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Cover drawing:
In the Early Iron Age, the soil was ploughed so intensively that strong wind caused aeolian drift of both the soil and the sand below in the area now known as Stavanger Airport, Sola. Drawing: Flemming Bau.

# Abstract

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Aeolian sand deposits intercalated with organic layers have been reported from Holocene sediment sequences below the marine limit (ML) at twelve sites along the coastal rim of southwestern Norway for over a century. This study, based on field investigations, stratigraphical analysis, radiocarbon dates and archaeological information, has revealed several phases of aeolian activity. The premises and factors permitting sand drift, as well as the timing of this activity, have been compiled and synthesised. The premises for aeolian activity are the presence and supply of unconsolidated sandy sediments, wind strong enough to transport sand particles and a sparse or absent vegetation cover. Sand drift is not recorded along stretches of coast with numerous boulders. Aeolian activity is triggered by natural factors, human impact or a combination of these. The oldest aeolian activities started about 8100 yrs BP (9200 cal yrs BP) and were closely related to the Holocene sea-level displacement, while the youngest activity is more tied to various kinds of human land use. Sand drift in Late Weichselian and Preboreal times has not been recorded, perhaps partly because present-day sandy shores were submerged at that time. The 7400 yrs BP (8200 cal yrs BP) cooling event corresponding to a period of Northern Atlantic cooling is recorded by aeolian sand at only one site in this study. Sand drift is primarily located in areas that were submerged during the Tapes transgression when the shoreline was located more than one kilometre inland from the present coastline in parts of the area. Shallow fjords and estuaries were then filled by sandy sediments transported by rivers, onshore waves and longshore drift. The Holocene Tapes transgression was double-peaked which implies that the maximum high lasted for about 2000 calendar years (6800-4800 yrs BP, 7640-5540 cal yrs BP). During the subsequent regression, the sandy sediments were prone to erosion and sand drift. Aeolian activity is recorded continuously from about 6500 yrs BP (7430 cal yrs BP) (the onset of the first Tapes regression), but obviously intensified during the second, slow Tapes regression that started about 4800 yrs BP (5540 cal yrs BP). The way people have used the land, at least since the Neolitisation of the area which started about 5200-4800 yrs BP (5950-5550 cal yrs BP), first by forest clearance and pasturing, and later escalating through cultivation and heathland management, has also increased sand drift. Sand drift correlates well with the metachronous forest clearance steps 1-3 that started with the Neolitisation, and also with the two steps in the establishment of Norwegian coastal heaths, both of which are recorded in the area investigated. Thus people were important for altering climate, i.e. lower temperatures and stronger wind because of the deforestation. Aeolian sand drift has also been tied to activity of Mesolithic people from about 6470 yrs BP (7380 cal yrs BP), before agriculture was introduced. People probably influenced nature by burning and otherwise managing vegetation. Medieval aeolian activity is documented from the “Little Ice Age” (AD 1350-1850) and the Maunder Minimum (AD 1645-1715), the coldest phase of the “Little Ice Age”.

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*“The squatting tenant men nodded and wondered and drew figures in the dust, and yes, they knew, God knows. If the dust only wouldn’t fly. If the top would only stay on the soil, it might not be so bad.”*

THE GRAPES OF WRATH
JOHN STEINBECK 1939

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# Introduction

The coastal rim of southwestern Norway, along Jæren in Rogaland, is unique from a national point of view. The beaches along the coast of Jæren (Jærstrendene) embody a distinctive natural and cultural landscape, rich in wetland areas, cultural heritage remains and above all the northernmost aeolian sand complexes in Scandinavia. However, minor localities also exist further north in Norway, in Nordland and in Troms. Jæren has 25 km of sand dunes interrupted by short stretches with rocky beaches, moraine topography or moraine cliffs (County Governor of Rogaland 2008). Since 1977 (revised 2003), 70 km of the coastal area from Randaberg in the north to Hå in the south have been legally protected as the Jærstrendene Landscape Protection Area (e.g. Eldøy 1981).

This study focuses on the large areas covered by aeolian sand sheets within the continuously active sand-dune landscape (e.g. Andersen *et al.* 1987:28) (Fig. 1). These areas are also protected by law, except where they are more than 650 m from the shoreline (County Governor of Rogaland 2008). All but one of the localities we have studied lie within these sandwiched and compact aeolian sand sheets in Jæren with the exception of a corresponding locality on the island of Karmøy.

Aeolian activity occurred outside the Weichselian glacial margins. During the deglaciation in northern and central parts of Europe, sandy and silty sediments without or with a sparse vegetation cover were exposed to strong winds, which caused the accumulation of the well-known Glacial and Late Glacial loess and cover sands of the Netherlands, Belgium, northern Germany, Poland and Denmark (e.g. Buckley 1987, Kolstrup *et al.* 1990, Kolstrup 1997, 2007, see also Mycielska-Dowgiallo 1993). Movement of sand by wind was one factor that kept the vegetation open during Late Glacial times, and changing temperatures indirectly led to a reduction in cover sand accumulation because of interaction between denser vegetation and soil surface stability (Bennett 1983, Kolstrup 1997, 2007). The depositional environment of the landforms of the sheet-like cover sands from Glacial and Late Glacial times in northern and central Europe is comparable with the Holocene aeolian sand sheet environment. Decisive for sand drift are the interaction of the rarity of topographic barriers, the sparseness of the vegetation cover and a high ratio between wind energy and sand availability during transport and deposition. Vegetation to catch and retain the sand and silt is a prerequisite for the formation of sand sheets (Schwan 1988).

Norway is located north of the cover sand areas (Kolstrup 1997: Fig. 1). Nevertheless, Late Glacial aeolian activity has been recorded in Romerike in eastern Norway and at Evjemoen in Setesdalen, for example, but these deposits have not been radiocarbon dated (Nielsen 1937, Holtedahl 1953:855ff). From historical times, aeolian sand drift resulting in sand deposits have been recorded in two inland areas, at Elverum in eastern Norway (Bargel 1983:29-39) and Røros (the Kvitsanden 'desert') (Holmsen 1942). The Røros dunes are known to have been formed after the deforestation connected with the establishment of the Røros copper works in AD 1644, and are possibly also due to damage by sulphuric fumes from the smelter (Prøsch-Danielsen & Sørensen 2009). Drift of soil and mineral particles during the last 5000 years has been recorded at several inland localities in neighbouring countries, and sand drift was more intensive in Subatlantic than Subboreal time (e.g. Bahnson 1973, Nørnberg 1977, Vuorela 1983, Wilson 1989). Generally, sand drift is assumed to have the same causes at the inland localities as at the coastal localities, anthropogenic factors being most prominent (Selsing & Mejdahl 1994:102).

Today, the main areas for aeolian drift in central and northern European latitudes are along the coasts and, to some extent, in areas where cultivated fields are unprotected part of the year (Møller 1982 in Kolstrup 1997:91). Aeolian activity is well known in the dune areas along the North Sea coast of southern Norway, especially in Lista and Jæren, and also on parts of the islands of Andøya and Værøy in northern Norway, but it also occurs to a lesser degree in small bays where unconsolidated sediments are exposed to wind

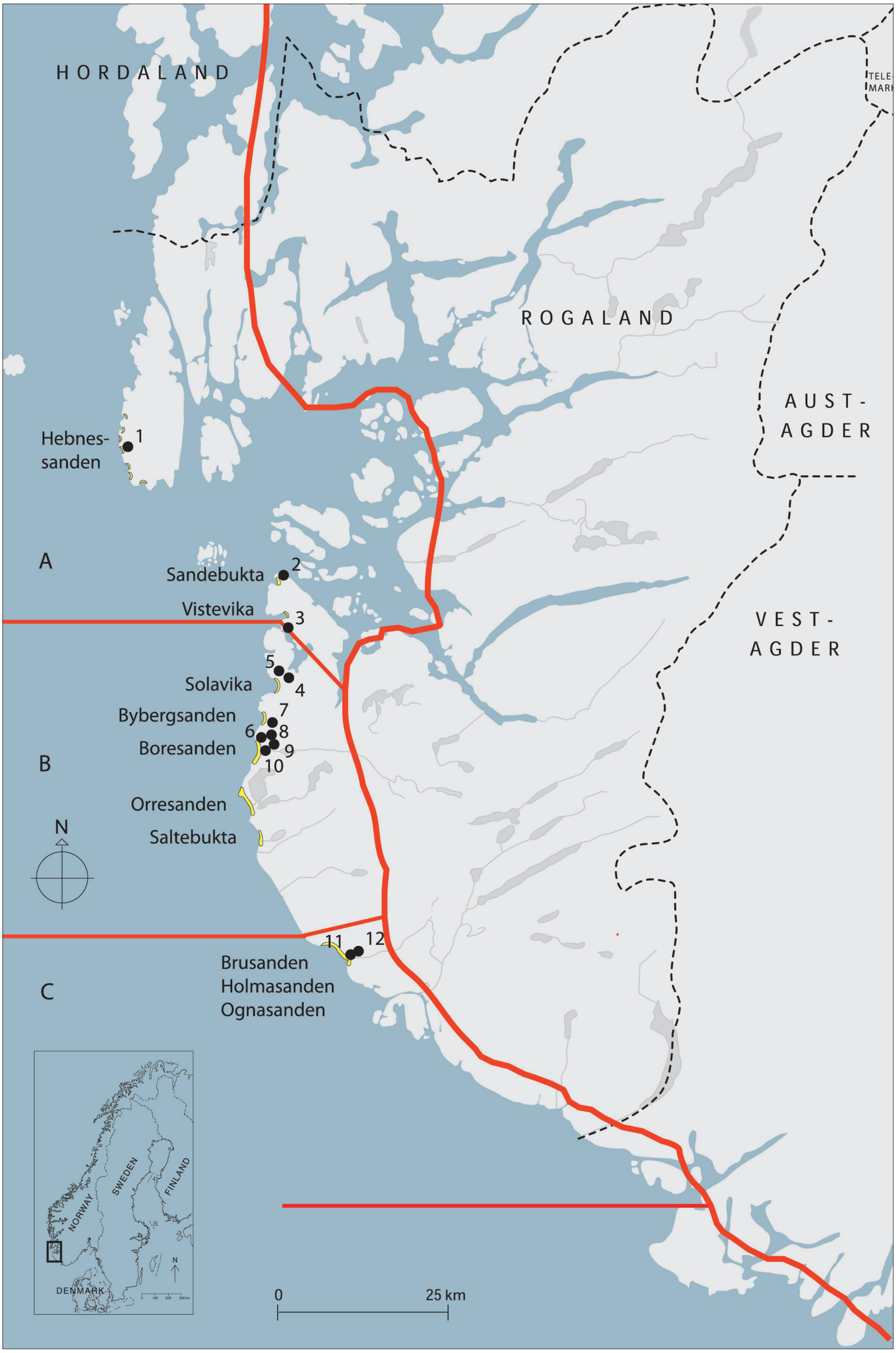


*Fig. 1. The investigated sites (black dots) from north to south along the coastal rim of southwestern Norway are 1) Hebnes, 2) Tunge, 3) Sunde, 4) Stavanger Airport, Sola, 5) Solavika, 6) Sele Channel, 7) Bybergsletten, 8) Ølstervatn, 9) Alvevatn, 10) Hølen, 11) Slettabø, and 12) Salthelleren. Sandy beaches are outlined (yellow). Areas A, B and C are physical geographical entities (see section 2).*

and other erosive forces (Holtedahl 1953:858, Klemsdal 1969:60, Griffin 1976, Longva *et al.* 1983:41, 43, Alm 1993, 1994).

The dynamics of the dunes include frequent alternation of erosion and accumulation, and cyclic reworking of sand. The organic material found in the dunes is therefore usually young because the sediment turnover is dynamic and fast. This is confirmed by studies of 19th- century paintings (Tørum & Gudmestad 2008), and has also been verified by a dating (31.8±0.5 % activity above the normal, yrs BP, TUa-6051A) of organic layers beneath a beach ridge in the distal part of the dunes at Boresanden, Jæren (Prøsch-Danielsen 2006b). The most favourable sites for studying the long history of aeolian activity are thus the aeolian sand sheets located on the leeside of the dunes where sand dunes are generally absent ("baklandet" in Norwegian, see Klemsdal 1979:163). The sand sheets are an integral part of the aeolian depositional system (Kocurek & Nielson 1986) and in southwestern Norway they are characterised by thick layers of aeolian sand with low-angle stratification intercalated by palaeosols and peat layers. The weak structures or structureless nature of the sand probably result from the root structure. The occurrence of sand sheets instead of dunes probably indicates that conditions are outside the range within which dunes form, or particular factors like a high water table, periodic flooding and vegetation interfere with the dune formation (Kocurek & Nielson 1986:812). A high water table is effective in limiting the amount of dry sand available for dune building (Kocurek & Nielson 1986). Other factors mentioned by Kocurek & Nielson (1986) which favour sand-sheet development in a warm climate are surface cementation or binding and a significant proportion of coarse-grained sediment. However, these factors are not relevant in the maritime climate along the North Sea coast. Recent focus on man and climate has generated new investigations with an emphasis on the factors that trigger sand drift, and the age, genesis and stratigraphy of the Holocene aeolian deposits (Selsing 1984, Wilson & Bateman 1986, Christiansen & Bowman 1986, Christiansen *et al.* 1990, Selsing & Mejdahl 1994, Clemmensen *et al.* 2001).

When they were investigating the peat bogs in Jæren, Blytt (1876) and Holmboe (1903) were the first scientists in Norway to speculate on whether or not sand layers in the peat were of aeolian origin. Our studies are also based on the classical work of Fægri (1940), which

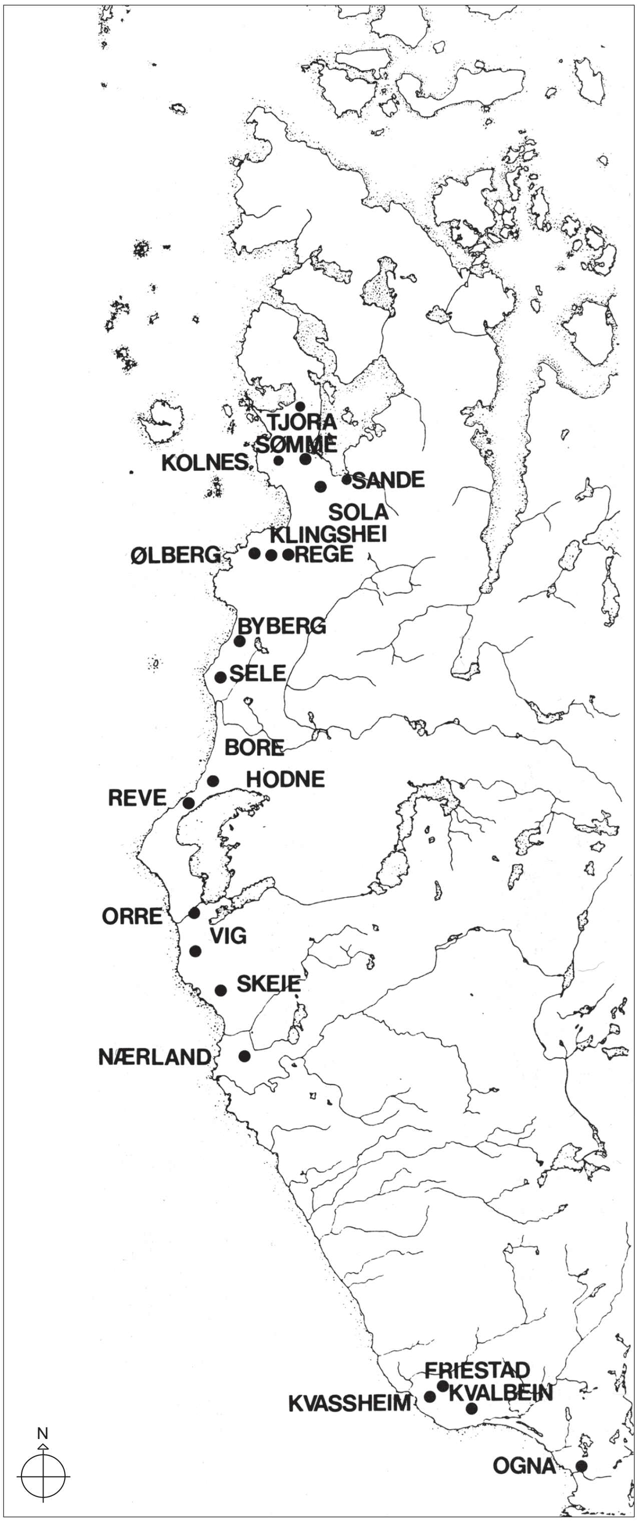

*Fig. 2. Farms in Jæren with information on aeolian activity in historical times (Thomsen 1988:32).*

focused on vegetation history and sea-level studies in Jæren. Aeolian activity was also documented. In 1953, Holtedahl made a brief survey of aeolian deposits in Norway, while Klemsdal (1969) investigated the morphology of aeolian deposits along the coast of Jæren. Subrecent aeolian deposits are known from several localities along this coast (Fægri 1940, Bird & Klemsdal 1986, Andersen *et al.* 1987:27-28). The sand drift was concluded to have occurred in connection with sea-level changes, climate changes and human impact involved with agro-pastoralism and, more recently, construction work, sand and gravel extraction, ploughing and sea tangle trawling (e.g. Bjørlykke 1905, Holmsen 1915, 1963, Flint 1971, Klemsdal 1969, Miljøverndepartementet 1976:6, Wishman 1990, Prøsch-Danielsen 1993, Selsing & Mejdahl 1994, Tørum & Gudmestad 2008 and the above mentioned references).

At the Museum of Archaeology in Stavanger, studies of aeolian deposits intercalated with occupation layers have been carried out for more than 30 years. Since the museum was established in 1975, archaeologists and natural scientists have collaborated in interdisciplinary research teams providing a good opportunity for the latter to participate in shaping the museum's policy – people and the environment – with cultural historical problems in mind. The Museum became a Natural Research Centre for Palaeostudies and Conservation with natural scientific collections in the fields of geology and botany. Today, this gives us the opportunity to synthesise themes like sand drift. This provides information about the relative and absolute ages of the finds, and the natural conditions which prevailed during the cultural activities.

Aeolian drift continued in historical times, and changing activities and problems caused by aeolian sand drift have been reported from many farms in western Karmøy and Jæren up to the present day (e.g. Sommerschield 1912, Grude 1914, Lillehammer 1982, Sjulsen 1982, Stavanger Aftenblad 1987, 1989a-d, 2008a-b, 2009, Ryggjavern 1996, Fyllingsnes 2004, Tørum & Gudmestad 2008, County Governor of Rogaland 2008, Lundberg 2008). Fig. 2 shows the location of the farms along the coast of Jæren which frequently had problems because of drifting sand in historical times. All these farms are situated close to sandy beaches (Fig. 1).

Selsing & Mejdahl (1994) synthesised their results for southwestern Norway in six formal, diachronous aeolian and non-aeolian phases grouped together as the Sola Episode for the last 3500 yrs BP (3780 cal yrs BP). They were correlated with two Polish localities, Swietuosc I and Troszyn (Borowka *et al.* 1986).

