the dipwell. Sampling should start with measurement of the water-level and purging of the dipwell. High-yield dipwells are pumped until stable conductivity, pH, temperature, and/or oxygen (measured in-line in a flow chamber) is reached. Low-yield wells may run dry during pumping – here flushing the headspace with an inert gas during purging and sampling may be necessary to avoid contamination with atmospheric oxygen. Samples for dissolved iron and manganese must be filtered in the field (0.45 µm in-line filter) and sealed immediately.

The sampling equipment must be clean and only sample containers and preservatives obtained from or approved by the laboratory should be used. The number of samples taken will depend on the analysis programme, but all samples are to be kept dark and cool until delivery to the laboratory no later than the following day.

After the sampling the water-level should be checked again, and all relevant data and observations noted in the sampling report.

Chemical analyses of water samples
All water samples must be analysed according to the expanded analysis programme for drinking-water chemistry – designated W1 – supplemented by selected redox-active species. This package is offered as standard at Danish laboratories (due to legislative requirements for drinking water), and comes at a – relatively – low cost.

W1

- pH
- Conductivity
- Calcium
- Magnesium
- Potassium
- Sodium
- Iron
- Manganese
- Ammonia
- Nitrite
- Nitrate
- Total-P
- Chloride
- Fluoride
- Sulphate
- Aggressive carbon dioxide
- Hydrogen carbonate
- Turbidity
- Colour intensity
- Dry matter
- Oxygen
- NVOC (Non-volatile Organic Carbon)
- Sulphide
- Methane

The drinking-water chemistry package forms the basis for evaluating the overall chemical characteristics of the groundwater, to identify the chemical environment of the site and the possible reactions that influence the preservation of the cultural deposits. The water chemistry can be used to map different groundwater bodies, the influence of marine water, gradients from upstream to downstream, input from leaking sewers and other external sources of nutrients, the release of nutrients from decomposition of organic matter, and so on.

To detect microbial activity, plate counts at 10°C and 37°C can be carried out on selected samples taken upstream, centre and downstream along the groundwater’s direction of flow.

If pollution is of concern, total hydrocarbons, PAHs, Phenols and NSO-compounds should be determined. Testing for lead, arsenic, nickel and even cadmium may be relevant as well.

3.3.2 Artefact/ecofact analysis

Archaeological deposits with high levels of organic preservation are amongst the most informative contexts for increasing our understanding of past societies. In addition, the finds contained in the deposits can provide the most evocative evidence available to us when seeking to present this understanding to the wider community. The finds include not just artefacts made of leather, wood, textiles etc,[11] but also plant remains representing food and raw materials, insects indicating living conditions, and parasite eggs evincing hygiene levels and livestock regimes.

The artefacts and ecofacts found in archaeological excavations are preserved because they have reached equilibrium with their immediate surrounds. Without access to oxygen, insects and other biological agents that normally devour organic matter cannot live in these wet archaeological deposits. Such archaeological deposits ensure good preservation for organic remains. It is clear that this equilibrium is very vulnerable, and even the slightest change in the surrounding environment can have catastrophic – and irreversible – effects.

In recent years has emerged a growing awareness among archaeologists and others working with environmental monitoring that certain of the most prevalent archaeological materials can be used to shed light on conditions and changes over time in the burial environment. A number of studies have now taken place where artefacts and ecofacts of different materials have been used as environmental indicators.

Metal
In Sweden the project *Fynd och Miljø* (Borg *et al*., 1995; Nord & Lagerlöf, 2002) aimed to determine the main factors, anthropogenic and others, affecting the deterioration of un-excavated archaeological bronze and iron artefacts. Here studies were carried out both on objects in museum collections and on recently excavated bronze and iron objects. Most of the objects studied were from rural sites and the study concludes that *(it) is evident that the archaeological deposits on urban sites present quite a different and much more complex environment. Soil composition, stratigraphic layers and hydrological conditions may change within a short distance. Further, the conditions have been disturbed by frequent installation and building works*.

Bone
The EU project *The degradation of bone as an indicator in the determination of the European archaeological property; ENV4-CT98-0712* has studied the degradation of archaeological bone material in soil (Kars & Kars, 2002). The three-year-long project examined material from the Netherlands, Sweden, Great Britain and Italy. The various analyses show that the problems with bone are more complex than those with, for example, the metals. Acidic soils and excessive water-flow appear to be amongst the more important factors.

In Norway a project has been carried out to see whether intervention has changed preservation conditions within the churchyard of the ruined St. Mary's Church in Oslo (Sellevold *et al*., 2006). Various types of analyses were carried out and the general conclusion is that interventions carried out in the churchyard down through the years do not appear to have impacted on the intact archaeological deposits or the skeletal material within them. However, the comparative value of the information gleaned here is uncertain because local conditions in other churchyards can cause differential progression in the degradation processes.

Wood
Wood is probably the most studied of all archaeological materials, with respect to microbial degradation processes, and numerous papers have been published on the degradation of archaeological wood in diverse environments. Microbial attack is clearly the most important form of degradation of wood. Chemical degradation occurs when wood is exposed to UV radiation or high concentrations of various salts. The attack leads to a deterioration of the

[11] In Norway, storage and preservation of archaeological artefacts is the responsibility of the five regional historical museums.

surface layers of wood, but is not important for waterlogged archaeological wood. Most studies so far suggest that waterlogging by itself has no significant effect on wood structure.

The degradation observed is caused by a variety of wood-degrading micro-organisms. The EU project *BACPOLES* (Preserving cultural heritage by preventing bacterial decay of wood in foundation piles and archaeological sites, EVK4-CT-2001-00043) has studied the degradation of foundation piles and archaeological wood exposed at terrestrial sites and in marine environments in Sweden, Germany, United Kingdom, the Netherlands and Italy (Klaassen *et al*., 2005). The main degraders in all types of wood were erosion bacteria. Some degradation was caused by soft rot fungi, whereas other forms of fungal decay were absent. No real correlation between extent of degradation and physico-chemical factors was found. Some indication was found that rate of degradation was influenced by water movements. Stagnant conditions appeared to result in less decay.

Other materials
In York Kenward and Hall have looked at the macrofossil remains of plants and invertebrates as indicators of decay, with their research centred on how the rate and timing of decay might be determined (Kenward & Hall, 2002).

On a number of sites, modern test materials – metal, wood and textile – have been inserted into the archaeological deposits in order to examine corrosion and decay rates (see section 3.4.2 for further detail). In some cases, as at Nydam in Denmark (Matthiesen *et al*., 2002), these results are being compared to corrosion on artefacts retrieved from excavations undertaken at different times, with a view to determining whether changes in environmental conditions have an adverse effect on the objects.

3.3.3 Soil micromorphology

Soil micromorphology is a microscopic study of undisturbed soils in accordance with an internationally standardized system of thin-section description. It can be used in archaeology to characterize undisturbed soils, reveal sedimentary processes, and identify anthropogenic and biogenic effects and disturbances (Courty *et al*., 1989).

Samples are taken from archaeological contexts, from sections or from drilling cores (see e.g. http://www.thin.stir.ac.uk/sampling.html). They may then be used to study changes and disturbances in the archaeological layers at a microscopic level, adding to and complementing information from the archaeological record of the same layers. The method has been tested in, among other places, the Netherlands, at the World Heritage Site at Schokland (van Heeringen *et al*., 2004).

In Norway, the method has so far been tested at Kaupang (French & Milek, 2006) and in Stavanger. The results from the medieval town of Stavanger are as yet unpublished.

3.4 Microbiological methods

3.4.1 Microbiology

- Decomposition processes in archaeological wood: the role of fungus and bacteria
Wood is composed of three main chemical components; cellulose, hemicellulose and lignin. Their proportions vary between wood species. Variation occurs also within one species as a result of heartwood formation in the innermost parts of the tree or formation of tension wood (hardwoods) or compression wood (softwood). Additional variation occurs between juvenile wood, formed during the first 10-20 years growth, and the wood formed after that. The variations are seen in the chemical and morphological structure, as well as in mechanical

properties and durability. Studies on wood should therefore, if possible, be done on well-defined samples only.

Wood is resistant to chemical degradation under normal conditions of waterlogging. The degradation observed is therefore a result of attack on the wood structure by a variety of different micro-organisms. Extensive research has provided quite detailed information on the organisms, types of degradation and the influence of environmental factors on microflora and rate of degradation.

Wood-degrading micro-organisms

Fungi

White rot

This is a fungal decay type characterized by degradation of cellulose, hemicellulose and lignin. The fact that these fungi are capable of degrading the three main wood components, may result in a complete loss of wood in the final stages of decay. White rotted wood often has a bleached appearance and a fibrous structure. White rot is an aggressive decay form in terrestrial environments. It is absent from fully submerged wood, but may occur in very wet wood. One species, *Physisporinus vitreus*, is commonly found at very wet sites. It has been found at Bryggen and in foundation piles in Copenhagen. White rot fungi can attack archaeological wood that has been extensively degraded by other micro-organisms during waterlogging (Björdal & Nilsson, 2002). The attack may start at excavation or through draining of land and could result in a complete loss of the wood material after relatively short time. Any excavated wood material should therefore be protected against attack. Submersion in water provides a simple protection method. White rot is caused by basidiomycete fungi.

Brown rot

This is a fungal decay type characterized by degradation of cellulose and hemicellulose. The lignin is oxidized, but not degraded. Heavily degraded wood has a brownish colour and a very fragile structure that easily collapses. Dried wood cracks into small cubes, that easily can be crushed to a powder between fingers. Severe strength losses occur already in quite early stages of decay. Brown rot is the most aggressive decay form in terrestrial environments. Buildings may be extensively degraded within a short time. It does not occur in submerged wood and is rare in very wet wood. This decay form does not appear to attack wood that already has been severely attacked by other decay organisms. Brown rot is caused by basidiomycete fungi.

Soft rot

This is a fungal decay form characterized by degradation of cellulose and hemicellulose. Some species cause partial degradation of lignin, but most of the lignin remains as a brownish black substance. The dark surface colour has occasionally been mistaken to be evidence of fire. Soft rot fungi typically attack from the surface and proceeds inwards. The surface of severely degraded wood forms square-shaped cracks when it dries out. Even severely soft-rotted wood maintains its structure when wet, but shrinks extensively when it dries out. Soft rot occurs in terrestrial and aquatic environments. The soft rot fungi require oxygen for their activity, explaining why soft rot is often restricted to the surface layers in waterlogged wood. Soft rot is caused by ascomycetes and fungi imperfecti (microfungi).

Bacteria

Tunnelling bacteria attack

This is a bacterial decay form characterized by degradation of cellulose and hemicellulose. The bacteria are single celled. The bacteria can also degrade lignin but to what extent is not known. Heavily degraded wood has a yellowish colour and a soft granular structure. The bacteria cause degradation by tunnelling within the cell-walls. The identity of the bacteria is not known. Tunnelling bacteria occur in aquatic environments, but generally cause more extensive damage in terrestrial environments. Degradation rates are low compared with fungal decay types. Like soft rot fungi they require adequate levels of oxygen and are therefore restricted to the outermost surface in waterlogged wood.

Erosion bacteria attack
This is a bacterial decay form characterized by degradation of cellulose and hemicellulose. Most of the lignin remains. The bacteria are single celled. Heavily degraded wood has a light colour, but the common occurrence of soft rot in waterlogged wood explains why most wooden artefacts have a darker colour. Severely degraded wood maintains its structure when wet and has occasionally been described as “perfectly preserved” by archaeologists. Here, there is a large discrepancy between the archaeological and the geochemical state-of-preservation assessment. When such wood dries out, its real condition can be seen from its extensive shrinking and distortion. Erosion bacteria are active at extremely low oxygen levels – they may possibly be active even in the absence of oxygen. Decay rates are low compared with fungal decay types. Erosion bacteria attack is the dominating decay form in waterlogged wood. Research on the identity of erosion bacteria suggests that they belong to the CFB (*Cytophaga-Flavobacterium-Bacterioides*) complex.

Waterlogging prevents or reduces the activity of typical terrestrial decay forms and it also preserves evidence of pre-burial decay. Archaeological wood can therefore be seen as a historical archive where records of early events can be found. One example is findings of white or brown rot attack in waterlogged wood, which indicate exposure above water before burial or that the water levels have varied over time. We have studied the remains of buildings at a lake settlement and found typical evidence of white and brown rot decay, suggesting that the constructions, which eventually collapsed into the lake, suffered from attack by such fungi. A further possibility is that the trees used for timber were already under attack by decay fungi. One example is the foremast of the warship *Vasa*. We found that the tree felled to become the mast was severely degraded by heart rot caused by a white rot fungus.

Analyses using light microscopy
All of the decay types described above can be identified by using light microscopy. Microscopy can also be done on fresh (sound) wood samples that have been introduced in an environment in order to measure decay rates (see section 3.4.2). It may be difficult to identify all decay types present in severely degraded samples, but dominating types can be identified in most cases. If the wooden artefacts are large a macroscopic assessment of the wood structure will facilitate the identification of decay. Samples with varying appearance should be selected for analyses. It is important that the samples are kept wet and cool all the time. Plastic bags are usually adequate for the storage. Extra water should be added to more or less cover the wood after which the bags are closed. A suitable storage temperature is ca. 4º C. Freezing of decayed wood causes distortion and should be avoided.

Basic knowledge of wood anatomy is required for microscopy; such knowledge is easily found in common textbooks on wood structure. An ordinary light microscope is required. It is a great advantage if the microscope is equipped with filters for polarized light. For documentation purposes a digital camera attached to the microscope should be used.

Thin sections have to be prepared for microscopy. This may be done with a microtome, but hand-cutting with a razor blade is simpler and faster and provides satisfactory results after some training. Ordinary double-edged razor blades have been found to better than single edged industrial razor blades. Identification of decay types requires two types of sections from each wood sample, transverse and longitudinal. More information is usually obtained from radial longitudinal sections compared with tangential longitudinal section. The sections should be stained to highlight the wood structure and the micro-organisms. For the wood structure we have used a solution of 0.1% safranine in a mixture of water and glycerol (1:1).

For the micro-organisms we have used a solution of 0.1% aniline blue in 50% lactic acid. Safranine is conveniently used for the transverse sections and aniline blue for the longitudinal sections, but the two stains can be used for any section. Below follows a short description of each decay type, and more information can be found in Björdal *et al*. 1999, Blanchette *et al*. (1990), Eaton & Hale (1993), and Kim & Singh (2000).