The aims of this paper are to:

a) Establish an absolute chronology of aeolian activity and the building up of sand sheets
b) Put the aeolian phases into a natural and a cultural historical framework
c) Reveal the causes of the aeolian activity in prehistoric times

# Study area and environmental setting

The southwestern coastal rim of Norway is part of three physical geographical entities, distinguished primarily on the basis of their topography and geology (Figs. 3 and 4) (Prøsch-Danielsen & Simonsen 2000a, 2000b). They are, from north to south:

> Area A: Karmøy, Haugalandet and Boknafjord
> Area B: Jæren
> Area C: Dalane

Their characterising features include (1) the presence of archipelagos (area A), (2) the nature of the bedrock, i.e. Precambrian (area C) or Caledonian orogenic bedrock complex (areas A and B), and (3) the general presence of thick Quaternary deposits (area B). Deglaciation of the coast in area A occurred as early as 14,150±160 yrs BP (17,184-16,577 cal yrs BP, T-6684, Paus 1989: Table 2), while two dates (13,640±60 and 13,500±90 yrs BP, 16,425-16,032 and 16,256-15,826 cal yrs BP) from areas B and C indicate that the Jæren coast (area B) was deglaciated before 16,000 cal yrs BP (Knudsen 2006, Knudsen *et al.* 2006: Table 2).

The Jæren area, the shelf edge and the North Sea Fan are characterised by thick, unconsolidated sediments (e.g. Andersen *et al.* 1987: Plates 1, 7 and 8, Sejrup *et al.* 1987, 1998, 1999, Janocko 1997, Stalsberg *et al.* 1999, Rise *et al.* 2008). A terrestrial ice sheet moved from east to southwest in Jæren during the last glaciation and retreated from the North Sea during the latest phase of the deglaciation. Simultaneously, a huge, active, ice stream flowed along the axis of the Norwegian Channel (Longva & Thorsnes 1997, Ottesen *et al.* 2005). During and after the final deglaciation, up to 300-400 metres of sediments were deposited at the shelf edge and in the North Sea Fan (Rise *et al.* 2008). The ice sheet then expanded for a short period before finally retreating. The remaining sediment cover is more than 50 metres thick along a seismic profile from Høgjæren to Grødeland (Sejrup *et al.* 1999: Fig. 5). The aeolian deposits presumably originated from these older glacial and interglacial deposits, which were reworked by sea and wind in Late Glacial and Postglacial times (e.g. Klemsdal 1969).

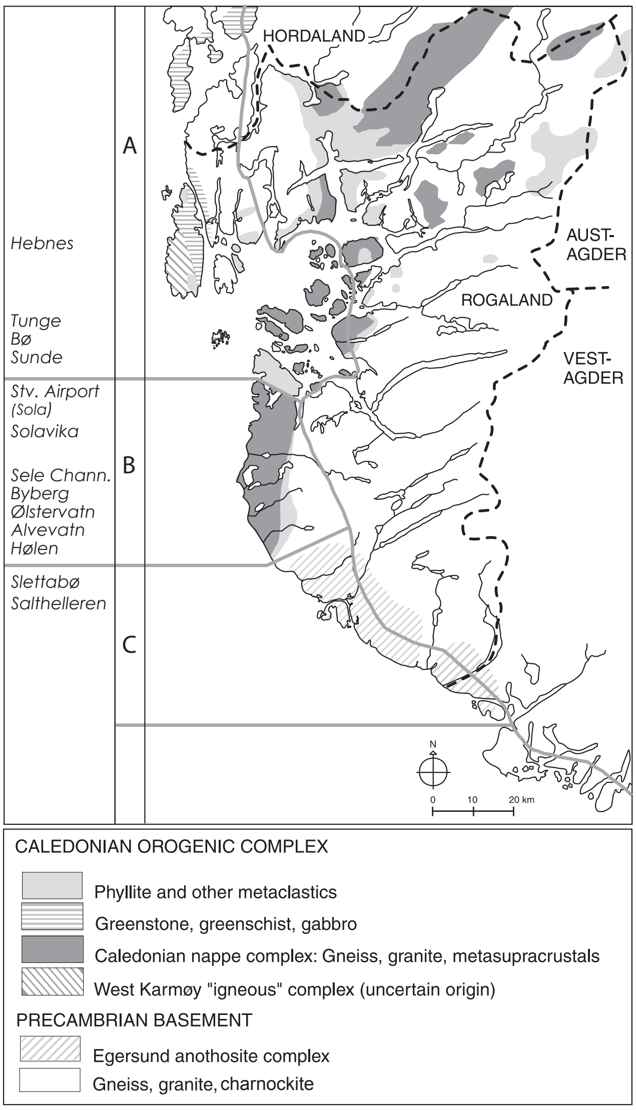


*Fig. 3. A simplified map of the bedrock in Rogaland, southwestern Norway (Prøsch-Danielsen & Simonsen 2000a: Fig. 1b).*

The types of coast in southwestern Norway were described by Klemsdal (1982), Sjulsen (1982), Bird & Klemsdal (1986) and Janocko (1997). This area, where aeolian sand dunes and/or aeolian sand sheets have been encountered, may be classified as a “strandflat” coast (Larsen & Holtedahl 1985) or sandy beach coast (Klemsdal 1979, 1982, see also Miljøverndepartementet 1976:25ff). Sand drift is not recorded in the south-

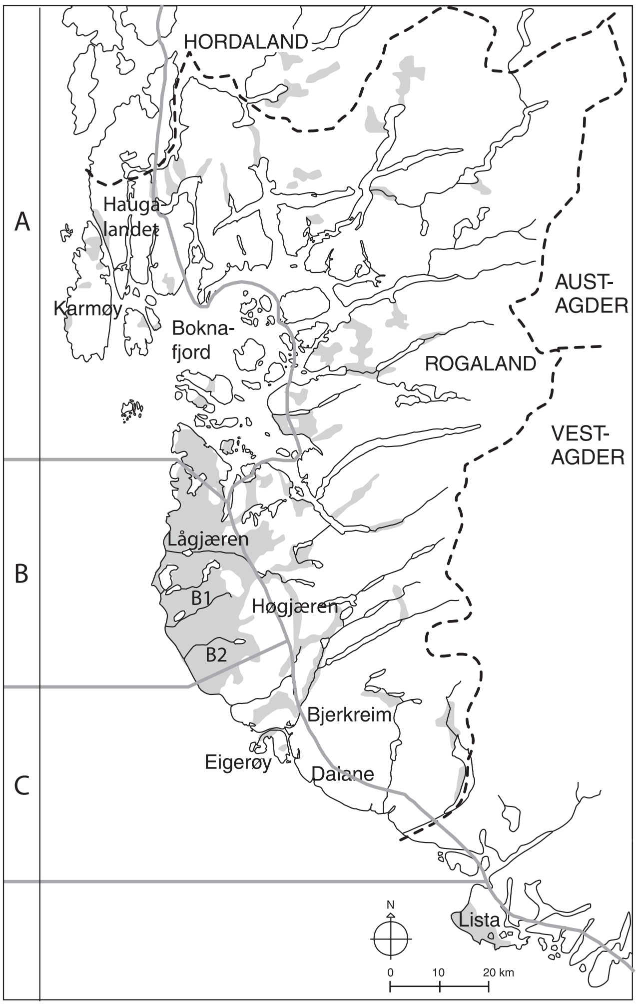


*Fig. 4. The distribution of Quaternary deposits (grey) in southwestern Norway. Modified from Prøsch-Danielsen & Simonsen (2000a: Fig. 1a).*

western part, from Obrestad to Kvassheim, where boulder-rich till dominates and drumlins occur parallel to the coast (Sejrup *et al.* 1998). Stretches comprised of bedrock or till may contain small bays with sandy beaches.

In the "strandflat" area (area A and the northern part of area B), the sediment cover is discontinuous. The flat coastal rim is comprised of bedrock with rock outcrops or rocky hills. This has resulted in a varied landscape with peninsulas, rocky headlands and small, protected pebbly or sandy beaches, but rocky shores predominate. The coast can also partly be classified as a fjord coast according to Klemsdal (1982). The low-lying Jæren area (parts of areas B and C) forms a rim of coastal lowlands close to the North Sea without protecting skerries and islands. The transition between the northern and southern parts of area B is to the north of Solavika. The Dalane coast (part of area C) is dominated by exposed bedrock termed "a cliff abrasion and fjärd coast" (Klemsdal 1982). It almost lacks Quaternary deposits and there are no areas with sand drift.

## Sea-level changes

The coastline is sensitive to sea-level changes and even small fluctuations in sea-level may cause large changes in the landscape. The sea-level displacement curves drawn from sites along this particular coast are complicated and reveal three (sometimes four) transgressions; one (or two) in Late Weichselian time and two in the Holocene because the Tapes transgression had two maxima (Fig. 5).

The Late Weichselian (Younger Dryas) transgression represents the marine limit (ML) on Karmøy (25 m asl) and in the northern part of Jæren (21 m asl) decreasing in altitude southwards along the coast of Jæren (Ogna 2 m asl), and intersecting with the Tapes transgression at Reve, near Orrevatn in Jæren. The Holocene sea-level was therefore highest in the southern part of Jæren. The regression following the Younger Dryas ML brought a drop in sea-level of approximately 2 m per 100 yrs in the northern part of the study area, but probably no more than 0.5 m per 100 yrs in the southern part of the low-lying Jæren. The shoreline therefore withdrew rather rapidly in the northern part, allowing a vegetation cover to advance seawards relatively fast. However, the Preboreal regression was slower southwards, implying that the shoreline in southern Jæren stayed at the same level for a long period during the early Holocene.

The Tapes transgression(s) started as early as 9000 yrs BP (10,200 cal yrs BP). The first Tapes maximum rises to the 12 m contour line in northern Jæren and drops southwards along the Jæren coast, reaching 5 m in the Ogna area. This event is dated to c. 6500 yrs BP (7430 cal yrs BP) and was followed by a slow, small-scale (1-2 m) regression. A second Tapes maximum, dated to c. 4800 yrs BP (5540 cal yrs BP), is observed from Karmøy southwards along the coast to the Ogna area (Prøsch-Danielsen 2006a). The two maxima intersect in the coastal zone at the Randaberg peninsula, the second being the highest one southwards, reaching about 7 m in the Ogna area. As a consequence, large coastal areas were exposed and prone to wind erosion and sand drift when the sea withdrew. The period from the first to the second Tapes maximum lasted about

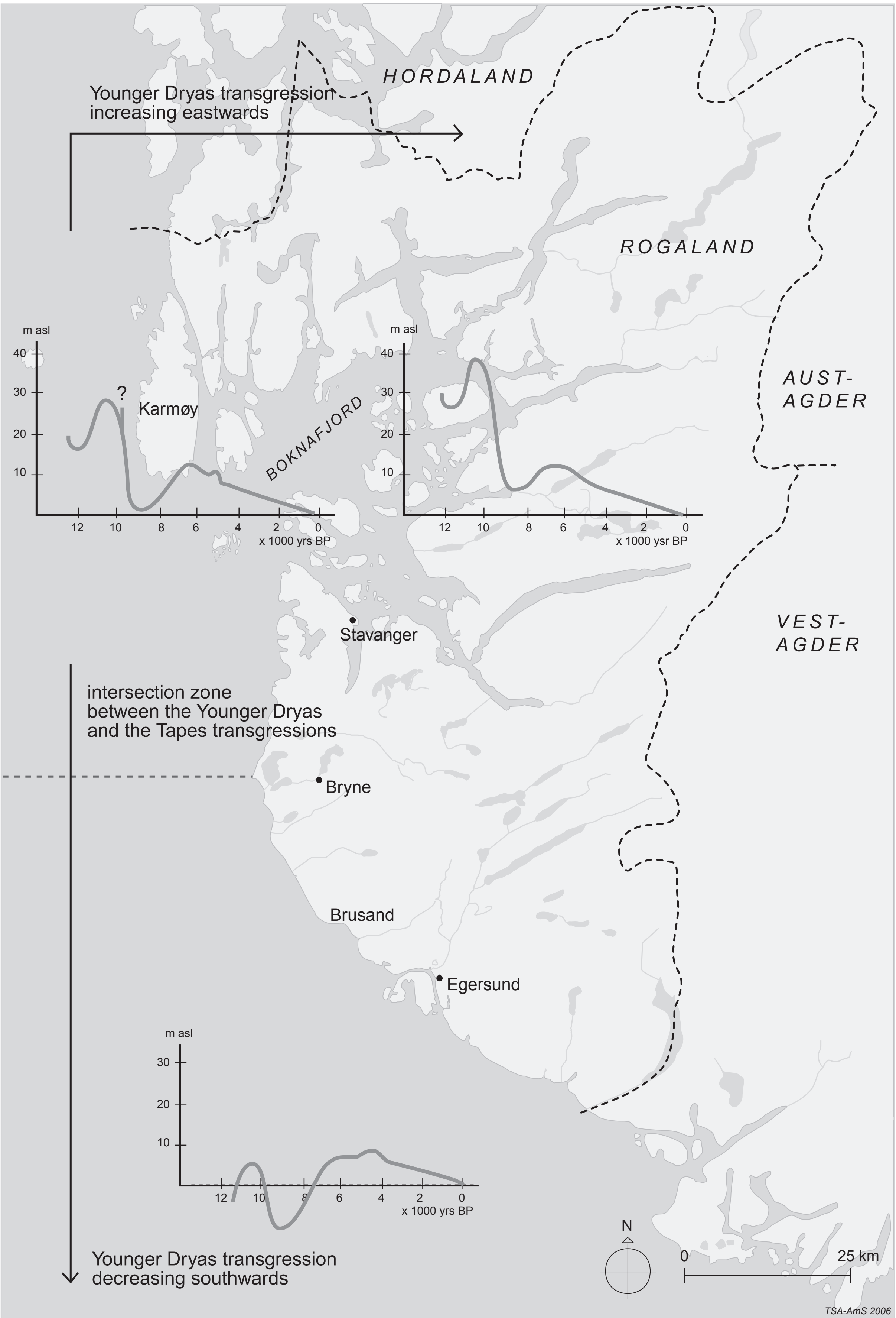


*Fig. 5. Sea-level displacement curves for Rogaland, southwestern Norway, showing the north-south and west-east variations. Modified from Prøsch-Danielsen (2006a: Fig. 79).*

2000 calendar years, with slow changes amounting to a few metres. This implies that large areas with a flat or very gently sloping relief with lagoons and shallow inlets and fjords, mostly combined with river estuaries, dominated the near-shore zone of Jæren. Large quantities of easily reworked, unconsolidated sand without a vegetation cover were moved to and from marine to terrestrial environments by both wind and waves.

## Forest clearance and the development of the coastal heathland

The study area lies within the Norwegian coastal heaths section (Dahl *et al.* 1986, Moen 1999). The Norwegian coastal heaths in western Norway are anthropogenic in origin, maintained through continuous grazing and intentional burning (Kaland 1979, 1986). The heathland has been impacted by human activities since the beginning of the twentieth century, and been partly replaced by plantations and grassland (County Governor of Rogaland 2008, Lundberg 2008). The deforestation that led to the heathland being established was studied in southwestern Norway by Prøsch-Danielsen & Simonsen (2000a, 2000b) and discussed by Høgestøl & Prøsch-Danielsen (2006).

Three pronounced steps in the clearance of forest have been recorded (Prøsch-Danielsen & Simonsen 2000a, 2000b) (Fig. 6) since the transition from the Mesolithic to the Neolithic. The clearance was metachronous and varied in intensity in the separate areas. It led to a regional mosaic of different vegetation types dominated by forested areas, heaths and mires with a gradually decreasing forest cover:

1) 4000-3600 BC (5200-4800 BP, 5950-5550 cal BP) (area A)
2) 2500-2200 BC (4000-3750 BP, 4500-4100 cal BP) (areas A, B and C)
3) 1900-1400 BC (3550-3100 BP, 3850-3350 cal BP) (areas A, B and C)

The establishment of the coastal heathland vegetation was also metachronous, occurring in two main steps, 900-700 BC (2750-2500 yrs BP, 2850-2600 cal BP) in area B and 300-0 BC (2200-2000 yrs BP, 2250-1950 cal yrs BP) in areas A and C.

Step 1 in the forest clearance reflects the introduction of animal husbandry, a pastoralistic type of land use that included an extensive use of the land. The early Neolitisation included a slash-and-burn strategy that involved felling trees for fuel and timber and to open up for pasturing (see e.g. Aaby 1994:35 and Sageidet 2005a, 2005b, 2009). Pollen from cereals and weeds is virtually absent in samples from areas A to C in the Early and Middle Neolithic. Weak traces of cereal cultivation are recorded by palynomorphs in the first forest clearance phase at Karmøy, dated to 4305±80 yrs BP (5040-4730 cal yrs BP, TUa-1193) (Prøsch-Danielsen & Simonsen 2000a).

Massive forest clearance marks step 2, which is detected from 2500 BC (4000 yrs BP, 4500 cal yrs BP). From then on, virtually the entire landscape was opened up. The final consolidation of agriculture was primarily dominated by husbandry (Prøsch-Danielsen & Simonsen 2000a, 2000b, Høgestøl & Prøsch-Danielsen 2006). Pollen from cereals and weeds is also virtually absent from Late Neolithic samples. The earliest crop cultivation of cereals at Kvåle in northern Jæren is dated to the Late Neolithic, 3855±40 yrs BP (4403-4162 cal yrs BP, TUa-4030) (Solem 2005). Plant remains recovered from archaeological sites indicate two main steps in the expansion of cereal cultivation; small-scale cereal cultivation 2500-2200 BC (4000-3750 yrs BP, 4500-4100 cal yrs BP) followed by the major breakthrough around 2200-2000 BC (3750-3650 yrs BP, 4100-3950 cal yrs BP).

The Neolitisation led to more permanent settlement and thus to ownership of the land, and the more intensive land-use brought more impact and pressure on the soil cover. In the worst cases, it led to erosion and aeolian activity. Forest clearance and burning led to the vegetation cover being destroyed locally, allowing aeolian processes to operate. A dense forest prevents the movement of air on the soil surface. The large-scale clearance of forest for fuel, timber and grazing in Neolithic time therefore changed the local climate.

## Climate

Nitter (2008, 2009) discussed "climate spaces", and recognised four steps or levels, macro, meso, local and micro, the first two of which are important in southwestern Norway (compare Jönsson's (1992) regional, local and micro scales of wind climate). On the macro scale (>200 km), this area is characterised by a (temperate) oceanic (maritime) coastal climate located in the Polar Front oscillation area. It involves frequent shifts in the

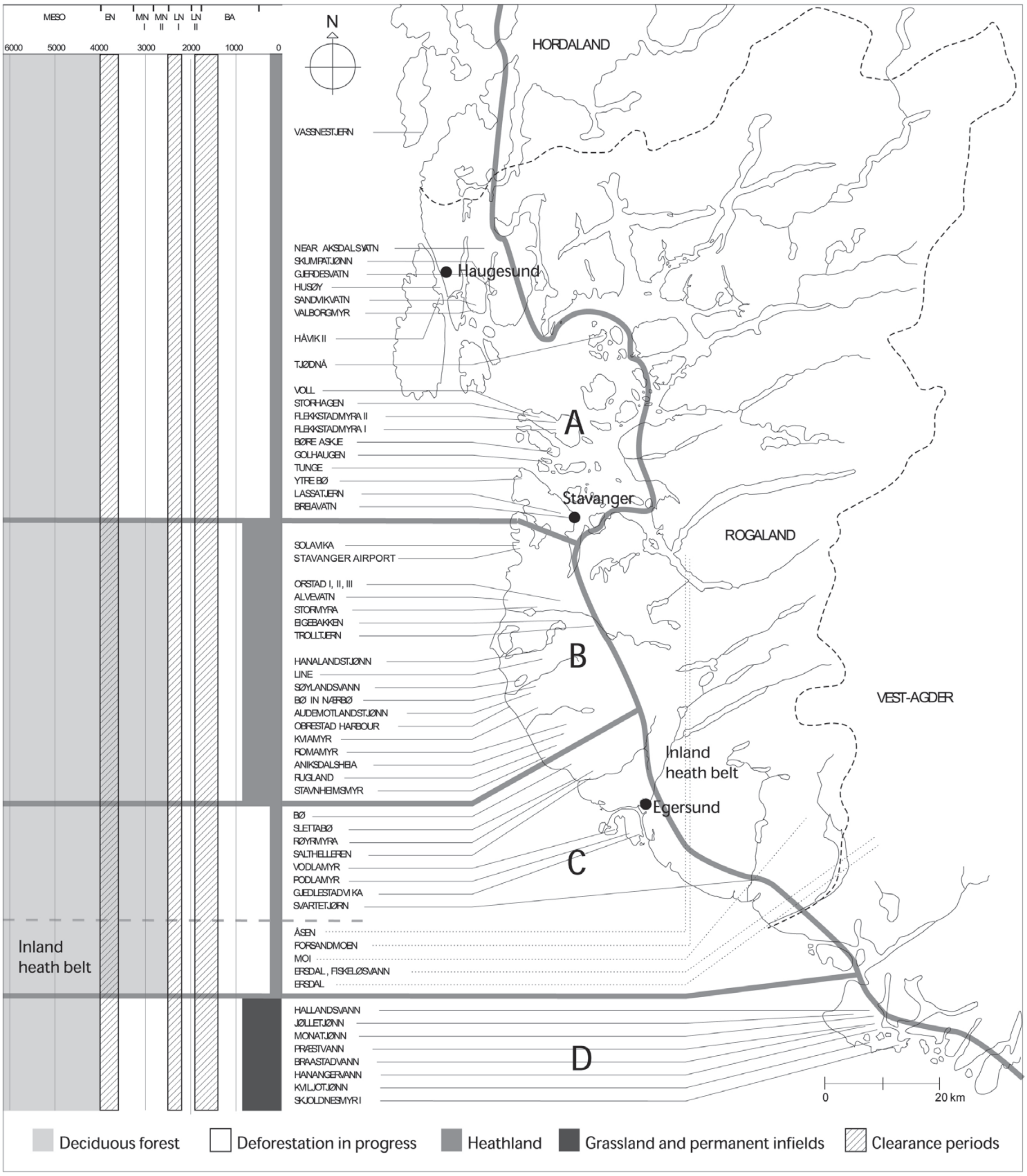


*Fig. 6. The age of the forest clearance steps and the final establishment of heathland or grassland and (permanent) infields in areas A-D, including the inland heath belt. Clearance phases are hatched. Høgestøl & Prøsch-Danielsen (2006: Fig. 3) based on Prøsch-Danielsen & Simonsen (2000b: Fig. 14).*

position of the Azores High and the Icelandic Low, and winds therefore constantly blow from different directions. On the meso scale (10-200 km), the distance to the sea is most important for the temperature changes in Rogaland. The yearly mean temperature is between 7.0 and 7.5 °C in the investigated coastal area (Nitter 2008: Fig. 2). The mean July temperature is 14.0 °C (the maximum temperature on the coast is in August) (Nitter 2008: Fig. 4). The mean February temperature is 0.5 °C to the south and between 0.5 and 1.5 °C to the north of the Stavanger peninsula (Nitter 2008: Fig. 3). Precipitation in Rogaland depends upon the position of the Polar Front, the isobar field, depressions, the season, the topography and the wind direction (Nitter 1999). The yearly mean precipitation is between <1500 mm and <1250 mm (see Nitter 2008: Fig. 5). The prevailing wind in Jæren in winter is south to southeast. In summer, northerly and northwesterly winds dominate, and have the greatest ability to move sand on the Jæren coast (Klemsdal 1969:55, Wishman 1990:107-108).

# Premises for aeolian activity

Aeolian activity takes place primarily in areas with strong winds where the vegetation cover is lacking or discontinuous and the superficial sediments are unconsolidated and dominated by silt and sand (Kolstrup 1997:91). In the present-day northern European climate, these conditions are mostly present along the coasts.

The premises for sand drift have been present since the deglaciation. The main requirements for aeolian activity along the coastal rim of southwestern Norway are exposed, sandy sediments, specific climatic conditions and sometimes also sand brought to the beach from offshore sources (Selsing *et al.* 1988).

The original sources of sand are primarily till, glaciofluvial, fluvial and marine sediments, which are abundant in the Jæren area and the North Sea off southwestern Norway (see section 2). Various processes have continuously been reworking the sediments in this dynamic, outer coastal landscape after the deglaciation.

Changes in climate, such as the shift to a more humid climate during the Holocene, might have led to dune field degradation and the development of vegetated sand sheets (Talbot 1980, 1984, 1985 in Kocurek & Nielson 1986). This might suggest the possibility that sand sheets have increased in the area during the Holocene at the same time as dune fields have decreased along the Jæren coast.

A characteristic of sand sheets as opposed to dune fields is that, while they are being built up, the former are covered by vegetation whereas the latter have no or only very sparse, sporadic vegetation. Only a vegetation cover (or comparable shelter) can stabilise aeolian activity in an area where winds are sufficiently strong to activate sand drift. In summer when the plants are most vital, the sand is stabilised, but in winter when they are inactive and the wind is often stronger, erosion is more dominant (Lundberg 1997:11). Cultivation destroys the

*Fig. 7. The figure illustrates how the depositional environment may have been in the river mouths along the Jæren coast since the time of deglaciation. The estuary of the River Aorere with Cape Farewell in the distance, in the northwestern part of the South Island of New Zealand. It is low tide with exposed sandbanks (New Zealand Cards, photo Bob Beresford). The tidal range is much greater in the Cape Farewell area than along the southwest coast of Norway.*

vegetation cover and the soil is thus exposed to erosion and deflation in some parts of the year (Klemsdal 1969, 1979:165). In sand-sheet areas, vegetation interferes with the free movement of sand and is effective in promoting the accumulation of sand sheets. Many plants grow simultaneously with sand deposition and where vegetation is relatively dense and evenly spaced, irregular surfaces do not occur, but the flat surface undergoes vertical accretion (Kocurek & Nielson 1986:813).

Northwesterlies and other onshore winds may have been weaker during periods when temperatures were higher than at present. During the Holocene thermal optimum (defined by Hafsten (1960) as corresponding with the Atlantic and Subboreal biozones in the lowlands around Oslofjord), winds exceeding the critical force necessary for sand drift probably occurred less frequently than today and extensive forests must have moderated the wind force, thus limiting the aeolian activity to a narrow beach area (Wishman 1990:112).

In periods with lower temperatures, such as the "Little Ice Age", winds were generally stronger and exceeded the limit necessary for sand drift more often than today (Wishman 1990:111). Written records also indicate that storms were stronger and more frequent than in more recent times (Tørum 2007:66). Hansen (1957) was probably the first to interpret increased aeolian activity in areas with lower temperatures and higher humidity, and this was confirmed later by, for instance, Lamb (1977) and Wishman (1985, 1999). Increased peat growth in Scandinavia (Denmark) was caused by a change in climate in these humid, temperate latitudes where precipitation is mainly brought by passing depressions. They began to follow a more southerly path, thus bringing more precipitation than previously. Stronger winds lasted sufficiently long to dry the wet, upper part of the sand, set it in motion and move it to a much greater extent than would occur in a less humid and windy climate (Hansen 1957). At the same time, the vegetation and its root systems, which are important for binding the sand, were removed for livestock fodder, fuel and roofing purposes (Hansen 1957:85).

Wind that is strong enough for aeolian activity has characterised the northern European climate since the deglaciation (Klemsdal 1969:58, Wishman 1990). The mean frequency of the strongest winds has probably not changed significantly during the Holocene because the yearly change in the wind direction is connected with a fundamental Scandinavian monsoon that must have existed since the deglaciation (Wishman 1990:111).

The threshold of the wind force required to keep sand particles moving (Bagnold 1973) indicates that the wind force in Jæren is sufficient to move sand particles at all times of the year, but most frequently in winter (Wishman 1990:107). Southeasterly winds along the Jæren coast primarily move sediment particles from the land towards the sea, except in the area south of Orre and the Jæren Reef where they will move them more or less parallel to the coast. With northwesterly winds, the aeolian deposits may have had a marine origin.

The frequency and direction of storms are more important than the yearly mean wind direction for transporting material both onshore and offshore (Wishman 1990). Drought is essential for sand drift (Wishman 1990:109-111), and since sand drains well it rapidly dries out and is rarely soaked in water. When beach sediment is dry enough, it may be transported inland by onshore winds and is mostly deposited close to the coastline on the beach, as dunes or sand sheets. Variations in tides improve the drying process, but variations in sea-level caused by alternating calm and stormy weather are more important in the areas in question (Klemsdal 1969:60). Precipitation and groundwater may change the pattern to some extent, since dry sediment increases the efficiency of transport (Klemsdal 1969:49).

Storms may come from all directions and the wind speed may also have changed over time, as indicated by Lindanger (1990) and Tørum & Gudmestad (2008: Fig. 22) for the last 150 years. Wind transport of sand particles along the coast and on land may differ in direction from marine transport because the latter is influenced by the form and character of the coastline, the sea currents and the wave strength. Wave refraction and breaking waves change direction across a bay, towards the beach (Tørum 2007:60-64).

On the Jæren coast, waves are the main marine transport agent for sand towards and from the beach, and the height of the water is important for sand-dune erosion on the coast (Tørum 2007:55, see also Jelgersma *et al.* 1970 and Risberg & Björck 1997). Variations in the height of the water are primarily caused by astronomical conditions. The highest sea-level recorded in the area investigated was at Stavanger and was 1.19 m above the average of 65 cm, i.e. 184 cm above present-day sea-level (Tørum 2007:64-65).

Sea-level changes also cause changes in the water table, which influence the water flow in lakes and rivers. This effect has been especially large in flat, low-lying parts of Jæren and may have favoured the accumulation of organic material. In the area investigated, the present-day water table varies on a yearly cycle and irregularly from year to year (e.g. Rein 1977, E. Wishman, pers. comm.). The erosion base was lowered during regressions, bringing about more erosion and transportation of sediments to the coastal rim (Sjulsen 1982:137, Abrahamsen *et al.* 1972, cited from Sjulsen). The flat, sandy plains are known to have formed and been maintained approximately at groundwater level (e.g. Zagwijn 1984). The sediment load in river systems may be deposited close to river mouths along the coast and may be an important source of material for aeolian activity (Klemsdal 1969:62) (see Fig. 7). Thus the river mouths on the Jæren coast may have added to the frequency and amount of aeolian activity during the Holocene sea-level changes.

The complex interaction of various parameters has controlled the Holocene evolution of the Dutch coast (Beets *et al.* 1992). The parameters are wave activity, tides, the rate of sea-level rise and the morphology of the pre-transgression surface. The last-mentioned, in combination with the rate of sea-level rise, has mainly determined the location of sediment sources, while the hydrodynamic parameters have mainly determined the rate and direction of sediment transport. The sedimentation regime along the coast of southwestern Norway is not directly comparable with that on the coast of the Netherlands; in particular, there are differences in the post-deglaciation sea-level displacement, and the tidal regime is very different. Tørum (2007:75) and Tørum & Gudmestad (2008:104) proposed that waves are the main agent bringing sand to the beach on the Jæren coast, whereas the wind takes the particles further inland. Tørum (2007:57) and Tørum & Gudmestad (2008:94, 103) also cited the movement of sand particles by waves at depths as great as 70 metres on the seabed near the Ekofisk Oil Field in the North Sea. The erosive and transporting efficiency of the sea with respect to sand is also influenced by the fetch (the distance over which the wind blows), which is at its maximum along the North Sea coast (see also Elvestad *et al.* 2009).

To sum up, the original sediments of the aeolian deposits derive from both terrestrial and offshore sources, and deposition, erosion and redeposition may have been repeated several times since deglaciation took place.

# Methods

## Lithostratigraphy

Information about the lithostratigraphy was obtained by excavations, drilling with a modified 110 mm piston corer and a 54 mm piston corer, soil augering (Selsing 1987, Selsing & Lillehammer 1987) or from open soil profiles. Aeolian material is generally considered to have uniform grain size and to be well sorted, but it varies within the limit of coarse silt to fine sand, and sorting is better in coastal areas than at sites further inland (Klemsdal 1969:65, Fig. 16, 1979:165).

It is difficult to distinguish between aeolian and marine sand because processes close to the beach generally involve continual movement of sand from the marine to the terrestrial environment and *vice versa* (see e.g. Klemsdal 1979:164-165). It is, however, generally possible to distinguish between the two types of sediments, particularly if winds are predominantly onshore (Shepard & Young 1961). In the near-shore environment, sand is moved from one environment to the other and may be transported from the beach to the dunes and back again, depending upon the wind direction. Each sand grain may have been deposited many times by water and wind before being left in its ultimate environment. Many sand particles in marine sand close to the beach may therefore have participated in aeolian transport, and sorting may have occurred before they reached the processes on the beach.

Dune (aeolian) sand can usually be distinguished from beach sand by grain-size distribution analysis (Friedman 1961). In Jæren, typical marine (beach) sand often has a tail in the granulometric curve in the coarser fractions, whereas typical aeolian sand now and then has a tail of fine material. The aeolian sand is very well sorted in the fine and medium sand fractions, and is better sorted than the marine sand. The two forces which characterise the beach environment, incoming waves and outgoing wash, act in opposite directions removing the finest particles and resulting in a frequency distribution curve which lacks the tail at the fine end of the curve, while dune sand usually contains more silt (Friedman 1961:521, Shepard & Young 1961). Granulometric analyses were carried out at the Salthelleren and Stavanger Airport sites, but the results are not included as they do not provide information about the topics in this paper. The sand sections in the present paper are primarily interpreted by comparing the height above sea-level of the sediment with the sea-level displacement curve.

Records of palaeosols indicate that the deposit remained for some time in an undisturbed state, allowing plant colonisation and soil development to occur (Filion 1984), and the palaeosols developed under generally stable climatic conditions. The presence of a palaeosol in aeolian sand indicates rapid burial of the formerly vegetated surface by sand, because if burial had been slow the soil-forming processes, such as mixing by burrowing fauna, would have been continuous and the organic matter would have been mixed with the overlying sand. Palaeosols, and other organic deposits, are useful for dating, correlations of standstills and reconstructing landscapes and environmental changes.

## Loss on ignition, charcoal and palynological analyses

To obtain a measure of the organic content, loss on ignition (LOI) was determined after the samples were ignited at 550 °C for 2 hrs (Sønstegaard & Mangerud 1977). The results are shown on some of the pollen diagrams as weight per cent LOI.

Charcoal pieces (macroscopic) were determined by Aud Simonsen at the Museum of Archaeology in Stavanger, according to Mork (1966), Grosser (1977), Schweingruber (1978) and Stemsrud (1988). Standard acetolysis treatment was used when preparing the pollen samples (Fægri & Iversen 1975). Palynomorphs were identified using a Zeiss microscope with magnifications of 500x and 750x using phase contrast objectives. The keys for pollen identification were Beug (1961), Fægri & Iversen

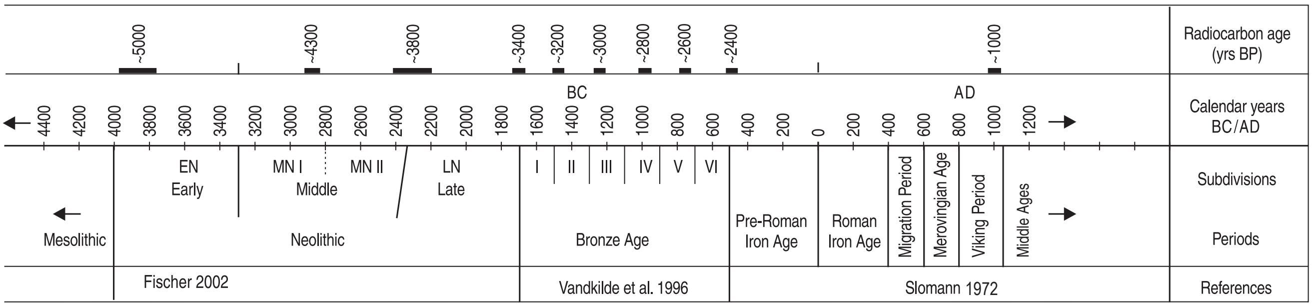


*Fig. 8. The archaeological chronology used in this investigation presented in uncalibrated years BP years and calibrated calendar years BC/AD. Modified from Prøsch-Danielsen & Sandgren (2003: Fig. 4).*

(1975, 1989) and Andersen (1979) for cereal pollen, and Sorsa (1964) and Moe (1974) for monolete and trilete spores, respectively.

The pollen diagrams were plotted using the CORE 2.0 program (Natvik & Kaland 1994). They show percentage values on the basis of a total pollen sum (ΣP). The percentages of spores, algae and charcoal dust particles are based on ΣP+X, where X is the number of the constituent in question. Local pollen assemblage zones (PAZs) are distinguished. The sediment and peat signatures proposed by Fægri & Gams (1937) are used in the left-hand column in the pollen diagrams made by Fægri (1940).

## Chronology

An absolute chronology is established by using $^{14}$C dates of the organic material, thermoluminescence (TL) dates of the inorganic sediments, knowledge of sea-level changes and archaeological typology. Most of the $^{14}$C dates (Table 1) were performed by the Radiological Dating Laboratory in Trondheim, Norway (reference nos. T- ) and reference nos. TUa- denotes collaboration between the laboratory in Trondheim and the Svedberg Laboratory at Uppsala University in Sweden. Dates labelled β were obtained at Beta Analytical Inc., Florida, USA. Thermoluminescence dates were performed at the Risø National Laboratory in Denmark. The chronology is presented in both uncalibrated years BP and calibrated years (before AD 1950) i.e. yrs BP and cal yrs BP. The dates were calibrated by using the Calib Radiocarbon Calibration Program version 5.1 (Calib Rev 5.1 beta) worked out by Minze Stuiver and Paula J. Reimer in 1986-2006 and used in conjunction with Stuiver & Reimer (1993). A and B fractions refer to the NaOH soluble and insoluble fractions, respectively. The chronostratigraphical subdivision follows Mangerud *et al.* (1974). The archaeological chronological subdivision is according to Høgestøl & Prøsch-Danielsen (2006) for the post-Mesolithic period (Fig. 8), where the Neolithic subdivision follows Fischer (2002), the Bronze Age on Vandkilde *et al.* (1996) and the standard Norwegian subdivision of the Iron Age is from Slomann (1972). The Mesolithic subdivision follows Høgestøl (1995) based on Bjerck (1983, 1986): Early Mesolithic 10,000-9000 yrs BP (11,480-10,200 cal yrs BP), Middle Mesolithic: 9000-7000 yrs BP (10,200-7860 cal yrs BP) and Late Mesolithic: 7000-5200/5000 yrs BP (7860-5930/5730 cal yrs BP).