Microscopic characterization of decay types

White rot

There are two types of white rot decay. The first type is characterized by simultaneous degradation of cellulose, hemicellulose and lignin. The attack is seen as erosion of the wood fibre walls leading to thinner walls. The middle lamella is degraded in the final stages resulting in a complete loss of the wood structure. The second form of decay is characterized by a preferential degradation of hemicellulose and lignin. The degradation starts at the inner wood-fibre wall and proceeds towards the middle lamella. Defibration (separation of the wood fibres from each other) occurs when the middle lamella breaks down. Indications of white rot attack are often seen as an increased uptake of safranine in affected wood. Large boreholes are often observed. White rot is the only decay type where extensive degradation of the middle lamella can be observed.

Brown rot

Brown rot extracts the hemicellulose and the cellulose from the wood cell-walls leading to a gradual disappearance of these components from the cell-wall. This explains why early stages of brown rot are difficult to detect when using microscopy. Late stages are characterized primarily by loss of birefringence in polarised light and a somewhat granular structure of transverse sections of the fibre cell-walls. Safranine stains the cell-walls reddish brown. The middle lamella is not degraded, but may be weakened.

Soft rot

There are two types of soft rot decay: Type 1 is characterized by formation of rhomboidal cavities within the wood cell-walls; Type 2 is characterized by erosion of the cell-walls. The latter form shows some resemblance to white rot, but soft rot fungi never degrade the middle lamella. Type 2 attack is only important in hardwoods. Type 1 is the most common form. The cavities are seen as holes in the cell-walls when transverse sections are observed. Polarized light makes the cavities easy to observe in longitudinal sections, as they will appear dark in contrast to the bright, sound cell-wall. Boreholes of soft rot fungi always remain small.

Tunnelling bacteria attack

The attack is initiated by a single bacterium that penetrates into the wood cell-wall. Here it starts to tunnel through the cell-wall. The bacterium divides to form new individuals that tunnel in different directions. Repeated divisions and formation of new tunnels will lead to a honeycomb structure. The bacteria may tunnel through the middle lamella from one fibre into the adjacent fibre. The degradation of the middle lamella is restricted to the tunnel. Early attack by tunnelling bacteria is seen as small holes in transverse sections and as variable rhizoid patterns in longitudinal sections. Late stages lead to a granular structure of the wood cell-walls, which can be observed in transverse as well as longitudinal sections. Polarized light is useful for studies of tunnelling bacteria attack.

Erosion bacteria

These bacteria attach to the wood cell-walls and cause erosion of the walls. A striped appearance of the wood cell-walls or rhomboidal cavities, shorter and broader than soft cavities, can be observed in longitudinal sections. Here it is useful with polarized light. High magnification reveals nibbling (indentations) in the cell-wall from the lumen side. In the late stages, the whole cell-wall will be converted into an amorphous substance. The attack is often not uniform – seemingly sound fibres are frequently seen among severely degraded fibres when transverse sections are viewed. This results in a typical chequered pattern. The middle lamella is not degraded. It has been found to be well preserved even after ca. 10,000 years in a waterlogged environment.

3.4.2 Use of modern test materials

Environmental conditions – and hence, by inference, preservation conditions – can be evaluated through a variety of approaches, one of which involves burying modern test materials and studying how fast they decompose. In combination with other methods, a reliable decay model can be built.

When buried in the ground, wood – be it modern or archaeological – will be decayed by micro-organisms such as fungi and bacteria. Evidence of this decay can be seen using microscopic techniques. From the morphology of the decay pattern, the kinds of micro-organisms causing decay can be ascertained, and – if we know the environmental constraints of the micro-organisms – their presence or absence will serve as a proxy indicator for the environment in which the wood is lying. This information, together with results from ongoing environmental monitoring, can help to elucidate previous deterioration processes and, perhaps more importantly, the potential for further deterioration.

However, when looking at a deteriorated piece of wood for instance, it can sometimes be difficult to evaluate whether this deterioration is due to adverse conditions in the present, or if it results from earlier damage during a period with other environmental conditions. Here the use of modern test materials can be fruitful. Their exact state of preservation is known at the time when they are incorporated in the soil, and any damage will therefore take place within a given interval and under known environmental conditions. They can thus be used to check if there is actually an ongoing deterioration and also to check the current deterioration model.

The first implementation of this method in Bergen took place in November 2002. Nine modern pine-wood samples were attached to a graphite rod, which was then inserted vertically in the soil close to dipwell MB5 at Bryggen. The dipwell is just to the northeast of the truncated Bugården tenement, where the groundwater-level varies between 0.3-0.9 m above sea-level. The samples were at 0-0.6 m above sea-level (1.7-1.1 m below the ground surface).

These were removed after two years in November 2004 and assessed to determine the types of wood-decaying micro-organisms currently active in the cultural layers. To supplement this, three samples of archaeological wood, obtained from an excavation in 2004, were also assessed for comparison. All samples were examined using light microscopy, and their densities were also determined to assess the extent of deterioration (Gregory & Matthiesen, 2006).

The results show that the modern wood samples are moderately decayed by bacteria, whereas no soft rot is found. One or more samples showed attack of white rot. The density of the samples was still high and only the outer 1 mm of the wood had turned soft. The archaeological samples on the other hand had a low density and showed attack by soft rot, whereas no evidence of white rot or bacterial decay was found. The iron samples showed corrosion rates of 0.02–0.03 mm/year, and the corrosion rate correlated to the depth of the samples. Siderite ($FeCO_3$) was identified in the corrosion products.

The site is characterized by very changeable environmental conditions, so several of the modern samples have experienced both oxic and anoxic conditions. This gives a complex decay pattern and makes interpretation difficult, but the results are nevertheless quite informative with regard to decay rates.

3.5 Monitoring projects: overall design

In principle, any monitoring project/programme or study of preservation conditions – especially where drilling is involved – will embody the following main points:

1 *Heritage management status and objectives*: legislation, basic administrative information, responsibilities, organization of programme etc

2 *Investigation area:* Basic information on archaeology, geology, topography, climate and hydrology

3 *Locality:* Location and delimitation, land use and zoning plans, historical developments, previous and ongoing projects, other relevant information (foundation methods, presence of sheet piling, ongoing dewatering etc)

4 *Preliminary investigation(s):* Drilling programme for determination of presence and extent of and rough stratigraphic divisions in cultural deposits, level of the water-table and the natural surface, samples for particle size analysis (texture), determination of direction of sub-surface water-flow, and preliminary chemical characterization of strata and groundwater

5 *In-depth investigation(s):* Drilling programme for detailed determination of the cultural deposits' extent and stratigraphic divisions, description of individual strata, determination of redox conditions and chemical gradients in the strata, redox potential and flow-rate in the groundwater, the groundwater's chemical composition, and infiltration in the unsaturated zone

NB.: in practice, parts 4 and 5 will frequently be amalgamated.

6 *Preservation conditions:* Synthesis with presentation and interpretation of data, including description of redox zones and preparation of a model of the area's hydrogeology. This will form the basis for a thorough risk assessment and conclusions regarding preservation conditions, identification of specific threats, and recommendations for possible counter-measures, including accompanying monitoring programme, where relevant

If information on preservation conditions is to be acquired in connection with archaeological excavation, then detailed archaeological documentation provided by means of layer/context recording sheets will also be necessary, along with a full programme of palaeobotanical sampling.