*Table 1. Compilation of radiocarbon dates from investigated and excavated sites relevant to the study of sand drift in Rogaland, southwestern Norway. The radiocarbon dates are presented with one standard deviation (68.2 % probability) in uncalibrated yrs BP (before AD 1950) and calibrated yrs before the present (cal yrs BP) by using the Calib Radiocarbon Calibration Program version (Calib Rev 5.1 beta) (Minze Stuiver and Paula J. Reimer 1986-2006) (Stuiver & Reimer 1993). A and B fractions refer to the NaOH soluble and insoluble fractions, respectively. Abbreviations: asl = above sea-level, max. = maximum, min. = minimum, EN = Early Neolithic, MN = Middle Neolithic, LN = Late Neolithic. AS = A. Simonsen, LPD = L. Prøsch-Danielsen, LS = L. Selsing, VM = V. Mejdahl. * calculated from Skjølsvold (1977).*

| Locality, borough | cm asl | Lab. no. | Age yrs BP ±1 sd | Age cal yrs BP ±1 sd | $\delta^{13}C$ | Dated material | Sample no. | Location of sample | Comments | References |
|---|---|---|---|---|---|---|---|---|---|---|
| Hebnes, Karmøy | About 1000 (calculated) | β-96509 | 1320±60 | 1298-1180 | -27.2 | Charcoal from *Betula*, *Corylus* and *Salix* | 96/637 | Lowest occupation layer in next lowest occupation horizon | Middle to late Merovingian Age | Juhl & Selsing 1997:37 |
| Tunge, Randaberg | 800 | TUa-7250 | 2435±25 | 2665-2363 | -27.3 | *Vaginatum* peat | Tunge 1201 | Below the transition to aeolian sand | | Fægri 1940 (material), this paper |
| Tunge, Randaberg | 755 | TUa-1580 | 3530±60 | 3887-3720 | -27.7 | *Polytricum* peat | Tunge 1209 | | Sand connected to deforestation and heathland establishment | Fægri 1940 (material), LPD & AS 2000 |
| Stavanger Airport, Sola | 848 | TUa-6932A | 770±35 | 724-676 | -28.0 | Palaeosol | 85/303-3 | Layer 7 | In aeolian sand | This paper |
| Stavanger Airport, Sola | 793-791 | T-7042B | 1530±80 | 1517-1351 | -28.4 | Peat top/ palaeosol | 85/303-50 | Profile A, 99.75x/155.75y, layer 7 | In aeolian sand | LS & VM 1994 |
| Stavanger Airport, Sola | 796 | TUa-6931A | 1650±35 | 1606-1520 | -28.0 | Palaeosol | 85/303-8 | Layer 7 | | This paper |
| Stavanger Airport, Sola | 793-791 | T-7042A | 1790±60 | 1814-1628 | -28.7 | Peat top/ palaeosol | 85/303-50 | Profile A, 99.75x/155.75y, layer 7 | In aeolian sand | LS & VM 1994 |
| Stavanger Airport, Sola | 775 | T-6380A | 1820±160 | 1924-1553 | -27.7 (not measured) | Peat bottom/ palaeosol | 85/303-51 | Profile A, 99.75x/155.55y, layer 7 | In aeolian sand | LS & VM 1994 |
| Stavanger Airport, Sola | 687-690 | T-6379A | 2190±80 | 2300-2152 | -29.8 | Lowest palaeosol | 85/443-1 | 115x/144y, layer 7 | Palaeosol covering plough layer, min. age of plough marks | LPD 1993:237, LS & VM 1994 |
| Stavanger Airport, Sola | 672-673 | T-6598 | 2360±60 | 2654-2330 | -27.4 | Peat top, above sand lense, above plough marks | 85/322-10 | Site IV, 114,67x/142y, layer 6 | Min. age plough marks | LPD 1993:237, LS & VM 1994 |
| Stavanger Airport, Sola | 702-704 | T-7045B | 2360±80 | 2688-2313 | -27.7 (not measured) | Peat top | 85/324-29 | | 1st appearance *Spergula arvensis*, other agricultural indicators and charcoal dust | LPD 1993:237, LS & VM 1994 |
| Stavanger Airport, Sola | 702-704 | T-7045A | 2420±70 | 2693-2351 | -29.2 | Peat top | 85/324-29 | Site I at auger coring 1, 90x/100y, layer 6 | 1st appearance *Spergula arvensis*, other agricultural indicators and charcoal dust | LPD 1993:237, LS & VM 1994 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Stavanger Airport, Sola | 652-654 | T-6378A | 2540±80 | 2749-2490 | -27.8 | Peat top | 85/312-10 | Profile B, site VII, 120,75x/138y, layer 6 | Max. age aeolian activity | LS & VM 1994 |
| Stavanger Airport, Sola | 648-649.5 | T-6599A | 2550±70 | 2751-2475 | -27.3 | Peat | 85/312-12 | Profile B, site VII, 120.75x/138y, layer 6 | 1st appearance *Triticum* type | LPD 1993:237, LS & VM 1994 |
| Stavanger Airport, Sola | 725 | T-8226A | 2660±60 | 2844-2742 | -27.0 | Oldest palaeosol | 85/433-6 | Profile A, layer 7 | In aeolian sand | LS & VM 1994 |
| Stavanger Airport, Sola | 768 | T-7044 | 2670±70 | 2850-2743 | -26.1 (not measured) | Roots from *Alnus*/ *Betula* in till | 85/441-20 | Western area, 91.6-91.7x/127.5y, layer 1 | Max. age of marine gravelly silt | LPD dating report Oct.1987 |
| Stavanger Airport, Sola | 815 | TUa-6929A | 2805±40 | 2954-2859 | -27.0 | Palaeosol | 85/303-4 | Layer 7 | In aeolian sand | This paper |
| Stavanger Airport, Sola | 762 | TUa-6930A | 3430±40 | 3818-3632 | -26.6 | Palaeosol | 85/303-12 | Layer 7 | In aeolian sand | This paper |
| Stavanger Airport, Sola | 678-681 | T-6903B | 3450±90 | 3835-3592 | -27.5 | Peat | 85/324-27 | Sonder coring 1, site 1, 90x/100y, layer 6 | 1st appearance *Plantago lanceolata* | LPD 1993:237, LS & VM 1994 |
| Stavanger Airport, Sola | 678-681 | T-6903A | 3510±70 | 3871-3695 | -30.2 | Peat | 85/324-27 | Sonder coring 1, site I, 90x/100y, layer 6 | 1st appearance *Plantago lanceolata* | LPD 1993:237, LS & VM 1994 |
| Stavanger Airport, Sola | 638-640 | T-6890A | 3540±80 | 3920-3702 | -26.9 | Peat bottom | 85/312-11 | Profile B, site VII, 120.75x/138y, layer 6 | Oldest recorded *Plantago lanceolata* | LPD 1993:237, LS & VM 1994 |
| Stavanger Airport, Sola | 584-592 | T-10888 | 3995±180 | 4811-4185 | -25.7 | Astragalus of *Cervus elaphus* (Red Deer) | B490 and B498 | 120x/142y, layer 4 | Bottom marine gravel | LPD 2006 |
| Stavanger Airport, Sola | 570 | β-171185 | 4320±70 | 5029-4832 | -25.0 | Roots from *Alnus glutinosa* | 1987/401-1 | Layer 3 | Upper part layered marine sandy gyttja, roots *Alnus glutinosa* of younger origin | LPD 2006 |
| Stavanger Airport, Sola | 590-595 | T-6601 | 4335±110 | 5266-4729 | -15.6 (without doubt a marine mammal, e.g. seal , S. Gulliksen pers. comm.) | Right astragalus of *Cervus elaphus* (Red Deer) | B225 | Eastern area, 119x/139.7y, top layer 4 | Bottom marine gravel, EN artefacts | LS & VM 1994 |
| Stavanger Airport, Sola | 664-665 | T-7043B | 4360±80 | 5044-4843 | -26.1 | Peat bottom | 85/324-28 | Auger coring 1, site I, 90x/100y, layer 6 | Min. age of sea-level regression, seashore meadow | LPD 1993:237, LS & VM 1994 |
| Stavanger Airport, Sola | 664-665 | T-7043A | 4540±90 | 5430-5045 | -24.1 | Peat bottom | 85/324-28 | Auger coring 1, site I, 90x/100y, layer 6 | Min. age of sea-level regression, seashore meadow | LPD 1993:237, LS & VM 1994 |
| Stavanger Airport, Sola | 754-757 | T-6600 | 4890±100 | 5744-5479 | -26.1 (not measured) | Charcoal of *Salix* & *Betula* | 85/650 | Eastern area, 104.36x/134.9-135y, layer 6 | Peat bottom, MN artefacts | LPD 1993:237, LS & VM 1994 |
| Stavanger Airport, Sola | Upper part | T-6891 | 4930±90 | 5852-5587 | -26.1 (not measured) | Burnt hazelnut shells | 85/649 | Western area, 92x/128y, layer 4 | Top marine gravel, EN artefacts | LPD 2006 |

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|---|---|---|---|---|---|---|---|---|---|---|
| Stavanger Airport, Sola | Upper part | β-171187 | 4950±40 | 5720-5615 | -15.2 | Humerus of *Phoca vitulina* (common seal) | 1985/ B226B | 139x/118y, layer 3 | Upper part layered sandy marine gyttja | LPD 2006 |
| Stavanger Airport, Sola | 561.5-563 | T-6893A | 5480±90 | 6396-6191 | -20.5 | Top layered marine sandy gyttja | 85/316-14 | 121.8x/138y, layer 3 | Min. age Tapes max./Mesolithic | LS & VM 1994, LPD 2006 |
| Stavanger Airport, Sola | Middle part | β-171186 | 6110±40 | 7150-6909 | -23.4 | Teeth of *Sus scrofa* (wild boar) | 1985/ B226A | 139x/118y, layer 3 | Middle part of layered marine sandy gyttja | LPD 2006 |
| Stavanger Airport, Sola | 515-527 | T-6894 | 7080±90 | 7997-7799 | -21.0 | Partly burnt hazelnut shells from bottom layered marine gyttja | B222 | 120x/138y, layer 3 | 1st appearance of people | LS & VM 1994, LPD 2006 |
| Stavanger Airport, Sola | 515-516,5 | T-7022 | 7130±100 | 8040-7837 | -22.0 | Bottom layered marine sandy gyttja | 85/323-23 | 119.6x/138y, layer 3 | Min. age 1st appearance *Malus sylvestris* (wild apple) | LPD 2006 |
| Solavika, Sola, P7 | 1076-1078 | T-5721 | 1170±70 | 1174-985 | -28.2 | Bottom dark-brown peat | 83/205-11 | | Min. age aeolian sand layer | Ugland 1984 unpublished, LS & VM 1994 |
| Solavika, Sola, P7 | 1058-1060 | T-6131 | 4720±70 | 5580-5326 | -27.7 | Top dark-brown peat | 83/205-9 | | Max. age of aeolian sand layer above | Ugland 1984 unpublished, LS & VM 1994 |
| Solavika, Sola, P7 | 1017-1019 | T-5720 | 7120±100 | 8030-7831 | -28.4 | Bottom dark-brown peat above occupation layer | 83/205-10 | | Min. age of occupation layer and marine? sand layer below occupation layer | Ugland 1984 unpublished |
| Solavika, Sola, P9 | 1423-1425 | T-5723 | 100±70 | 265- to -3 | -28.4 | Bottom brown peat with a little sand | 83/206-24 | | Max. age peat containing sand particles | Ugland 1984 unpublished, LS & VM 1994 |
| Solavika, Sola, P9 | 1412-1414 | T-6130 | 1020±60 | 1048-801 | -27.0 | Top dark peat with plant/ wood fragments | 83/206-25 | | Max. age peat containing sand particles | Ugland 1984 unpublished, LS & VM 1994 |
| Solavika, Sola, P9 | 1408-1410 | T-6968A | 1910±80 | 1941-1736 | -29.3 | Dark peat with wood fragments | 83/296-P9 | | | Ugland 1984 unpublished, LS & VM 1994 |
| Solavika, Sola, P9 | 1387-1389 | T-5722 | 4230±50 | 4854-4652 | -28.3 | Bottom dark peat with plant/ wood fragments | 83/206-26 | | Min. age dark sand & gravel | Ugland 1984 unpublished, LS & VM 1994 |
| Solavika, Sola | 155-160 cm below surface | T-5321 | 8500±240 | 9882-9131 | | Burnt hazelnut shells in occupation layer with Mesolithic artefacts | | Gravel & sand (layer 1) | Below T-5720 | Tom H. Haraldsen 1984:17, unpublished |
| Bybergsletten, Sola | 750 | T-7564A | 3380±80 | 3715-3483 | -29.1 | Peat with sand | 82/35 | | Min. age last aeolian phase (correction of a too old date) | Thomsen 1983 unpublished |
| Bybergsletten, Sola | 720-725 | T-6780 | 3930±90 | 4516-4239 | -27.7 (not measured) | Peat with sand | 82/32 | | Max. age aeolian activity, age of forest before decrease | Thomsen 1983 unpublished |
| Bybergsletten, Sola | 525-530 | T-6779 | 4860±50 | 5651-5490 | -27.5 | Peat with sand | 82/27 | | First aeolian activity | Thomsen 1983 unpublished |
| Sele Channel, Klepp | 125-130 | T-6783 | 2790±100 | 3003-2772 | -29.1 | Peat with charcoal | 82/10 | | Min. age regression, human activity close by | Thomsen 1983 unpublished |
| Sele Channel, Klepp | 95 | T-7562A | 11610±280 | 13749-13225 | -27.8 | Gyttja with sand | 82/11 | | Gyttja among stones & gravel in beach sediment correlated with beach ridge, age of transgression which built up the ridge | Thomsen 1983 unpublished |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Sele Channel, Klepp | 35-65 | T-7563A | 11710±240 | 13784-13321 | -27.0 | Freshwater gyttja with sand | 82/16 | | Age of gyttja just below the layer of stones which can be correlated with the beach ridge, max. age of transgression | Thomsen 1983 unpublished |
| Sele Channel, Klepp | 130-135 | T-6782A | 11750±160 | 13756-13431 | -27.7 (not measured) | Gyttja | 82/9 | | Below c. 6 m of sand with peat horizons, max. age of major phase of aeolian activity | Thomsen 1983 unpublished |
| Sele Channel, Klepp | 95 | T-7562B | 11990±230 | 14135-13569 | -28.1 | Gyttja with sand | 82/11 | | See T-7562A | Thomsen 1983 unpublished |
| Sele Channel, Klepp | 35-65 | T-7563B | 12110±330 | 14601-13645 | -27.6 | Freshwater gyttja with sand | 82/16 | | See T-7563A | Thomsen 1983 unpublished |
| Ølstervatn, Sola | 435 | T-6784A | 4560±150 | 5461-4977 | | Gyttja | | | Min. age *Plantago lanceolata* and aeolian activity, max. age deforestation | Thomsen 1983 unpublished |
| Ølstervatn, Sola | 393 | T-7565A | 10160±220 | 12143-11341 | -17.0 | Detrital gyttja | 82/153 | | Age lowest part of detrital gyttja, age of 2nd regression, in Ølstervatn; change from marine to freshwater (diatoms) collected 2 cm from T92 and 2 cm from A9 | Thomsen 1983 unpublished |
| Ølstervatn, Sola | 273-275 | T-7567A | 11370±90 | 13312-13156 | -25.8 | Freshwater gyttja below sand and gyttja (brackish to marine), age of the following transgression | 82/105 | | | Thomsen 1983 unpublished |
| Alvevatn, Klepp | 900 | TUa-7254A | 3030±30 | 3325-3209 | -25.2 | Fine detrital gyttja | 95/300-F | | Cereal cultivation, increase SIRM | This paper |
| Alvevatn, Klepp | 862-868 | T-12550A | 3805±125 | 4408-4006 | -26.0 | Fine detrital gyttja with sand | 95/300-A | | *Calluna* rise | LPD & AS 2000a, 2000b |
| Alvevatn, Klepp | From Fægri 1940, same level as T-12550A | TUa-1577A | 3860±85 | 4412-4157 | | Fine detrital gyttja | | | *Calluna* rise | Fægri 1940, LPD & AS 2000a |
| Alvevatn, Klepp | 855-861 | TUa-1598A | 4315±65 | 4968-4835 | -24.5 | Fine detrital gyttja | 95/300-B | | 1st appearance *Plantago lanceolata*, decrease in AP | LPD & Simonsen 2000a, 2000b |
| Alvevatn, Klepp | 835-837.5 | TUa-2938A | 5410±55 | 6288-6130 | | Fine detrital gyttja | 95/300-E | | Slight anthropogenic erosion | LPD & Sandgren 2003:38 |
| Alvevatn, Klepp | 778-787 | T-12552A | 6545±145 | 7569-7323 | -24.9 | Fine detrital gyttja | 95/300-C | | Rise in QM | LPD & Simonsen 2000a, 2000b |
| Alvevatn, Klepp | 616-617 (713-719) | TUa-1599A | 8145±65 | 9236-9007 | -21.5 | Fine detrital gyttja | 95/300-D | | *Alnus* rise | LPD & Simonsen 2000a, 2000b |
| Hølen, Klepp | 360 | TUa-7251A | 1985±25 | 1985-1896 | -27.9 | Upper gyttja | Hølen 1623 | | Max. age aeolian drift | Fægri 1940, this paper |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Slettabø II, Hå | 730 | TUa-7253A | 435±25 | 514-492 | -28.4 | Palaeosol | 76/P94 | | Start aeolian activity | This paper |
| Slettabø II, Hå | 720 | TUa-7252 | 665±25 | 666-567 | -29.4 | Peat | 76/P95 | | Standstill in aeolian activity | This paper |
| Slettabø I, Hå | 530 | T-2001 | 820±100 | 900-670 | | Raw humus | Ogna 2A | | Max. and Min. age aeolian activity at archaeological site | Simonsen unpublished, Skjølsvold 1977, Selsing 1984 unpublished, LS & VM 1994 |
| Slettabø I, Hå | 530 | T-2002 | 840±110 | 904-677 | | Raw humus | Ogna 2B | | Max. age aeolian sand? at archaeological site | Simonsen unpublished, Skjølsvold 1977, Selsing 1984 unpublished, LS & VM 1994 |
| Slettabø I, Hå | 480 | T-2000 | 1740±90 | 1775-1540 | | Peat | Ogna 1 | | Max. and Min. age aeolian sand at archaeological site | Simonsen unpublished, Skjølsvold 1977, Selsing 1984 unpublished, LS & VM 1994, LPD & AS 2000a |
| Slettabø, Hå | 738-740* | T-740 | 2420±90 | 2697-2350 | | Charcoal | | S13, occupation layer I, 2o 12/14 cm | Early Bronze Age | Skjølsvold 1977:175 |
| Slettabø, Hå | 765-770* | T-629 | 2840±130 | 3142-2793 | | Charcoal | | S13, occupation layer I | Hearth | Skjølsvold 1977:178 |
| Slettabø, Hå | 730* (unclear level) | T-457 | 2850±100 | 3141-2850 | | Charcoal | | S13, occupation layer I, 8c | Early Bronze Age, hearth | Skjølsvold 1977:175 |
| Slettabø, Hå | 730-735* | T-626 | 2900±90 | 3205-2898 | | Charcoal | | S13, occupation layer I, 5l 30-35 cm | Early Bronze Age | Skjølsvold 1977:175 |
| Slettabø, Hå | 783-785* | T-562 | 2900±100 | 3207-2890 | | Charcoal | | S13, occupation layer I, 1h 15-17 cm, | Early Bronze Age | Skjølsvold 1977:175 |
| Slettabø, Hå | 655-645* | T-739 | 3790±70 | 4290-4009 | | Charcoal | | S12, occupation layer II, 5n 10-20 cm | MN IV-V (perhaps also LN) | Skjølsvold 1977:177, 182 |
| Slettabø, Hå | 715-725* | T-628 | 3860±100 | 4418-4104 | | Charcoal | | S12, occupation layer II, 3l 10-20 cm | MN IV-V (perhaps also LN) | Skjølsvold 1977:177, 182 |
| Slettabø, Hå | 785-795* | T-627 | 3970±100 | 4568-4247 | | Charcoal | | S12, occupation layer II, -2j | MN IV-V (perhaps also LN) | Skjølsvold 1977:177, 182 |
| Slettabø, Hå | 670-680* | TUa-652 | 4190±60 | 4837-4627 | -26.1 (not measured) | Food remains in pottery | S9648, 4pII 20/30 | Occupation layer II, S9648, 4pII 20-30 cm | | Glørstad 1996:13 |
| Slettabø, Hå | 690* | T-1780 | 4470±120 | 5299-4966 | | Charcoal | | S11, occupation layer III, 3q III | EN/MN1 or late EN | Skjølsvold 1977:178-179, 182 |
| Slettabø, Hå | 740-750* | TUa-645 | 4575±75 | 5446-5054 | -25.0 (normal for terrestrial food) | Food remains in pottery | S9648, OKII 20/30 | Occupation layer II, 0kII 20-30 cm | | Glørstad 1996:13 |
| Slettabø, Hå | 652* | T-1779 | 4640±130 | 5582-5071 | | Charcoal | | S11, occupation layer III | EN/MN1 or late EN | Skjølsvold 1977:178-179, 182 |
| Slettabø, Hå | 790-805* | T-561 | 4650±100 | 5580-5145 | | Charcoal | | S12, occupation layer II, 0d 0-15 cm | | Skjølsvold 1977:177 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Slettabø, Hå | 700-710* | TUa-646 | 4695±65 | 5575-5322 | -26.1 (not measured) | Food remains in pottery | S9648, 2pII 10/20 | Occupation layer II, 2pII 10-20 cm | | Glørstad 1996:13 |
| Slettabø, Hå | 640-650* | T-738 | 4730±100 | 5583-5326 | | Charcoal | | S11, occupation layer III, 4q (p?)III | EN/MN1 or late EN | Skjølsvold 1977:178 |
| Slettabø, Hå | 750* | T-560 | 4780±130 | 5642-5323 | | Charcoal | | S10 (below layer S11), -1a | Charcoal flake in sand below occupation layer III | Skjølsvold 1977:178 |
| Slettabø, Hå | 720-730* | TUa-649 | 4785±70 | 5597-5334 | -26.1 (not measured) | Food remains in pottery | S9648, 2jII 0/10 | Occupation layer II, 2jII, 0-10 cm | | Glørstad 1996:13 |
| Slettabø, Hå | 658-660* | T-1803 | 4820±180 | 5740-5319 | | Charcoal S11 | | Occupation layer III, 0nIII | EN/MN1 or late EN | Skjølsvold 1977:178 |
| Slettabø, Hå | 785-795* | TUa-647 | 4845±80 | 5658-5472 | -26.1 (not measured) | Food remains in pottery | S9648, OCII 10/20 | Occupation layer II, 0cII 10-20 cm | | Glørstad 1996:13 |
| Slettabø, Hå | 660* | TUa-648 | 4940±65 | 5727-5602 | -26.1 (not measured) | Food remains in pottery | S9648, 2pIII | Occupation layer III, 2pIII | | Glørstad 1996:13 |
| Slettabø, Hå | 685-695* | TUa-650 | 5080±65 | 5906-5748 | -26.1 (not measured) | Food remains in pottery | S9648, 2pII 30/40 | Occupation layer II, 2pII 30-40 cm | | Glørstad 1996:13 |
| Slettabø, Hå | 640-650* | TUa-651 | 5305±80 | 6188-5955 | -26.1 (not measured) | Food remains in pottery | S9648, 4pIII | Occupation layer III, 4pIII | | Glørstad 1996:13 |
| Salthelleren, Hå | 724-726 | T-5114A | 2340±70 | 2652-2184 | -28.7 | Top carr peat | 83/400-39A | | Max. age aeolian activity, age of deforestation/ human activity, heath establishment | Selsing 1984 unpublished, Skar Christiansen 1985 unpublished, LS & VM 1994 |
| Salthelleren, Hå | 702-704 | T-5115A | 3430±80 | 3826-3585 | -30.5 | Bottom carr peat | 83/400-38A | | Min. age aeolian sand, start of deforestation | Selsing 1984 unpublished, Skar Christiansen 1985 unpublished, LS & VM 1994 |
| Salthelleren, Hå | 693.5-701.5 | T-5116A | 4150±90 | 4825-4577 | -29.4 | Palaeosols in aeolian sand | 83/401-4 | | Standstills in aeolian activity | Selsing 1984 unpublished, Skar Christiansen 1985 unpublished, LS & VM 1994 |
| Salthelleren 2, Hå | 600-850 | T-3589 | 5460±90 | 6395-6128 | -26.1 (not measured) | Charcoal of *Pinus* and *Quercus* | Sample 7 | 23x/7y, top occupation layer 2, 0-5 cm | LM artefacts | Skar Christiansen 1985 unpublished, LS & VM 1994 |
| Salthelleren 2, Hå | 700-850 | T-3588 | 5470±130 | 6406-6026 | -26.1 (not measured) | Charcoal of *Pinus* | Sample 3 | 23x/4y, bottom occupation layer 1, 0-5 cm | LM artefacts | Skar Christiansen 1985 unpublished, LS & VM 1994 |
| Salthelleren 2, Hå | 600-850 | T-3590 | 6110±90 | 7156-6891 | -26.1 (not measured) | Charcoal of *Pinus* and *Quercus* | Sample 14 | 21x/9y, occupation layer 2, 10-15 cm | LM artefacts | Skar Christiansen 1985 unpublished |
| Salthelleren 2, Hå | 600-850 | T-3591 | 6470±100 | 7460-7279 | -26.1 (not measured) | Charcoal of *Pinus* | Sample 10 | 21x/7y, bottom occupation layer 2, 15-20 cm | LM artefacts | Skar Christiansen 1985 unpublished, LS & VM 1994 |