4. Conclusions and principal challenges

The overall aim is to protect the medieval towns and find ways of fulfilling this goal at the same time as allowing the modern towns to develop. In order to achieve this there is a need for baseline reference data as well as monitoring data from different parts of the deposit areas in each city. This is necessary to secure the best possible management and policy formulation regarding spatial planning, and to enable the implementation of preventive actions/mitigation strategies. Decision-making and policy implementation related to the management of these sites depend on good data. It should, however, be kept in mind that the study of the decomposition of organic archaeological deposits, and the monitoring of these deposits, are still emergent fields of expertise, and the complex processes taking place in the deposits need a great deal more study before they can be understood.

The presence of water, either as groundwater or as moisture in the deposits above the water-table, is without a doubt the most critical parameter for the deposits' preservation. Oxygen and temperature are the major factors that can pose a considerable threat to organic deposits. Continuous monitoring of the level of O_2 in deposits above the water-table is not unproblematic, and one of the main research thrusts at Bryggen in 2006 was precisely in regard to the measurement of oxygen in the unsaturated zone.

It is important to realise that it is not necessary to monitor more than a few essential parameters continuously. Larger-scale programmes for monitoring are called for only when there is evidence, primarily provided by analysis of the groundwater, revealing the occurrence of major changes in the ground. However, it is axiomatic that archaeological description of the deposits and their state of preservation be carried out together with standard analyses during drilling or any kind of intervention, since without detailed prior description of the deposits any subsequent monitoring would be stripped of much of its worth.

No matter how strenuously one endeavours to protect areas containing organic deposits, it is an inevitable fact that decomposition can be neither stopped nor reversed. Still, the process may be extremely slow, and there is an obvious need to be able to quantify decomposition rates – and discuss what rates are acceptable.

It is an undisputed fact that virtually every form for intervention – including investigation – entails some risk to the deposits, and it is therefore to be hoped that the years to come will bring progress in the development of innovative, non-invasive methods for both construction and investigation.

Perhaps the most important aspect is to ensure that mitigation strategies with attendant monitoring programmes, including the installation of dipwells, be initiated as far in advance of the intervention/development project as possible in order to provide baseline/comparative data from the before, during and after situations. Monitoring programmes should normally be designed to run indefinitely, with measurements yearly in the beginning and less frequently later on (unless monitoring results reveal accelerated changes for the worse).

As of the end of 2006, monitoring projects of one form or another have been initiated in all of the major Norwegian medieval towns, including Stavanger (cf. Appendix 1). It is not envisaged that initiation of new projects will be coordinated centrally, but rather left to the discretion of the local heritage management authorities. The scale of new projects is flexible: they may cover either larger areas or smaller, selected areas. Starting off with smaller areas is no problem – the main issue is to start collecting information on the underground deposits, in order to acquire knowledge concerning the continued preservation of the medieval towns' substrate.

Initiation of monitoring projects, or expansion of existing ones, may be triggered by the following:

- Large-scale building activity
- Tunnels, drainage systems
- Areas where former activities (tunnels, building activity, change of groundwater, pollution) have resulted in settling
- Discovery of visible depressions/subsidence in, for instance, road surfaces etc
- Detection of high levels of pollution (through analysis of soil and/or water samples, normally)
- Sample analysis shows cultural deposits threatened by decomposition
- Selected urban areas where defined "threats" are apparently absent.

Future work for preservation of the medieval towns

- More detailed mapping
- Use of remote sensing
- Extrapolations/interpolations from existing data
- Identification/definition of threshold values/levels of significant change
- Interpretation of monitoring data in terms of actual decay rates
- Modelling/simulation of rate of spread of decay (both vertically and horizontally)
- Monitoring's contribution to the retention of economic value (historic buildings etc) as well as to overall heritage value
- Strong emphasis on co-operation between different disciplines
- Address the lack of concrete mitigation measures (viz. Appendix 7)
- Standardization of documentation in order to enable comparison between different sites
- International cooperation: among other things, an Archaeological Monitoring Standard has recently been published in Holland (Smit *et al*., 2006).

As stated previously, at the core of each of the Norwegian medieval towns is a zone of interdiction, where the deposits and remains are automatically protected under the Cultural Heritage Act. This statutory protection does not automatically ensure preservation, of course. There is an urgent need to investigate subterranean preservation conditions, and evaluate the types of threats that can affect different areas within each town. Continued extensive mapping of the groundwater situation is essential. Long-term monitoring projects must contribute to the development of Conservation Plans tailored to the individual town.

Riksantikvaren's primary goals in connection with monitoring can be formulated as follows:

- To participate in the international monitoring community, in the initiation of new research and development of new methods.
- To find the best methods for the reporting of assessments of the state of preservation of archaeological remains.
- To be able to set in motion appropriate mitigation strategies, based on a constantly updated body of scientific knowledge.

5. Contact persons/Centres of expertise/Network

GENERAL

Subject	Partner	Contact	Expertise	Status
Project management	*Riksantikvaren*	Ann Christen-sson Anke Loska		Already involved in all ongoing projects
General overview of all projects	*Riksantikvaren*	Ann Christen-sson Sjur Helseth	Comparison and evaluation of all projects, to adjust monitoring strategy	Already involved in all ongoing projects
Concluding reports for each project	*Riksantikvaren* NIKU	All reports must be submitted to relevant libraries, and in digital format for WEB-publication		

SPECIAL

Subject	Partner	Contact	Expertise	Status
Archaeological re-cording, description of state of preserva-tion etc	NIKU	Rory Dunlop Vibeke Martens Anna Petersén	Archaeological description and recording	Involved mainly in Bergen and Stavanger Oslo Trondheim
Mapping	NIKU	Thomas Risan	Database and GIS specialist	Involved in Tøns-berg and Trond-heim
Preservation of flora and fauna	Archaeological Museum in Stavanger	Paula Utigard Sandvik	Experience from Stavanger	Involved in Stavanger
	York University	Allan Hall Harry Kenward	Focused on preser-vation conditions, great experience from York	Not involved in Norwegian pro-jects yet
Preservation of wood and metal	National Museum of Denmark	Henning Matthiesen	Experience from wetlands, and Bryggen and York	
Preservation of wood		Thomas Nilsson (Sweden)	International experience	
Preservation of bone		Henk Kars (Netherlands)	International experience	
Use of modern test materials	National Museum of Denmark	Henning Matthiesen	Experience on wood and metal from wetlands and Bryggen	
	Vitenskapsmuseet	Elisabeth Peacock	Experience on different organic materials from wetlands	
Environmental monitoring	National Museum of Denmark	Henning Matthiesen	Focused on preser-vation of archaeo-logical remains	Involved in Bergen