# Results

The results from the sites are presented from the north (area A) to the south (area C), but most sites in this paper are in areas B and C: Solavika, Stavanger Airport, Sele Channel, Bybergsletten, Ølstervatn, Slettabø and Salthelleren (Fig. 1). Solavika, Stavanger Airport, Slettabø and Salthelleren are archaeological sites located in the Holocene sea-level fluctuation zone (Fægri 1940, Thomsen 1982a, Bird & Klemsdal 1986, Bang-Andersen & Thomsen 1993, Prøsch-Danielsen 2006a) on the smooth plains of aeolian sand inland from the dune area.

## Area A

Western and southern Karmøy has shell sand and other marine deposits (Lundberg 1997:6-8), which are the sources for aeolian deposits. The shell sand originates from banks off Karmøy (Lundberg 1997:9, 2008). The largest areas of aeolian sand are shown in Fig. 9.

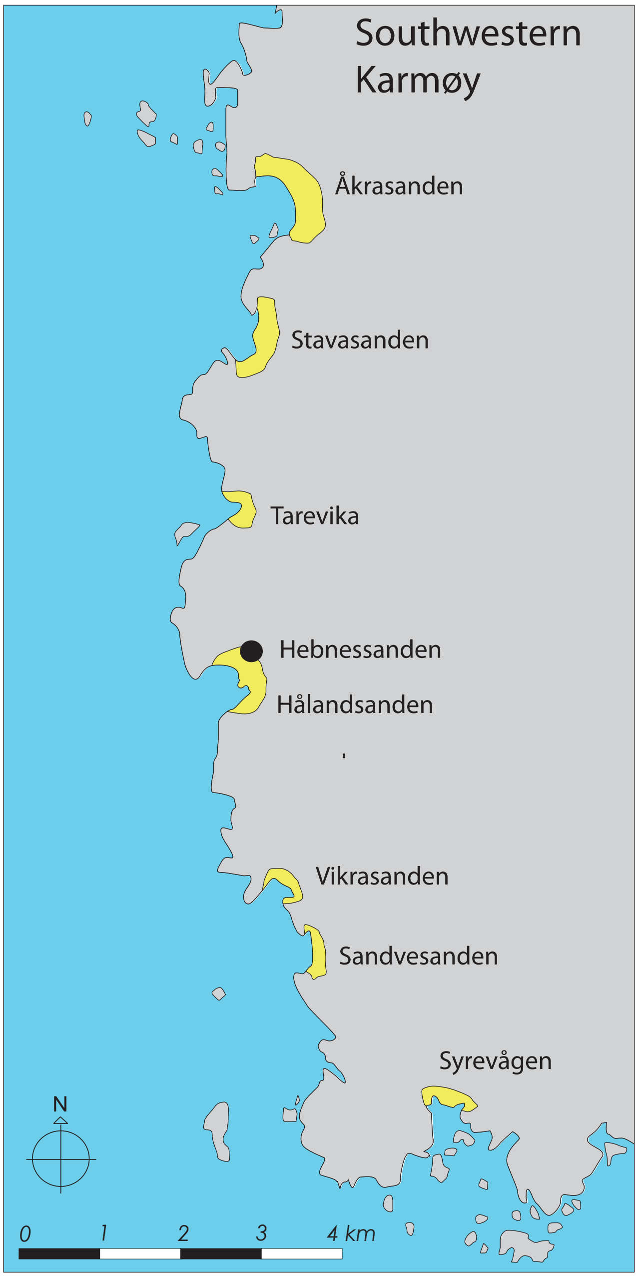



*Fig. 9. Areas with aeolian deposits in southwestern Karmøy, southwest Norway. The investigated site, Hebnes, is marked (black dot). Redrawn from Lundberg (1997: Fig. 1).*

### 1. Hebnes

The investigation of an archaeological site at Hebnes on southwestern Karmøy, c. 11-12 m asl, was required under the terms of the Norwegian Cultural Heritage Act and was carried out by Kirsten Juhl and Lotte Selsing (Juhl & Selsing 1996, 1997, Selsing 1996b). The site is located close to the coast in an area covered by aeolian sand which goes under the name of Hebnessanden-Hålandsanden. A preliminary investigation was carried out in 1996. The sea-level displacement curve constructed for the area east of Karmøy by Lindblom *et al.* (1997) was modified and used for Hebnes (Fig. 10).

The site is located among rock outcrops surrounded by sporadic and discontinuous sediments (Fig. 11) about 200 m from the sandy bay of Hebnessanden on the North Sea coast. It is situated on a gentle south-facing slope on the end of an east-west terrace built up of sediments that were probably deposited during the deglaciation since the terrace is located above the maximum Holocene sea-level. About 40 m below the terrace is a small rock outcrop, which may have attracted the people to settle just there (Juhl & Selsing 1996, 1997). Aeolian sediments have shaped the landscape, and sand drift is still in progress.

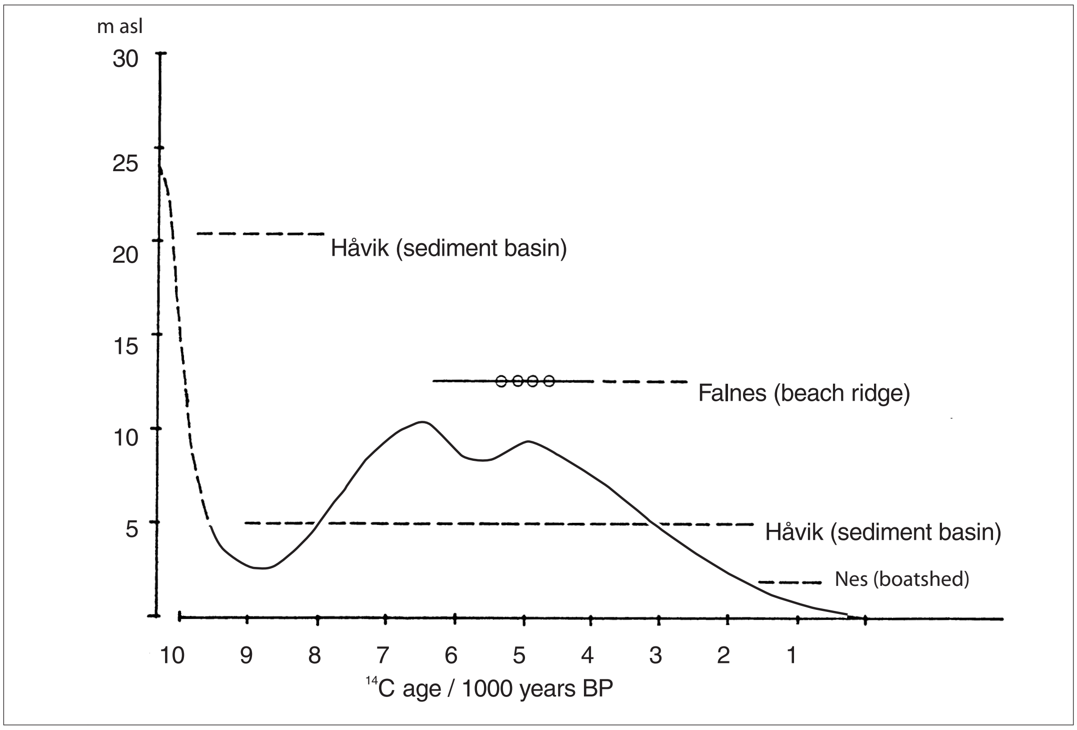



*Fig. 10. Sea-level displacement curve outlined for the eastern part of Karmøy, southwest Norway. Modified from Lindblom et al. (1997: Fig. 20).*

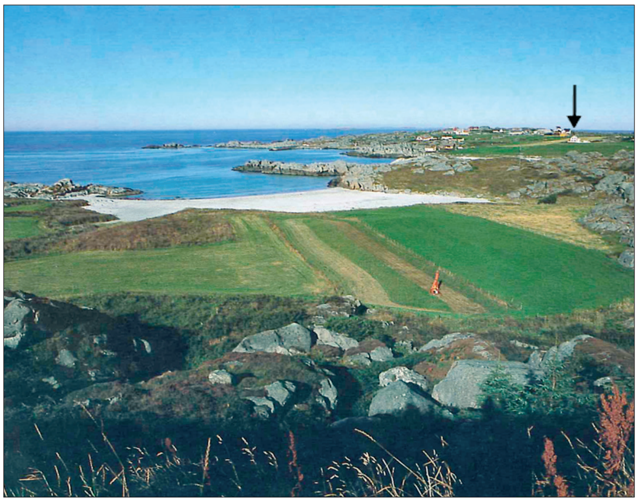


*Fig. 11. Hebnes is in the southwestern part of the island of Karmøy, north of Boknafjord. The site is close to the house on the right-hand side of the photograph (Lundberg 1997: Fig. 7).*

### *Lithostratigraphy and chronology*

The lithostratigraphical record is, in general, from top to bottom:

Layer 4: modern plough layer
Layer 3: aeolian sand, 0-80 cm
Layer 2: 3 or 4 occupation horizons containing aeolian sand, separated by aeolian sand, 80-155 cm
Layer 1: sand (aeolian, beach or marine sand), 155-350 cm

The complicated stratigraphy (Juhl & Selsing 1996, 1997) (Fig. 12) typically had three or four occupation horizons (several thin occupation layers, Juhl & Selsing 1997:34) on aeolian sand with a large amount of unburnt bones, charcoal and fire-cracked stones. The occupation horizons were sealed by up to 80 cm of overlying aeolian sand. These horizons, located 80-155 cm below the surface, were intercalated with aeolian sand containing many calcareous shells and fragments of shells which created good preservation conditions for the bones. This intercalation of sand and occupation layers indicates that aeolian activity also took place during the habitation periods.

All the layers contained bones, but those in the aeolian sand were scattered and fragmented (Juhl & Selsing 1996:35). The osteological material was identified by Perdikaris (2009). Most of the bones indicate exploitation of fish resources and animal husbandry. No wild mammals were identified, but there were sparse bird bones and some mollusc, mussel and snail shells. Some shells of common limpet (*Patella vulgate*) had been deliberately broken, indicating that limpets formed part of the diet of the inhabitants. The people inhabiting the Hebnes site thus principally based their economy on fishing, animal husbandry and collecting shellfish. The homogeneous impression given by the occupation layers suggested that they were perhaps formed during a short period (Juhl & Selsing 1997:37).