Subject	Partner	Contact	Expertise	Status
	Bioforsk	Thomas Hartnik	General expertise on soil, including microbiology Good laboratory facilities	Previously involved in Bergen and Tønsberg
	NIKU	Ian Reed	General expertise in archaeological monitoring Good contacts with British experts	Experience from Tønsberg and Trondheim
	Vitenskapsmuseet	Elisabeth Peacock	Recent involvement in reburial testing	Experience from Trondheim
Settlement of buildings and ground surface	Multiconsult AS	Jann Atle Jensen	Monitoring and geotechnical interpretation	Involved at Bryggen
	NGU	John Dehls	Remote sensing and satellite data	Not used in archaeological context yet
Drilling, dipwell installation, water and soil sampling	Multiconsult AS	Jann Atle Jensen	Access to all necessary equipment and experience	Involved at Bryggen and Stavanger
Hydrogeology	Multiconsult AS	Jann Atle Jensen	Monitoring, modelling	Involved at Bryggen
	NGU	Atle Dagestad Hans deBeer	Modelling	Involved at Bryggen from June 2005
Microbiology		Thomas Nilsson (Sweden)	Archaeological wood	Involved at Bryggen
Mycology	Mycoteam AS	Johan Matsson	Timber foundations and fungi	Involved at Bryggen
Micromorphology	(University of Stavanger)	Barbara Sageidet	Preservation conditions	Testing method in urban contexts

External, occasional consultants
Gunnar Borg, geoBorg Consulting, Göteborg, Sweden
Dr. Chris Caple, University of Durham
John Oxley, York City council
Ian Panter, York Archaeological Trust
Steve Roskam, University of York
Sander Smit, Vrije Universiteit, Amsterdam, Nederlands

Miscellaneous
SASSA – Soil analysis support system for archaeologists (http://www.sassa.org.uk/)
The European Parliament's directive proposal on soil protection (http://www.sft.no/nyheter/brev/0612_jorddirektivet.pdf)

Acronyms etc
Bioforsk = The Norwegian Institute for Agricultural and Environmental Research
NGU = The Geological Survey of Norway
Vitenskapsmuseet = The Museum of Natural History and Archaeology (part of the Norwegian University of Science and Technology, Trondheim)

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7. Appendices

7.1 APPENDIX 1 Overview/status Norwegian urban monitoring

Overview/status regarding concluded and ongoing monitoring projects in Norway's major medieval towns

Bergen

The monitoring programme in the World Heritage Site of Bryggen has been underway since 2001. The mapping of the area's underlying deposits includes minor trial excavations and augering, with archaeologists, geotechnicians and a geochemist/preservation specialist working closely together to acquire a maximum of data through field measurements and sampling. The archaeological description work has adhered as far as possible to the standard methods and layer recording form used in Bergen. The geotechnical part primarily comprises measuring and/or mapping variations in groundwater-levels and settling rates. Chemical analysis of the soil samples includes a detailed mapping of water content, organic content and chloride levels, with a more comprehensive analysis of pH, nutrients and sulphur species for selected samples. Much effort is put into evaluating the results in detail, especially so as to correlate the three different types of description. Three minor excavations and eighteen augerings have been carried out since 2001. The trial excavations have been located in areas with subsidence problems, while the positioning of the augerings has been dictated largely by the need to establish a grid of dipwells for measuring groundwater-levels and thereby build up a model of the area's hydrogeology.

The continuous monitoring of the area includes measurements of rate of subsidence (both ground and buildings), groundwater-level, and analysis of water samples from dipwells. The rate of subsidence is measured twice a year, and has until now allowed a division between subsiding areas and non-subsiding areas. However, the discovery of ground subsidence rates of up to 6 mm/year has meant that the monitoring work has temporarily focused on clarifying and solving this problem. Other problems addressed are the effects of fresh oxygen-rich rainwater flowing through some of the deposits, as well as the effects of occasional flooding by seawater.

Groundwater-levels are (up till now in one of the dipwells) measured hourly by automated logger in order to obtain an understanding of how the hydrological system reacts to precipitation, tides and flooding. Groundwater samples are taken by the firm of *Multiconsult AS* and sent to a commercial laboratory for a full analysis of principal ions, nutrients, and redox-sensitive species. The water samples are supplemented by an automated logger measuring the oxygen concentration hourly in one of the dipwells.

Plans for 2006-7 include extending coverage of the area by installing new dipwells and water-table loggers, the working up of a hydrogeological model, interpretation of the monitoring data in terms of actual deterioration rates, monitoring in the unsaturated zone, and developing ways to stop/mitigate the subsidence.

Overall, the study has profited from sound financial resources and the establishment of good working arrangements between the various partners. Some interesting results have already emerged, including the following: baseline data for the soil and water chemistry in areas with excellent preservation conditions, discovery of high settling rates in areas with a low water-table, the finding of high oxygen concentrations deep below the water-table in some of the dipwells, indications of substantial groundwater flow through some layers, a preliminary model for using chloride as an indicator for water flow, a preliminary model for calculating settling potential of the soil, and a preliminary correlation between archaeological description of strata and chemical analysis of soil samples taken from the same strata. These results are presented in a range of reports (Dunlop, 2000; Dunlop, 2003; Dunlop, 2004; Dunlop, 2005; Jensen, 2003a; Jensen, 2003b; Matthiesen, 2002a; Matthiesen, 2002b;

Matthiesen, 2003; Matthiesen, 2004a; Matthiesen, 2004c; deBeer, 2005), as well as in a couple of other publications (Christensson, 2004; Matthiesen *et al*., 2004).

The envisaged long time-span of the project will enable real long-term monitoring to be carried out, a seldom opportunity in a world dominated by research projects lasting only 3-5 years.

Oslo

Two auger drillings were carried out in Oslo's scheduled area in late August 2006. A dipwell was installed on the edge of the Oslogate 6 site (excavated archaeologically in the mid-1980s), but it remains to be seen whether there is any groundwater there; if not, it may still be possible to use the borehole to install other monitoring equipment. Soil samples were taken from both drillings, but have not yet been analysed.

Stavanger

In 2004 a monitoring programme was initiated at *Torget* (the Market) in Stavanger, after the discovery of preserved archaeological remains from the Middle Ages. The mapping of the area includes a relatively large trial excavation as well as a rough grid of augerings. Field measurements during the trial excavation focused on – among other things – the porosity, water content and air content in soil layers above the water-table. Soil samples from the excavation were described according to the standard Bergen layer recording sheet, and subsequently analysed with respect to the same chemical parameters as in the Bryggen project. Furthermore, the Stavanger Museum of Archaeology has been engaged to investigate the fauna and flora in the samples.

According to current plans, the monitoring will focus mainly on preservation conditions in the deposits in the groundwater zone. The programme includes the installation of several well-spaced dipwells for taking water samples and the logging of groundwater-level and oxygen concentrations. Monitoring has only just started, and no results are available yet – but there are measurements and results – along with other information – from the trial excavation at Torget in 2004 (Ringsted & Matthiesen, 2006).

Trondheim

Monitoring was undertaken at Schultzgate 3-7 from 1996-2001 (Peacock, 2002) to register the possible effects of a new building erected over the archaeological deposits. The mapping of the area included core samples from the installation of monitoring equipment – it was not possible to undertake trial excavations. The soil was analysed for moisture content, organic content, pH, conductivity, sulphate and sulphide.

The continuous monitoring included measurement by neutron probe of the moisture content in the soil, and soil water was sampled from different strata using suction samplers installed from the ground surface. The water samples were analysed by the Conservation laboratory at the Museum of Natural History and Archaeology, Trondheim. The study showed that the buildings have caused no significant change in the moisture content of the deposits, whereas the water chemistry data is difficult to interpret.

One important experience derived from this study is that it can be difficult to install monitoring equipment directly from the ground surface, due to the heterogeneous nature of the deposits – only a small percentage of the suction samplers would appear to be actually located in deposits with high organic content. The report points out that due to the complex and varied nature of the archaeological deposits "there now needs to be a more rigorous recording of the physical fabric when investigating cultural layers in the city" (Peacock, 2002: 55).

In December 2004 a trench excavated in Schultzgate in 1985 was re-opened by machine; this trench was situated directly across the road from Schultzgate 3-7. A section in the south-eastern corner of the original trench was re-drawn, and five soil moisture probes (Theta ML2x) and five temperature sensors (Campbell 107) were installed. Soil samples were taken during the installation of the monitoring equipment, and these will be analysed for water content, organic content, pH and conductivity. The data from the data-logger (Campbell CR10X) has been downloaded twice and shows that the equipment is functioning well.

Tønsberg
In order to register the possible effects of a new building at Nedre Langgate 40 in Tønsberg, a monitoring program was initiated in 1999 and concluded in 2004 (Reed, 2001, 2004; Reed & Edvardsen, 2005). The sample dataset and probe layout was devised in collaboration with a soil scientist from the Norwegian Institute for Agricultural and Environmental research (formerly *Jordforsk*, now *Bioforsk*). The mapping of the area included an excavation together with coring in connection with the insertion of piles. Soil samples taken during the installation of the monitoring equipment and from the core samples were analysed for water content, organic content, pH and conductivity.

The continuous monitoring in the area included measurements of subsidence, groundwater- level, analysis of water samples (pH and redox), and measurement of soil temperature and water content in deposits both above and below the water-table by means of permanently installed probes. The validity of the results was undermined by faulty readings, leading to the need for calibration and finally replacement of the redox probe.

The results of the elevation measurements have not uncovered any subsidence in the medieval deposits at the site. The water-level seems to fluctuate due to seasonal variations in air pressure, tide, and precipitation. Hitherto there has been no apparent change in the water-table caused by the new building at the site. The water chemistry dataset has “holes” due to the faulty probe, as mentioned above, as well as weather-afflicted data reading problems. The manual reading of the redox values has been difficult due to a rather large variation in values whilst performing the readings.

The building on the site had been in operative use for three years by the end of the monitoring project. An increase in soil temperature could be observed, as well as a reduction in the water content of the deposits – possibly caused by the increase in soil temperature. The chemistry of the groundwater – including that in the dipwell inside the building – indicates that the site still provides a relatively benign environment for the preservation of deposits containing organic matter (Reed & Edvardsen, 2005).

The project has demonstrated that it is advantageous to install monitoring equipment directly in an open soil section, rather than “blindfold” from the soil surface. Furthermore, it has shown that the probes for measuring water content and temperature are still in working order after five years (Reed & Edvardsen, 2005).

A five-year developer-funded monitoring project at Storgaten 45 is currently being planned, focusing on the effects of piling at the site. The initiation date of this project is at present uncertain, due to delay of the part of the developers, but the project might start up in 2006.

The table below attempts to present a schematic overview of positive and negative aspects and experiences concerning the monitoring projects undertaken in the various towns so far:

Town/Site	**Positive aspects**	**Negative aspects**
Tønsberg, Nedre Langgate 40	Long-term perspective (5 years) Insertion of probes directly in an open soil profile Durability of probes	Faulty redox probe Weather problems during rea-ding of probes
Trondheim, Schultzgate 3-7	Long-term perspective Testing out of different probes	Installation of monitoring equipment directly from the ground surface not optimal

Trondheim, Schultzgate	Long-term perspective (5 years) Insertion of probes directly in an open soil profile	No problems so far Monitoring limited to temperature and moisture content
Bergen, Bryggen	Good funding Combination of monitoring and research projects Long-term perspective (foreseeable future)	Expensive
Oslo, Oslogate 6	Too soon to evaluate	Too soon to evaluate
Stavanger, Torget	Too soon to evaluate	Too soon to evaluate

7.2 APPENDIX 2 State of the Environment Norway 2000

In 2000, in connection with a major environmental survey entitled *State of the Environment Norway 2000*, the *Riksantikvaren* office in each of the four main medieval towns was asked to produce estimates regarding the volume of removed cultural deposits – basically in order to determine a maximum figure of how much that may remain intact, and to get a rough idea of the average annual loss rate. Trondheim and Tønsberg produced the most detailed breakdowns, and will be used here as "benchmarks".

TRONDHEIM

- In 2000 it was estimated that approximately 26% of the archaeological deposits in the scheduled area were either partly or totally removed. However the map of areas where the archaeological deposits are either partly or totally removed shows that this estimate is too low, the actual proportion is in excess of 50%.
- The greatest part of the removal of archaeological deposits took place prior to the establishment of an excavation office in 1971. Since then most of the interventions in the scheduled area have taken place following some form of archaeological work.
- Redevelopment in the area bounded by Kjøpmannsgata, Dronningens gate, Nordre gate and Kongens gate has between 1971 and 1994 resulted in the archaeological excavation of total area of ca. 7,600 m², constituting a very large volume of deposits. Most of these were highly organic and displayed excellent preservation.

TØNSBERG

- Deposits that were partly or completely destroyed before the year 2000 constitute 26 % of the entire protected area. 66 % of these were removed before 1950.
- As much as 78 % of the destruction took place in the years before *Riksantikvaren* was given responsibility for heritage management in Tønsberg (1971-72). After that nearly all works involving excavation have taken place following some form of archaeological investigation, whether full-scale excavation or a watching brief.
- Large areas of the medieval town have never held thick cultural deposits – it is only in the central "black earth" area that the deposits reach appreciable thicknesses.
- The damage in the central "black earth" area is proportionately greater than indicated by the general overview.
- 72 % of the central "black earth" area has had the deposits either partly or completely removed.
- The volume of cultural deposits is estimated to have been about 475,000 m³. Of this it is estimated that roughly 231,000 m³ have been removed, and of that only 22,800 m³ have been archaeologically investigated.
- The figures indicate that ca. 48 % of the original deposit volume has vanished, and of this only 9.9 % has been archaeologically investigated before removal.

7.3 APPENDIX 3 Context recording sheet, Trondheim

NIKU, DISTRIKTSKONTOR TR.HEIM. LAG REGISTRERINGS SKJEMA

RUTE	DATO	FELT	LAG
TEGNING	**FOTO**	**DAGBOK**	**SIGN**

STRATIGRAFISKE FORHOLD

UNDER	OVER
ANDRE	**MATRIX**

Bestanddeler (karakter og hyppighet) * = spredt, ** = middels, *** = ofte	BESKRIVELSE (se baksiden for stikkord)
leire silt sand grus kvister treflis mørtel stein fragmenter tegl frag. (rød /gul) never trekul bygningstømmer bein (bearbeidet) bein (ubearbeidet) tre (bearbeidet) lær keramikk krittpiper glass metall slagg tekstil skjell ekskrement	

FUNN Risiko for forurensning: ....(liten) ....(høy) ....(ukjent)	Funn tilstede men ikke innsamlet:

Spesielle funn:

Prøver:	botanisk	zoologisk	etom.	dendro	C14	annet

TOLKNING (innvendig, utvendig, konstruksjon, nat. avsatt, planering, oppfyllning, bruk, destruksjon, annet)

Kontrollert av og dato:

Etterarbeids kommentar:

7.4 APPENDIX 4 Instructions for completion of layer/context recording sheet

Colour basic additional shade - light/medium/dark **Colour change** 1 - light to dark other? **Colour change rate** none, slow (minutes), medium (about a minute), fast (seconds)	**Lamination** 1 - absence of horizontally deposited groups of components 2 - horizontal components in compact or granular matrix 3 - groups of components in relatively well-defined horizontal lenses 4 - as for "3", but displaying stratigraphical order 5 - laminated multi-layer	**Inclination (components & artefacts)** 1 - OTHER (impossible to define/ascertain, forgotten, not applicable - SPECIFY) 2 - >75% parallel to plane of deposition 3 - >50% parallel to plane of deposition 4 - most elements are inclined 5 - completely random	**Mechanical factors (layer)** 1 - OTHER (impossible to define/ascertain, forgotten, not applicable - SPECIFY) 2 - absence 3 - erosion/washed out 4 - weathering 5 - scorched/burnt
Odour type just plain earthy, freshly cut wood, H_2S, pollution (diesel/oil), salt, dung/excrement **Odour strength** absent, faint, medium, strong, overpowering **Surface** 1 - regular 2 - undulating 3 - sharply irregular 4 - uneven (i.e., on different levels, shelf) 5 - uneven (sharp angles between levels)	**Compactness** 1 - loose (not possible to remove a block) 2 - components easily separated (block can not retain its shape) 3 - components separate during breaking of block 4 - components remain in block during breaking 5 - block difficult to break	**Distribution (components & artefacts)** 1 - OTHER (impossible to define/ascertain, forgotten, not applicable - SPECIFY) 2 - uniformly scattered throughout the layer (both horizontally and vertically) 3 - non-uniform distribution, but not concen trations 4 - in concentrations of irregular extent 5 - in concentrations of regular extent	**Rate of accumulation** 1 - OTHER (impossible to define/ascertain, forgotten, not applicable - SPECIFY) 2 – slow, continuous 3 - continuous, result of a specific activity 4 - fast continuous, as above 5 - redeposited
Limes 1 - sharp difference between layer in ques tion and underlying layer(s) 2 - interference to a depth <2mm. 3 - interference to a depth <5mm. 4 - interference to a depth <10mm. 5 - interference to a depth >10mm.	**Elasticity** 1 - plastic or loose (absence of "sponge reaction") 2 - slight reaction, but still plastic or loose 3 - visible reaction 4 - almost sponge reaction 5 - more than 90% sponge reaction	**Mechanical factors (components excl. artefacts)** (- varies according to type of component) crushed, cut, split, burnt/scorched, abraded, fungus/insect attack, leached, weathered, spread/flung	**Character** 1 - natural 2 – occupation/cultivation 3 - levelling 4 - building/stabilizing 5 - destruction/demolition (e.g., firelayer)
Homogeneity 1 - one component, unvarying structure 2 - one component, variable structure 3 - different components, unvarying struc ture 4 - different components, variable structure 5 - groups of different components, variable structure (multi-layer)	**Preservation (botanical)** 1 - organic components completely decom posed 2 - <25% definition 3 - <50% definition 4 - >50% definition 5 - >75% definition (virtually no decomposi tion)	**Mechanical factors (artefacts)** 1 - OTHER (impossible to define/ascertain, forgotten, not applicable - SPECIFY) 2 - residual and/or intrusive (number of) 3 - abraded 4 - crushed 5 - burnt/scorched	**Relative abundance of components** (1 - absence) 2 - single occurrence 3 - present in small quantities 4 - present in significant quantities 5 - dominant

7.5 APPENDIX 5 Bergen layer recording system

The original Bergen layer recording system: a brief history

Though the original system has been used almost exclusively by the Bergen excavation office, the designation is really a misnomer. It should be the Gołembnik system, after the Polish archaeologist Andrzej Gołembnik, who developed the system in Poland and subsequently refined it in connection with excavations in Poland (e.g., Pułtusk), in Bergen (Finnegården 3A, Dreggsalmenning 14-16, Bankgaten 4/Skostredet 10), and in Oslo (Oslogate 6). The version currently in use emerged in 1992, and has since been amended only superficially.

Prior to the Finnegården 3A excavation in 1982, the recording of archaeological deposits in Bergen was relatively sketchy. Herteig had devised a coding system for recording layers of different types (based on their principal components) for his excavations at Bryggen in the 1950-60s, but the system was neither flexible nor detailed. Moreover, it was mainly used in connection with recording artefact contexts, not as a distinct method of layer documentation.

The first excavations carried out by the Bergen excavation unit in the early 1980s made it very clear that the complexity and diversity of the archaeological contexts demanded some kind of integrated, standardized documentation/processing system. With such a system, the whole town could be considered and treated as a single archaeological site, rather than as an assemblage of separate sites.

To attain this objective, the system had to possess a number of specific attributes. As previously mentioned, it had to be integrated and standardized, so that sites in different parts of the town, quite possibly with very different stratigraphic sequences, could be accommodated and, later, compared. This also meant that the method of documentation had to be as objective as possible. At the same time, it had to be ‘flexible’ enough to preserve the individuality of each site; and it had to be adaptable, in order to accommodate changes made necessary by future advances. And finally, considering the huge quantities of information involved, it had to be amenable to processing by computer.

The system that evolved comprised more than Gołembnik’s layer recording sheet, but the latter nevertheless formed the heart of the system to a large extent.

The whole point of the layer recording sheet was to lead the recorder step by step to a conclusion about the layer in question’s depositional and post-depositional/taphonomic history: in short, its formation. The guiding premise behind this is that a layer's physical attributes, cultural contents and stratigraphic context/relationship to other layers and/or structures – in short, an assessment of the whole – will reflect the nature, conditions and approximate duration of its formation, together with any subsequent transformations.

Each layer was therefore recorded on a special sheet, which not only showed the layer’s spatial extent within each square – squares measuring 5 by 5 metres are the norm in Bergen – but also contained a detailed description of its stratigraphic context, its physical characteristics/attributes and its contents (supplemented where possible by laboratory analysis of soil samples), culminating with an interpretation of its formation – i.e., whether it represents a natural deposit, an *in situ* accumulation, redeposited material, etc.

The first versions did not have the 1 to 5 numbering of variables, and were quite different in layout and to a certain extent content too, but they did include provision for indicating state of preservation – which means that they can still play a part in monitoring work.

7.6 APPENDIX 6 Data presentation models

Archaeological observations/results: models for data presentation

Model for tabular comparative presentation of deposit "health" (i.e., state of preservation based on archaeological assessment), exemplified by results from various drillings in the Bryggen area, Bergen. Table format developed from Christensson (MB stands for *MiljøBrønn*=dipwell).