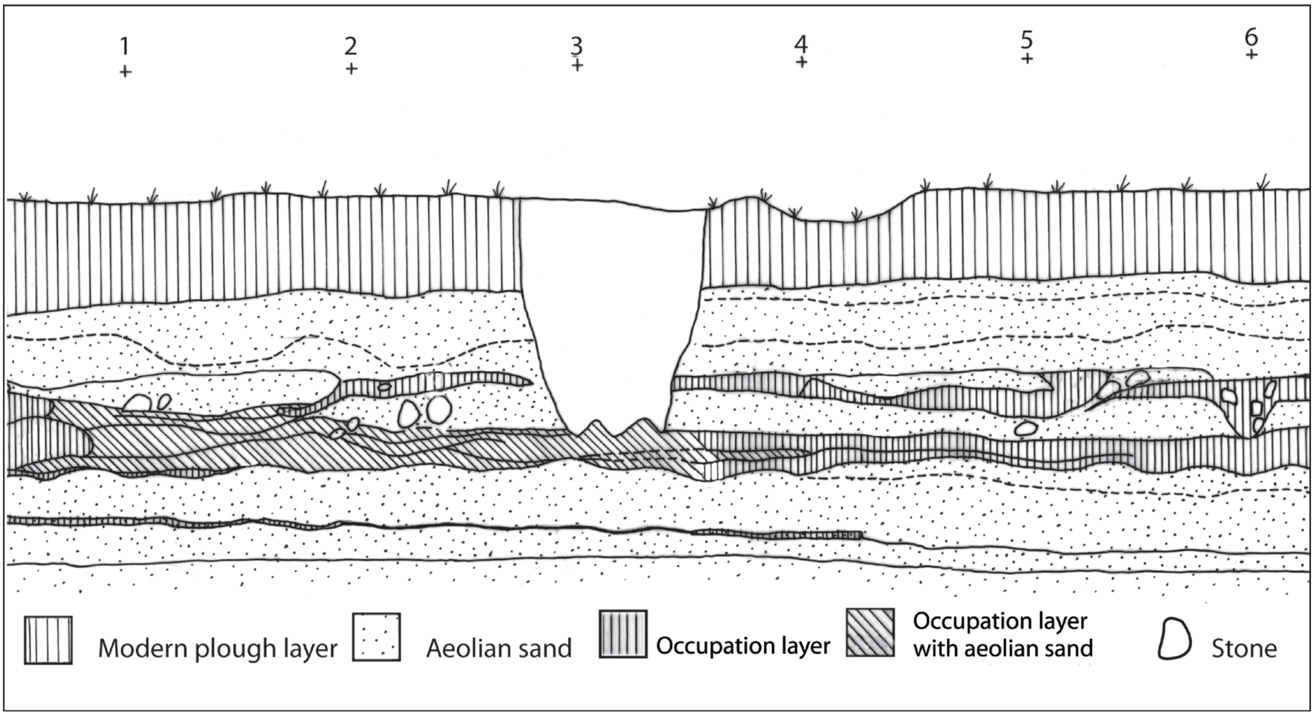



*Fig. 12. The lithostratigraphy at Hebnes along the northern profile. Drawing: Brynjar Sandvoll, traced by Astrid Hølland Berg (Modified from Juhl & Selsing 1997:37).*

Aud Simonsen identified the species of charcoal from two samples from the occupation layers. A sample comprised of *Corylus*, *Betula* and *Salix* fragments from the next lowest occupation horizon was radiocarbon dated to 1320±60 yrs BP (1298-1180 cal yrs BP, β-96509) (Kirsten Juhl, pers. comm.). This showed that the area was occupied during the Merovingian Period (AD 600-800), and implies that aeolian activity both pre- and postdates this date.

Plough marks with traces of several ploughings (Fig. 13) indicate that part of the site was a well-established field (Juhl & Selsing 1996:36). They were covered by the upper aeolian sand, which sealed the occupation horizons all over the site. However, they occurred at a level corresponding to the lower limit of the upper occupation horizon and cut down into the aeolian sand below where that horizon should have been (younger than the radiocarbon date, see below). The question is whether the plough marks are older or younger than the last occupation horizon. As the base of the upper occupation

*Fig. 13. Plough marks of presumed prehistoric age at Hebnes on Karmøy, formed after the site was abandoned (Juhl & Selsing 1997:35).*

horizon was cut by plough marks at one place, it seems reasonable that the field was cultivated for the first time after the site was abandoned by the people who left the occupation horizons and before (or at the same time as) the last aeolian activity started (Juhl & Selsing 1997:36).

The sand comprising the aeolian deposits may have originated in the deglaciation sediments, shell sand or other offshore sediments transported by wind blowing predominantly from two directions in this area.

*Discussion*

The maximum Holocene shoreline was situated about 9 m above present sea-level around 7000 yrs BP (7860 cal yrs BP) (Fig. 10). The lower sand layer (layer 1) may therefore be of marine origin. However, the age is probably younger than this marine event and indicates that at least the upper part of the sand below the occupation horizons (layer 2) may have been of aeolian origin. There was no visible difference between the lower and upper parts of this sand layer.

The sample for the radiocarbon date was collected from the next lowest occupation layer and gives a minimum age of the first aeolian activity; i.e. the sand drift is older than c. 1400 yrs BP (1300 cal yrs BP). The lithostratigraphy implies that aeolian activity was more or less continuous during the habitation period.

The vicinity of the sea indicates that the aeolian activity may have been triggered by natural processes like high wind speed and unprotected sand on and close to the beach. However, the people and their livestock may have contributed by removing the vegetation and destroying the soil cover. The last sand drift may be the consequence of intensive cultivation.

## 2. Tunge

Several soil profiles on the Randaberg peninsula in the northern part of Jæren (see Figs. 1 and 14) were investigated in the 1930s (Fægri 1940:83-84). One of these localities was Tunge, and the soil profile was situated just inside a beach ridge at 9 m asl.

*Lithostratigraphy and chronology*

The stratigraphy was as follows, from top to bottom (Fig. 15):

Layer 4: aeolian sand (0-100 cm)


*Fig. 14. Aerial view of Tunge (to the right), Tungenes, and the beach in Sandebukta. The modern beach ridge, Børaunen, is in the foreground. Photo: Norsk fly og flyfoto.*

Layer 3: *Vaginatum* peat (sedges) with sand particles in the lower 5 cm (100-150 cm)
Layer 2: *Polytrichum* peat (moss) (150-250 cm)
Layer 1: marine sand (250-? cm)

The pollen diagram shows locally influenced vegetation, especially between 2.1 and 1.5 cm (Fig. 16). According to Fægri (1940), this extended through the late Atlantic (IX), Subboreal (X) and Subatlantic (XI) pollen zones. Fægri placed emphasis on the occurrence of the *Ulmus* maximum in the lower part of the diagram, which he placed in the early Subboreal pollen zone. He also recognised a sudden change from forest vegetation to heathland at 145 cm. Sand particles were recorded at the same level. Fægri (1940:63) attributed the deforestation to a catastrophic deterioration in the climate about 2500 years ago, and placed this at the transition between the Subboreal (X) and the Subatlantic (XI) pollen zones. However, this study was carried out before radiocarbon dating was introduced in the 1950s.

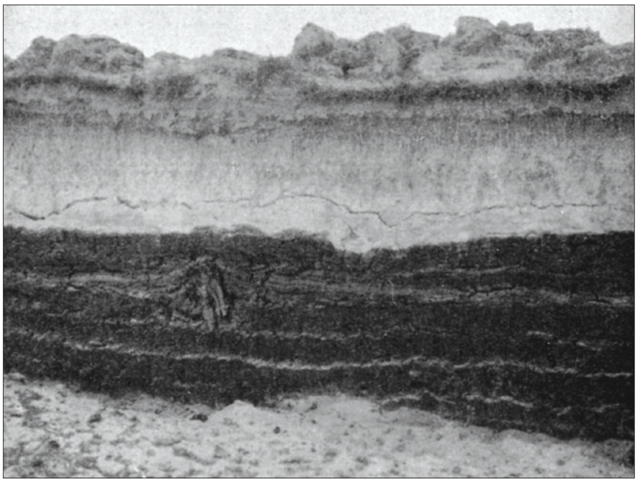


*Fig. 15. The stratigraphical section at Tunge on the Randaberg peninsula in northern Jæren (Fægri 1940:84, Fig. 7).*

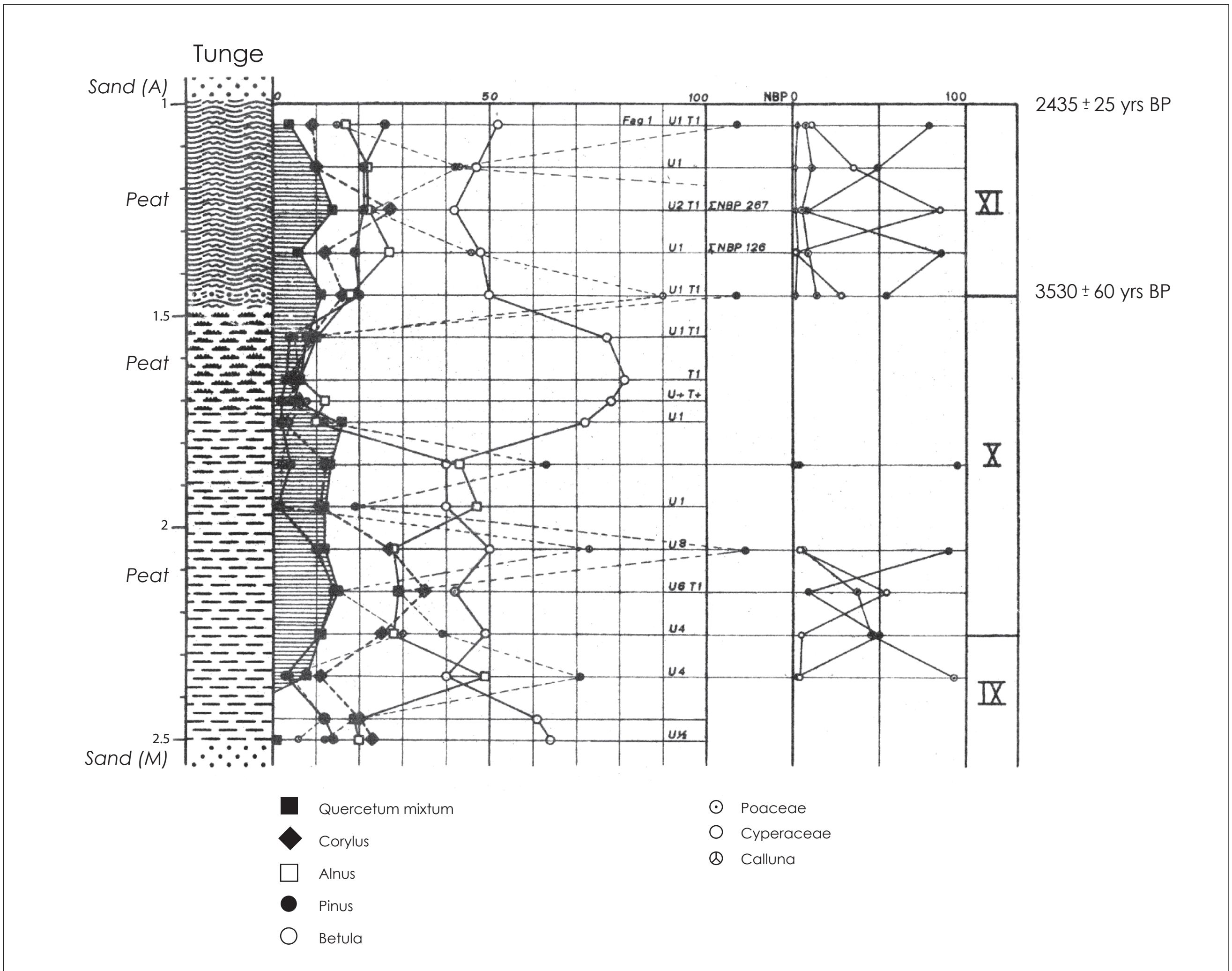



*Fig. 16. The pollen diagram from Tunge on the Randaberg peninsula in northern Jæren (Fægri 1940, with new radiocarbon dates added).*

Prøsch-Danielsen & Simonsen (2000a) were subsequently able to date this deforestation and found that it took place as early as 3530±60 yrs BP (3887-3720 cal yrs BP, TUa-1580) (Table 1 and Fig. 16), corresponding to the transition between the Late Neolithic and the Early Bronze Age. This early deforestation is verified in the pollen diagram for Bø on the Randaberg peninsula by the date 3885±90 yrs BP (4422-4157 cal yrs BP, TUa-1578A) (Prøsch-Danielsen & Simonsen 2000a:31). It is interesting to note that *Plantago lanceolata* appears simultaneously with the deforestation. The first appearance of sand particles (at a depth of 145 cm) is thus connected to human impact and a change in land-use involving traditional heathland management.

The *Vaginatum* peat, and the associated heath vegetation, is sealed by up to 100 cm of aeolian sand. The peat immediately below the transition to the aeolian sand has been dated as part of this study to 2435±25 yrs BP (2665-2363 cal yrs BP, TUa-7250). This gives the maximum age and start of sand drift in the area.

The source material of the aeolian deposits is probably the extensive marine shore deposits around the site transported by wind from two dominating directions.

**3. Sunde**

The archaeological excavation at Sunde 34 was required under the terms of the Norwegian Cultural Heritage Act and was carried out by Helge Braathen in 1979 (Braathen 1985) together with Hanne Thomsen (sea-level investigations, Thomsen 1982b, see also Prøsch-Danielsen 2006a), Lotte Selsing and Asbjørn Simonsen (palynological analysis, see Braathen 1985). Sunde is on the northern bank of the narrow inlet of Hafrsfjord on the southwest side of the Stavanger peninsula (Figs. 1 and 17). The occupation layer was located below a beach ridge situated 9-10 m asl.

The stratigraphy at Sunde augmented the proposed sea-level displacement curve for the area (Fig. 18). The lithostratigraphy through the beach ridge was described from a trench, from top to bottom (Fig. 19) (Thomsen 1982b:168, Braathen 1985:23-29):

*Fig. 17. The Sunde site (black arrow) is on a southwest-facing slope protected by a beach ridge at the mouth of Hafrsfjord on the Stavanger peninsula (Braathen 1985: Fig. 4).*

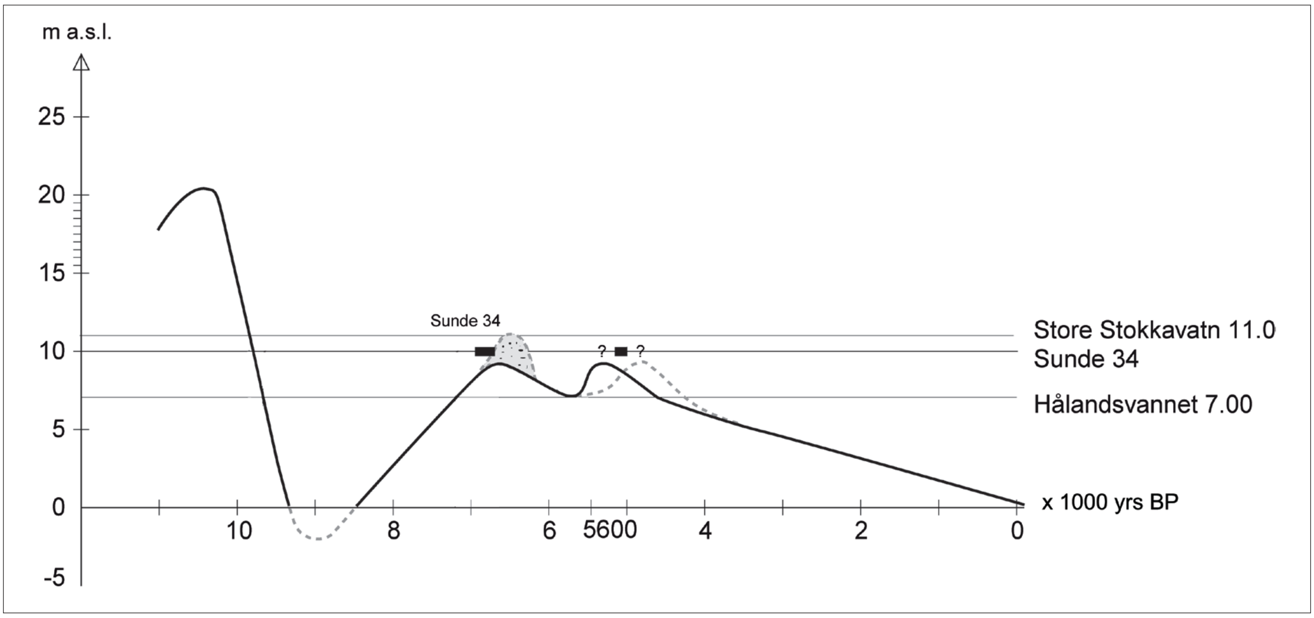



*Fig. 18. The site, Sunde 34, added to the proposed sea-level displacement curve for the area. Modified from Prøsch-Danielsen (2006a: Fig. 43).*

Layer 8: modern plough layer
Layer 7: aeolian sand which seals layer 6 and partly layer 5
Layer 6: sandy beach ridge sediments with gravel and stones
Layer 5: occupation layer, with a sand wedge
Layer 4: pockets of aeolian sand below parts of the occupation layer
Layer 3: carr peat partly below layer 4 and partly below layer 5
Layer 2: marine sand
Layer 1: till

Layer 2 – The coarse, blue-grey marine sand was stratified to the north (onshore) and probably was deposited during the Preboreal regression, about 10,000-9000 yrs BP (11,360-10,200 cal yrs BP).

Layer 3 – The carr peat contained bits of wood and, in the upper part, flint artefacts and fragments of hazelnut shells. The upper part of the peat has been dated to 8260±320 yrs BP (9540-8729 cal yrs BP, T-3716). The settlement phase, however, is younger than the peat (6900-6600 yrs BP, 7710-7490 cal yrs BP, Braathen 1985:94), indicating that human activity during the settlement phase occurred on the older peat and/or when the peat was being formed.

Layer 4 – Pockets of sand covered parts of the peat and underlay parts of the occupation layer. The sand resembled aeolian sand and lacked signs of human activity (Braathen 1985:26). It is probably an aeolian deposit formed of sand blown from the nearby seashore (Thomsen 1982b). It is younger than 8200 yrs BP (9170 cal yrs BP) and probably older than 6900 yrs BP (7710 cal yrs BP).

Layer 5 – The occupation layer consisted of grey sand with charcoal, burnt hazelnut shell fragments and Mesolithic artefacts (microblades). A sand layer, probably of aeolian origin and originating in layer 4, divided the occupation layer in the southwestern part (towards the beach) in an upper and lower part; the people probably lived on aeolian sand. The results of four radiocarbon dates were 6910±100 yrs BP (7911-7660 cal yrs BP, T-3536 – burnt hazelnut shell fragments), 6710±240 yrs BP (7832-7334 cal yrs BP, T-3535 – charcoal of Rosaceae), 6600±110 yrs BP (7574-7422 cal yrs BP, T-3715 – charcoal of *Betula* and/or *Alnus* from hearth 1 underneath stones) and 4930±210 yrs BP (5917-5333 cal yrs BP, T-3714 – charcoal of *Betula* and/or *Corylus* among stones in hearth 1. There is a time lag of about 1300 yrs BP (1230 cal yrs BP) between the top of the peat layer and the oldest date of the occupation layer.

Both Braathen (1985) and Bang-Andersen (1995)

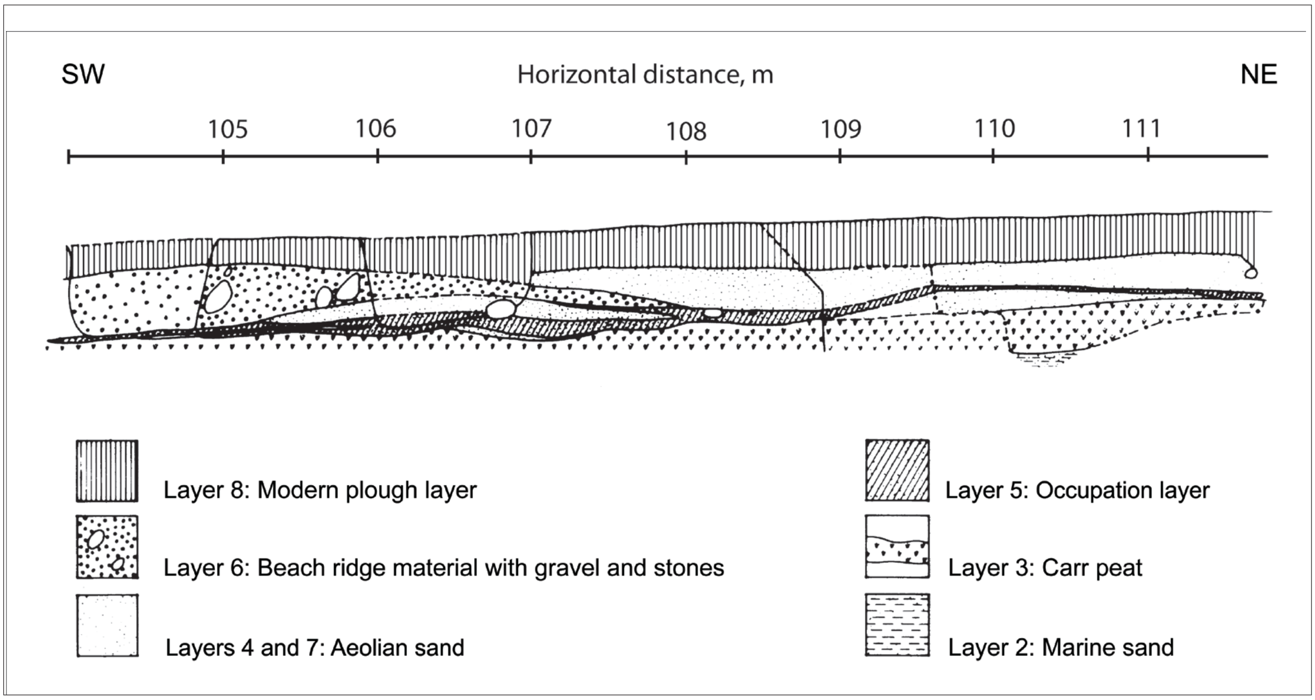



*Fig. 19. The lithostratigraphy through the beach ridge at Sunde. Modified from Thomsen (1982b: Fig. 13).*

interpreted the youngest date to be incorrect because they assumed that the settlement period was relatively short, possibly two hundred years or so, since only a small number of the artefacts were water-rolled and patinated. Early Neolithic elements were, however, present in the artefact assemblage all over the site mixed with the Mesolithic artefacts and obviously situated beneath the beach ridge sediments like the material for the youngest radiocarbon date (see Braathen 1985, see also Prøsch-Danielsen 2006a:49-50). This indicates an additional Early Neolithic habitation phase pre-dating the youngest Tapes transgression and giving the maximum age of the regression.

The storm level must have been lower than 9.5 m asl during the habitation phase, 6900-6600 yrs BP (7710-7490 cal yrs BP). The available data also imply that the maximum transgression must be younger than 6600 yrs BP (7490 cal yrs BP). The shoreline possibly remained at 9-10 m asl for more than 1000 calendar years, but the youngest Neolithic habitation elements may have been exposed to a second marine event which moved beach deposits and aeolian sand containing both the Mesolithic and the Neolithic artefacts up the slope. To sum up, one, probably two, strictly shore-bound and transgressed sites occurred at Sunde, as supposed by Prøsch-Danielsen (2006a).

Layer 6 – The sandy beach ridge sediments with gravel, stones and artefacts sealed layer 5 in the southwestern part of the trench.

Layer 7 – Yellow to white aeolian sand sealed layer 5 in the northeastern part of the trench. Considering the two dominating wind directions, the source material for this deposit may have been offshore, from the Hafrsfjord area, or from the till around the site.

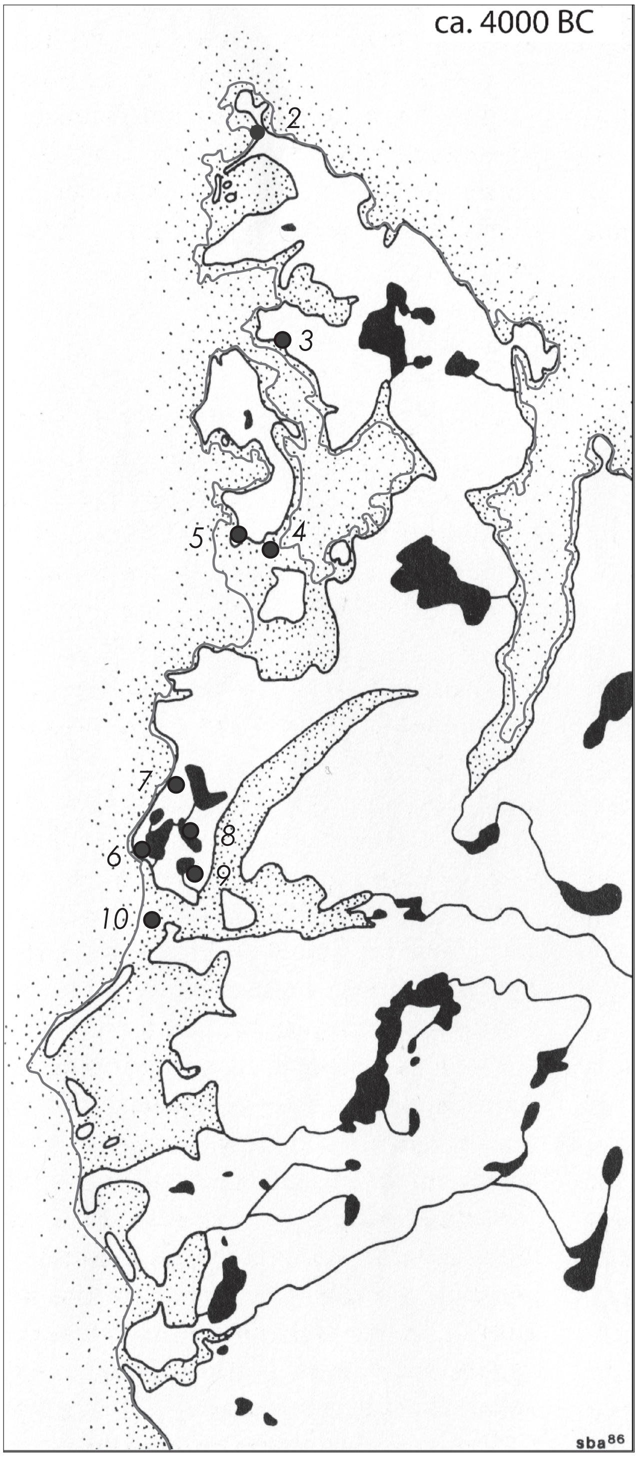



*Fig. 20. The landscape in Jæren about 6500-5000 yrs BP (7430-5730 cal yrs BP) during the Holocene transgressions when fjords and inlets dominated the coastal area. Black = lakes. The coast is reconstructed at the present 10 m asl contour in the north and the present 7.5 m asl contour in the middle and south. The present shoreline is also shown (Bang-Andersen 1986:63). 2-10: localities presented and discussed in this paper.*

*Discussion and conclusion*

The pockets of sand (layer 4) indicate limited aeolian activity between 8200 yrs BP (9170 cal yrs BP) and 6900 (4900) yrs BP (7710 (5620) cal yrs BP). Information is too inadequate to date this early aeolian event more precisely. The period spanning 8200-4900 yrs BP (9170-5620 cal yrs BP) is characterised by a slowly transgressing sea-level with an early peak at 6500 yrs BP (7430 cal yrs BP), followed by a regression and a younger peak at about 5200-4800 yrs BP (5930-5540 cal yrs BP). The sandy sediment forming the matrix of the occupation layer indicates that people settled on an aeolian deposit, remnants of which occur as the pockets of sand below the occupation layer. These are most probably older than the beginning of the

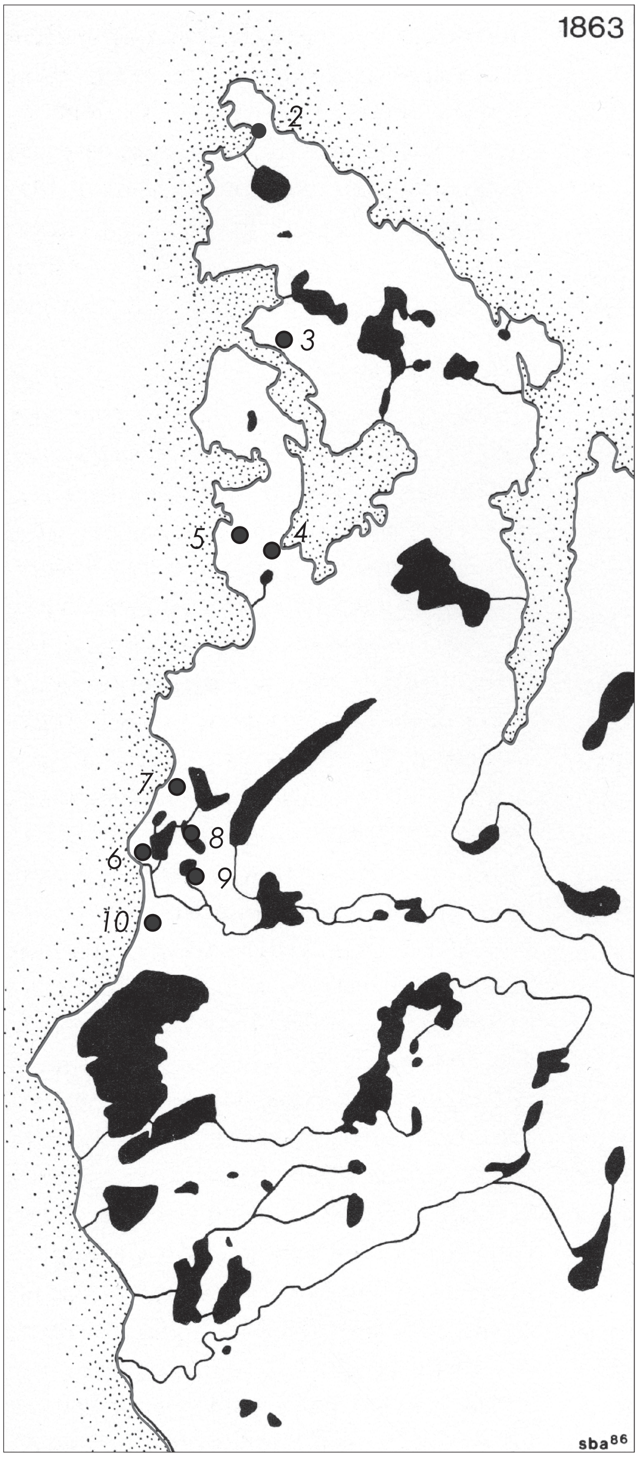



*Fig. 21. The coastline and lakes (black) in 1863, before many of the lakes were drained in the 1860s (Bang-Andersen 1986:61).*

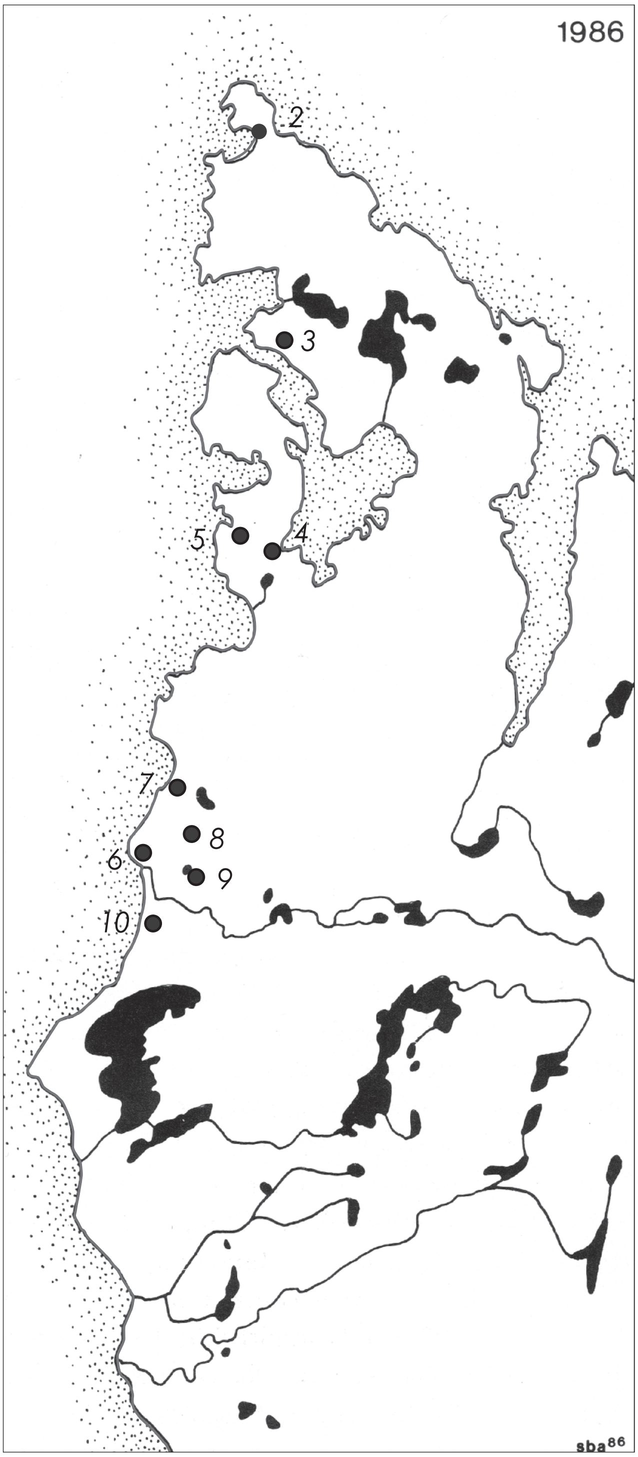



*Fig. 22. When compared with Fig. 21, this map shows the lakes that have been partially or entirely drained. During and after the draining, the sediments that lacked a vegetation cover were subjected to aeolian drift in the last part of the 19th century (Bang-Andersen 1986:56).*

settlement (6900 yrs BP, 7710 cal yrs BP), when the rising sea was close to the oldest peak level and the shore was close to the settlement site. The sand wedge within the occupation layer confirms that aeolian activity continued during the oldest period of settlement.

The sandy beach ridge sediments with gravel, stones and artefacts (layer 6) sealed the occupation layer in the southwestern part of the trench, indicating that they are at least partly younger than the occupation layer and probably younger than 4900 yrs BP (5620 cal yrs

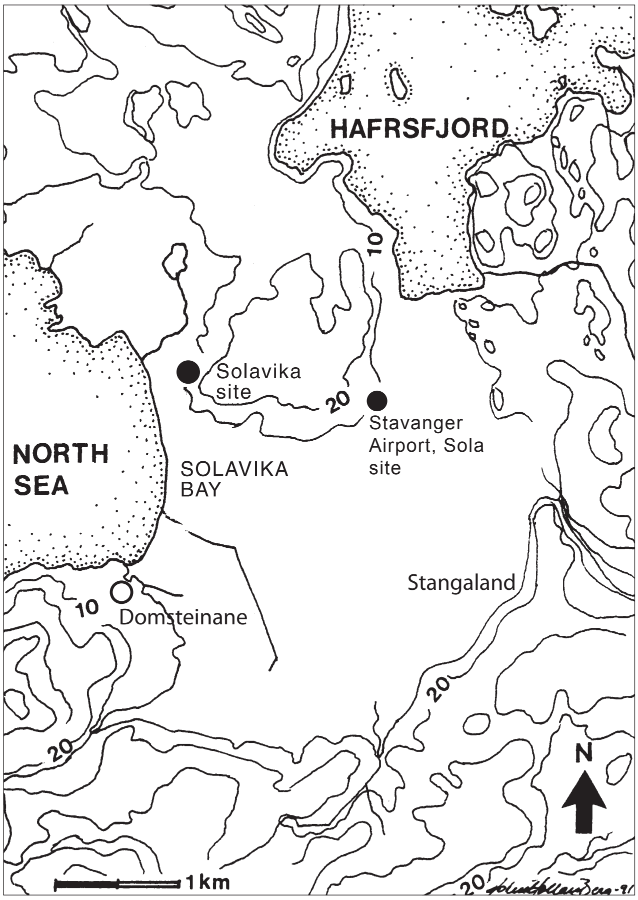



*Fig. 23. Location map of sites in the Solavika area, west of Stavanger. Modified from Selsing (1987: Fig. 1b).*

BP). However, it cannot be said whether the beach ridge in the Sunde area was built up during both or just one of the Holocene transgression maxima.

The upper aeolian sand (layer 7) sealed the occupation layer in the northeastern part of the trench and is probably younger than 4900 yrs BP (5620 cal yrs BP).

Aeolian activity on the slope at Sunde probably occurred more or less continuously from 8200 yrs BP (9170 cal yrs BP) to after 4900 yrs BP (5620 cal yrs BP), caused by strong onshore winds from the nearby sandy seashore that lacked a vegetation cover. Settlement activity in about 6900-6600 yrs BP (7710-7490 cal yrs BP) and during the Early Neolithic may have accelerated the sand drift.

## Area B

Along the Jæren coast, glacial deposits have been reworked by the sea to form sandy beaches, which provide the main source material for the aeolian deposits (Klemsdal 1969:62). To understand the factors shaping the beaches, it is necessary to bear in mind that sea-level fluctuations throughout the Holocene have dramatically changed this low-lying landscape.

In the period when the sea-level displacement curve shows a double-peaked Tapes transgression (Fig. 5), the Jæren landscape differed from the present one in having fjords and inlets (compare Fig. 20 with Figs. 21 and 22, where Fig. 22 shows the changes from 1860 to 1920). In this period, the majority of the lakes in Jæren had their water level lowered or were drained completely as part of a large-scale project to expand agricultural areas. At the same time, boggy areas and heaths were put under the plough (Sommerschield 1912, Stavanger Aftenblad 1980, Bang-Andersen 1986). The exposure of large areas of sand resulted in aeolian activity.

### 4. Stavanger Airport, Sola

This investigation, on the site of a projected road leading to a new airport terminal building southwest of Stavanger (Fig. 1), was undertaken in 1984-1985 to comply with the terms of the Norwegian Cultural Heritage Act. The excavation was carried out by an interdisciplinary group of researchers: Birgitte Skar and Arnvid Lillehammer (archaeology), Lotte Selsing (Quaternary geology), Lisbeth Prøsch-Danielsen (palynology) and Erik Wishman (meteorology).

The excavation revealed five phases of human activity sealed beneath thick layers of aeolian deposits (Prøsch-Danielsen & Selsing 1985, Skar 1985a, 1985b, Selsing *et al.* 1988, Prøsch-Danielsen 1993, Selsing & Mejdahl 1994). Late Mesolithic and Early and Middle Neolithic artefacts and ecofacts were found in marine gyttja and gravel. The two youngest occupation phases were only identified by palynological analysis of peat resting on a sand layer in the marine sequence. Some Middle Neolithic artefacts found in this peat initially caused dating problems, but an intersecting pattern of plough marks was seen to penetrate the peat. This observation solved the dating problems and extended the span of human activity at the site to the Late Bronze Age. Special attention was directed at solving chronological problems concerned with the archaeological material, the bio- and lithostratigraphy in the soil profiles and changes in sea-level (Skar 1985a, 1985b, Selsing 1987, Prøsch-Danielsen 1993, 2006a, Selsing & Mejdahl 1994).