MB10	MB12	MB13	Metres above sea-level
?		?????	2.0 – 1.0
???GWXX	?????	??XGWXX	1.0 – 0.0
??XXX	GW??XXX	XXXXX	0.0 – -1.0
XX?XX	?XXXX	XXXXX	-1.0 – -2.0
XXXXX	XXXXX	XXXXX	-2.0 – -3.0
XXXXX	XXXXX	XXXXX	-3.0 – -4.0
XXXXX	XXXXX	XXXXX	-4.0 – -5.0
XXXXX	XXXXX	XXXXX	-5.0 – -6.0
XXN	XX??X	N	-6.0 – -7.0
	XX?XX		-7.0 – -8.0
	XN		-8.0 – -9.0
			-9.0 – -10.0
Increasing depth within each 1 m length ——>			

X - VERY POOR
X - POOR
X - MEDIUM
X - GOOD
X - VERY GOOD
? - INDEFINABLE
0 - NO SOIL RECOVERED
N - NATURAL
GW - Average elevation of water-table

7.7 APPENDIX 7 Counter-measures

Artefacts and ecofacts found in archaeological excavations are preserved because they have reached equilibrium with their immediate surroundings. Insects and other biological agents that normally devour the organic material cannot live/thrive in these wet archaeological deposits without access to oxygen. Such archaeological deposits provide good preservation conditions for organic remains. It is clear that this equilibrium is very vulnerable, and even the slightest change in the surrounding environment can have catastrophic effects. Already during archaeological excavation changes begin, the most obvious of these being oxidation of the deposits. The initial onslaught is readily apparent in the darkening of layers that were quite bright in colour when first exposed – accompanied by the familiar “rotten egg” smell. In well-preserved layers that were deposited and covered quickly, this darkening often takes no more than a handful of seconds; in other layers, it is a more gradual process over several minutes. Colour change and smell are, of course, just the more obvious symptoms of ongoing decomposition – the more serious underlying changes cannot be detected unaided, and it is difficult to quantify the period of time necessary for these to kick in.

In order to establish a battery of appropriate remedial measures/mitigation strategies, we need to identify indicators that express values to be interpreted up against trigger values – meaning that when the trigger value in question is exceeded, remedial measures must be initiated. The present knowledge regarding deposit decomposition and monitoring has produced very few effective measures that can be used in deposit management. At present threshold levels and trigger values should be defined. At first this must be done without proper knowledge regarding their ideal values, but it must be assumed that future experiences and research will change this situation. Therefore, the indicators and their trigger values must be fine-tuned by further research. In 1999 Richard Hughes called for threshold levels of significant change to be defined; he suggested that this should at least be done for parameters such as temperature and moisture content. For changes in the percentage moisture content he proposed the following threshold levels: 0-5% (green), 6-10% (amber), and 11% and greater (red). The colours indicate the level of concern, with red being the trigger value (Hughes 1999). It is important to remember, however, that though deposits may remain “in the green”, they may not necessarily be enjoying good preservation conditions.

7.7.1 REMEDIAL MEASURES

Simple solutions

Already during the excavation of holes and trenches decay sets in. This decay is often compounded when excavated areas are backfilled using “neutral” materials: sand and gravel, or crushed stone. Being more porous than the surrounding cultural deposits, they permit access of both water and oxygen to these deposits. This can halted or slowed down by:

Backfilling with the excavated soil. In Tønsberg, a sewer trench originally excavated in 1976 was re-opened during the course of an archaeological excavation in 1999 and the sections redocumented. There was little or no tangible evidence of degradation of the organic deposits, and features recorded on the original section drawings were readily identifiable.

Sealing surfaces with clay. This strategy has been used by *Riksantikvaren* on several occasions. It is often difficult to completely seal vertical surfaces in this way, so that air pockets will probably inevitably occur between the clay and the archaeological deposits however carefully the work is done. It is therefore still unclear at present just how effective this method is.

Bentonite. A type of natural clay that swells with absorbed moisture, bentonite is most frequently used for sealing boreholes, but also as “dams/plugs” placed at intervals along deep trenches. In Bergen, it has even been used to seal and provide internal support for a medieval well within a stone ruin (Katarinahospitalet, Dreggen).

Non-permeable sand fill. Being made up of fractions that pack together, this type of sand fill prevents surrounding cultural deposits from being drained by trenches and excavations.

Re-use of existing foundations. The re-use/rehabilitation of existing foundations, whether of wood or of most other types of material, will almost always be better for preservation purposes than new interventions for the laying of replacement foundations.

Complex solutions

To date no effective method of reversing the process of decomposition has been identified. Several attempts have been made to re-water sites, these were mainly in rural wetland sites in England, e.g. Flag Fen and the Somerset Levels, where the remedial action has been to raise the water-table. Attempts have also been made in London where the discovery of the Rose and Globe theatres led to demands for these to be preserved *in situ*. These projects were more sophisticated than the rural ones since it was recognized that in order to preserve the archaeological remains, the anoxic waterlogged environment had to be fully maintained (Caple & Dungworth, 1998: 1.1). However, doubts have been raised as to the effectiveness of this process. Kenward & Hall (2004: 9) point out that there appears to be an assumption that in deposits undergoing active decay, the process can be halted by raising the water-table and re-establishing anoxic conditions. They point out further that although this may be true, an argument can be made that in some cases deposits will have been modified by the decay episode in a way that renders them more vulnerable to further damage. After some discussion about decay processes they conclude that ‘If short decay episodes can reduce the resistance of organics to further decay, then re-wetting is only a limited solution to the problem and the case for detailed excavation of representative “damaged” deposits before further decay occurs is greatly strengthened’ (Kenward & Hall, 2004: 10).

Conclusions

Only detailed understanding of these processes, and the factors responsible for them, will allow the identification of possible preventive and remedial measures to ensure the stability of organic strata within defined limits. Appropriate solutions will doubtless have to be adapted to particular circumstances, which may vary in critical respects at local, regional, national and international levels, but this work will allow the diverse factors that affect such decision making to be identified and quantified.

7.7.2 MITIGATION STRATEGIES

This section will be returned to later for a more thorough treatment. In the meantime, one may refer to Davis (2004), for instance. The points presented below are purely provisional, but should provide a springboard for subsequent work.

- even total archaeological excavation of an area can in some cases be considered a mitigation strategy, depending on the circumstances (cf. Kenward & Hall, 2004: 10) – i.e., when not excavating constitutes a worse alternative than excavation;
- numerous mitigation strategies will be concerned with the groundwater – either maintaining or even raising its level (caisson dams, recycling of pumped-out groundwater), and/or ensuring that it is as benign as possible (deoxygenation, encouragement of stagnant conditions). One important first step in this connection is to model the hydrogeological system in the area in question (e.g., Bryggen, particularly in relation to the SAS-hotel site);
- establishment of a grid of fixed points on the ground surface and buildings of the area being monitored; elevation measured to millimetre precision by total-station, at regular intervals, in order to determine the rate at which the ground and/or buildings are settling.

7.8 APPENDIX 8 GIS-work

Access to monitored data and other information from urban archaeological sites

Information on deposits from Norwegian urban sites of the medieval period is available – though so far only for internal use by Riksantikvaren and NIKU – in a database under construction called MABYREG[12]. This database will be linked with maps in a GIS-application (to be termed MABYGIS), which sometime in the future will be accessible via "Askeladden", the national database for cultural heritage.

MABYREG includes information on sites, with their addresses, data on ground-plot, status in planning, information on type and thickness of deposits, excavated or surveyed archaeological features and finds. Information on preservation will be included, by drawing data from *State of Preservation Scale* (SOPS) for each available site. The degree of preservation can then be shown as plots on GIS-maps, and subsequently transformed into thematic shape-files.

Preservation data, when combined with information on thickness, depth and character of deposits and excavated areas, can provide a basis for predictive modelling of the development of deterioration of (organic) deposits in different areas of the medieval towns.

[12] MABYREG is a Norwegian acronym for ***m**iddel**a**lder**byreg**ister*, the Medieval Town Record.

7.9 APPENDIX 9 Contributors

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