Stavanger Airport occupies part of the largest aeolian plain in the Jæren region and is located east of the sand dunes in the bay at Solavika and south of Hafrsfjord (Wangen *et al.* 1987) (Fig. 23). Observations from about 1900 until the airport was built in 1937 show that the

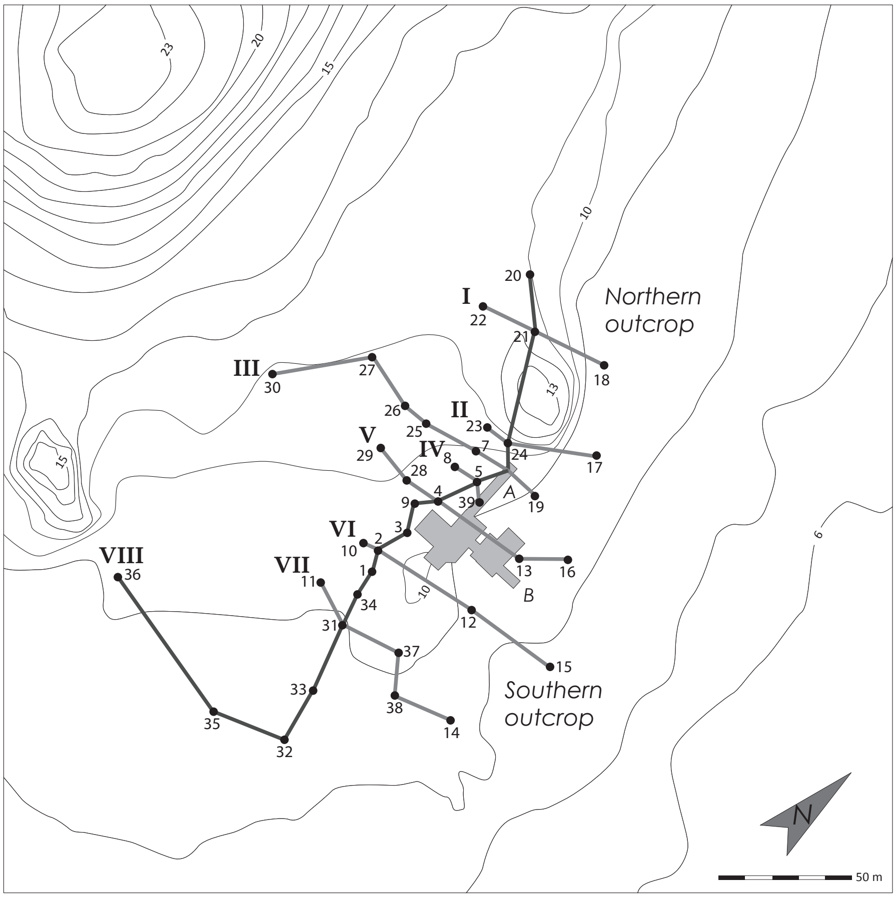



*Fig. 24. Location of 39 boreholes along nine transects in an area of 250 x 300 m at Stavanger Airport. Modified from Selsing & Mejdahl (1994: Fig. 5).*

*Fig. 25. View of the archaeological excavation at Stavanger Airport in 1985, looking east. Photo: Terje Tveit.*

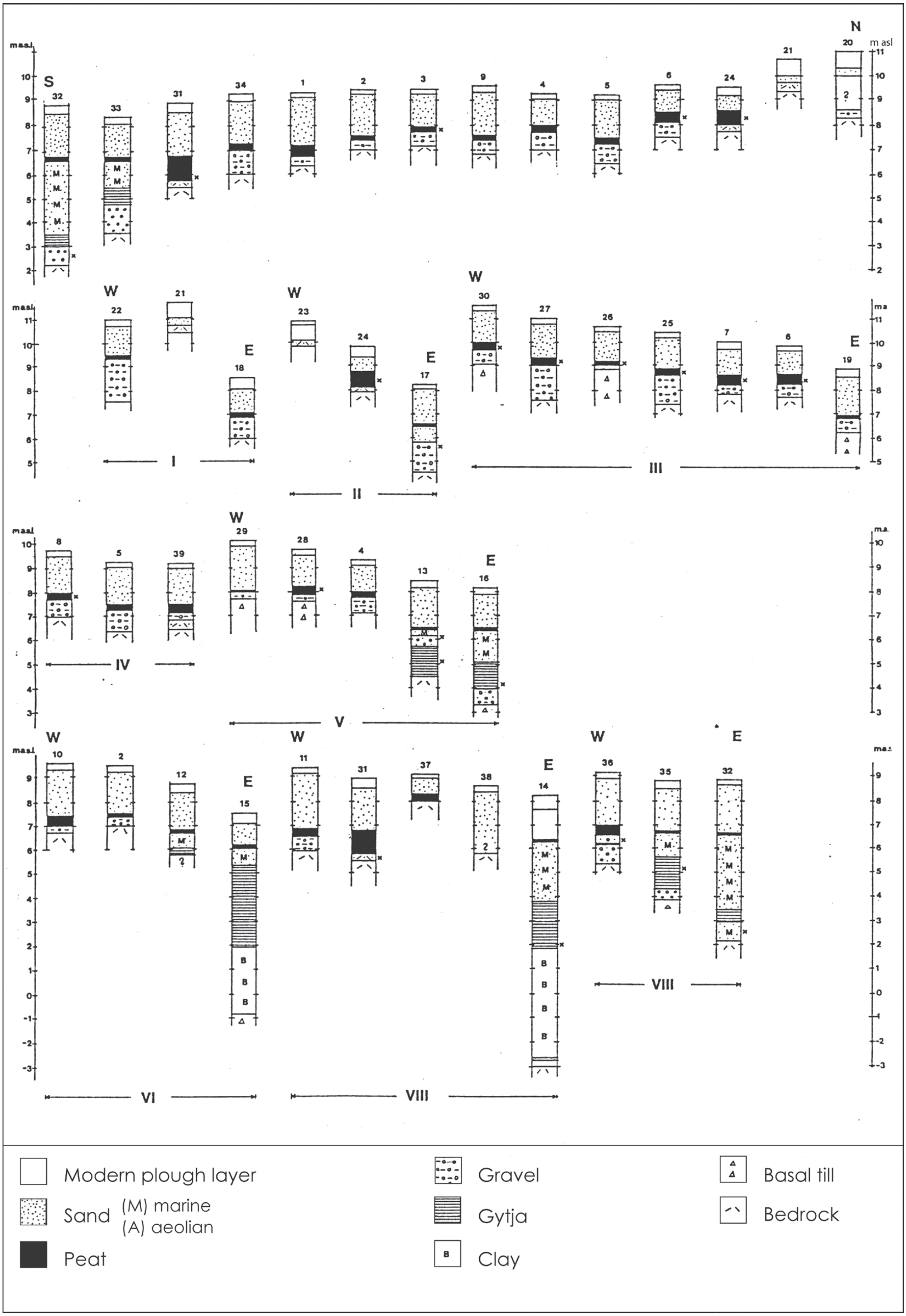



*Fig. 26. The stratigraphy at Stavanger Airport in 39 boreholes in nine transects (Selsing, unpublished).*


*Fig. 27. Part of trench B (see Fig. 24) in the eastern part of Stavanger Airport, with the most complete stratigraphical section. The section shows layers 5-7. Photo: Terje Tveit.*

plain was covered by sandy heathland partly planted with *Pinus* shrubs (Rein 1973). Due to plans to extend the airport, the civil aviation and military authorities commissioned geotechnical investigations of the plain in 1972-1973 and 1985. The results (Rein 1972, 1973, the Norwegian Public Roads Administration, Western Region 1985) provide a good basis for interpreting the separate layers and their extent on the aeolian plain.

The archaeological site investigated in 1985 was located 6-11 m asl on the northern part of the aeolian plain. Two rocky outcrops reaching 10 and 13 m asl were exposed in the south and north of the area, respectively (Fig. 24). Test trenches were excavated with a mechanical excavator between these outcrops. The artefact-bearing layers, covering a total of 300 m$^2$, were then manually excavated and documented by profiles, plan drawings and levelling (Fig. 25). Further information on the lithostratigraphy over an area of 250 x 300 m around the excavation site was obtained from 39 boreholes (on nine transects) drilled with a soil auger (Selsing 1986, 1987, Selsing & Lillehammer 1987) (Figs. 24 and 26).

Trench B and the southern rock outcrop separated the investigated area into westerly and easterly parts, and the most complete stratigraphical sequence was found in the east, in trench B (Fig. 27). It revealed a Holocene sequence resting on basal till and bedrock. The sediments contained both terrestrial (upper sequence) and marine (lower sequence) layers. This paper focuses on the terrestrial sequence.

*Lithostratigraphy and chronology*

The lithostratigraphy was described and discussed by Skar (1985a), Selsing (1987), Prøsch-Danielsen (1993, 2006a) and Selsing & Mejdahl (1994). Radiocarbon dates are given in Table 1.

The eastern section (trench B, 118x-122x/138y, Figs. 27 and 28) consisted of eight layers, from top to bottom:

Layer 8: modern plough layer
Layer 7: aeolian sand with palaeosols
Layer 6: terrestrial peat
Layer 5: marine sand
Layer 4: marine gravel
Layer 3: sandy marine gyttja
Layer 2: gravel with stones
Layer 1: sand/basal till

Layer 1 – The till is sometimes overlain by up to 6 cm of poorly sorted sand.

Layer 2 – This is poorly sorted and up to 8 cm thick.

Layer 3 – This is present from 5.0 m up to 6.1 m asl. In the middle, from c. 5.40 m to 5.50 m asl, is a layer of gravel. The gyttja is stratified and contains marine molluscs, hazelnut shell fragments, Late Mesolithic artefacts, bones from mammals, birds and fish, and teeth (Skar 1985a). A bone fragment (humerus) from a common seal (*Phoca vitulina*) and a tooth (molar or premolar) from a wild boar (*Sus scrofa*) were identified by Anne Karin Hufthammer and dated to 4950±40 yrs BP (5720-5615 cal yrs BP, ß-171187) and 6110±40 yrs BP (7150-6909 cal yrs BP, ß-171186), respectively. The layer consisted of organic material alternating with sand (quartz with some mica) lenses, and dipped towards the east. An erosional angular unconformity separated layers 3 and 4. Roots of *Alnus glutinosa* (identified by Aud Simonsen) penetrating into the upper part of the marine gyttja had also been cut off discordantly. A piece of root was dated to 4320±70 yrs BP (5029-4832 cal yrs BP, ß-171185).

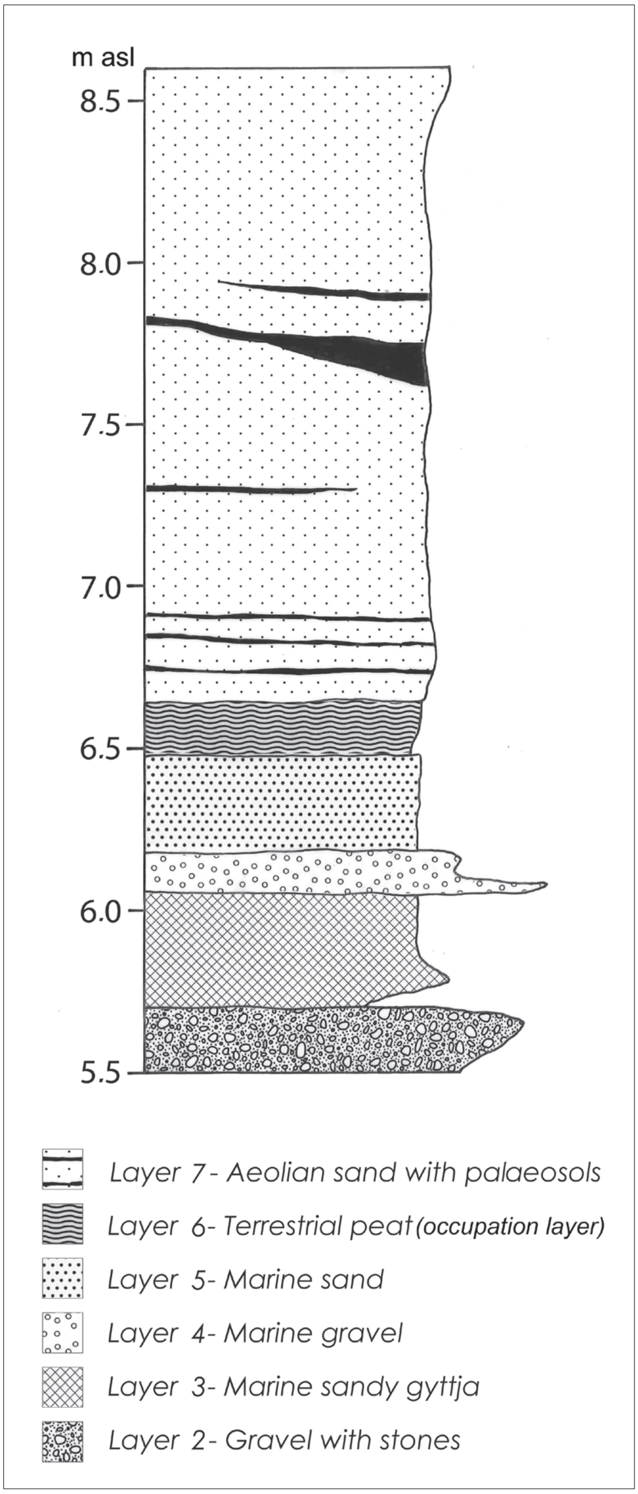



*Fig. 28. A stratigraphic outline of the excavated area at Stavanger Airport (modified from Selsing & Mejdahl 1994: Fig. 4).*

A bulk sample of hazelnut shell fragments from the lower part of layer 3 in the excavation area (120x/138y) was radiocarbon dated to 7080±90 yrs BP (7997-7799 cal yrs BP, T-6894), and the lower part of core 85/323 sampled in the same unit at 119.6x/138y was radiocarbon dated to 7130±100 yrs BP (8040-7837 cal yrs BP, T-7022). The top of the marine gyttja was dated to 5480±90 yrs BP (6396-6191 cal yrs BP, T-6893A).

Layer 4 – The marine gravel contains Early Neolithic artefacts and animal bones and teeth. Bones (astragalus) from red deer (*Cervus elaphus*), identified by Anne Karin Hufthammer, found in the lower part of this layer, were dated to 4780±110 yrs BP (5604-5326 cal yrs BP, T-6601) and 3995±180 yrs BP (4811-4185 cal yrs BP, T-10888). However, burnt hazelnut shell fragments from the upper part of this layer on the eastern slope were dated to 4930±90 yrs BP (5852-5587 cal yrs BP, T-6891), which fits well with T-6601.

Layer 5 – An erosion contact between layers 4 and 5 is marked by a few mm-thick iron precipitate. Layer 5 varies in thickness between 35 cm and 40 cm and is composed of homogeneous light-grey sand lacking material that can be radiocarbon dated. The base of the layer has been dated by thermoluminescence to 3500±350 years (R-853502). Selsing & Mejdahl (1994) suggested that this layer had been deposited close to or on the beach, and regarded it as either marine or aeolian sand. Granulometric analyses showed that it consisted of fine-grained, well-sorted sand that was indistinguishable from the clearly aeolian sand in layer 7. However, Klemsdal (1969) studied samples of marine and aeolian sand on the Møre coast in northwestern Norway and concluded that such sediments could not be distinguished by means of grain-size analysis alone. It is therefore suggested that this unit is marine sand deposited near or on the beach during a short period.

Layer 6 – The peat varies in thickness across the aeolian plain and reaches 3.5 m in the southeast (Rein 1972). In the excavation area, layer 6 reaches 80 cm immediately west of the southern outcrop. It thins out towards the rock outcrops. At site 1 (Fig. 29), the base of a peat section was dated to 4540±90 yrs BP (5430-5045 cal yrs BP, T-7043A) and 4360±80 yrs BP (5044-4843 cal yrs BP, T-7043B), whereas the youngest, upper part of the peat was dated in trench B, profile B (Fig. 30), to 2540±80 yrs BP (2749-2490 cal yrs BP, T-6378A). Radiocarbon dates of features in this layer that relate to human activities are described further in the section on palynology (see also Table 1). Middle Neolithic artefacts were found at the base of the peat, or within it. Charcoal of *Salix* and *Betula* collected together with artefacts at the base of the peat layer gave a date of 4890±100 yrs BP (5744-5479 cal yrs BP, T-6600A). A set of tilled grooves was observed when the peat containing the Middle Neolithic artefacts was removed. They penetrated the peat layer where it was thinner than about 20 cm, and were interpreted as plough marks reflecting cultivation dated to the time interval of 2550-2200 yrs BP (2730-2230 cal yrs BP) (Prøsch-Danielsen 1993).

Layer 7 – A thick layer of aeolian sand with palaeosols covers the peat. Its thickness varies between 1.5 and 2.25 m here, but a thickness of up to 5 m has been recorded on the southern part of the plain (Rein 1973). During geotechnical investigations in 1972, well-developed podsol profiles buried beneath the aeolian deposit were observed at several sites on the eastern part of the plain. The podsol was interpreted as representing formerly cultivated land (Rein 1972). The palaeosols found at various levels within this aeolian sand are generally only 1-5 mm thick and appear as dark layers in the wind-blown sand. They represent standstills in the aeolian activity which allowed the vegetation to recover. The lowermost palaeosols have radiocarbon ages of 2190±80 yrs BP (2300-2152 cal yrs BP, T-6379A) and 2660±60 yrs BP (2844-2742 cal yrs BP, T-8226A). The bottom and top of the thick palaeosol/peat layer in the upper part of the section gave radiocarbon ages of 1820±160 yrs BP (1924-1553 cal yrs BP, T-6380A) and 1790±60/1530±80 yrs BP (1814-1628/1517-1351 cal yrs BP, T-7042A and B). The results of the thermoluminescence dating are: (1) TL4 from the bottom of the aeolian sand: 2400±250 years, (2) TL2 from sand below thick palaeosol/peat: 1600±150 years, (3) TL1 from sand between (1) and (2): 2000±200 years. The present water table is between 0.8 and 1.2 m below the surface (Rein 1972), which implies that the surface dries quickly, causing the soil (palaeosol) to break up, accelerating sand drift.

At Stavanger Airport, the source of an aeolian drift originating in the southeast would be the extensive sandy marine gyttja (layer 3) below the peat (layer 6). With northwesterly winds, the origin of the aeolian deposits may have been marine shore deposits or till.

*Palynological analysis*
Palynological analysis was carried out on the peat deposit (layer 6) at seven sites (Prøsch-Danielsen 1993). The results of three of the peat sections (Figs. 29-31) and two sections (Figs. 32 and 33) related to the aeolian sand with palaeosols/peat (layer 7) will be discussed.

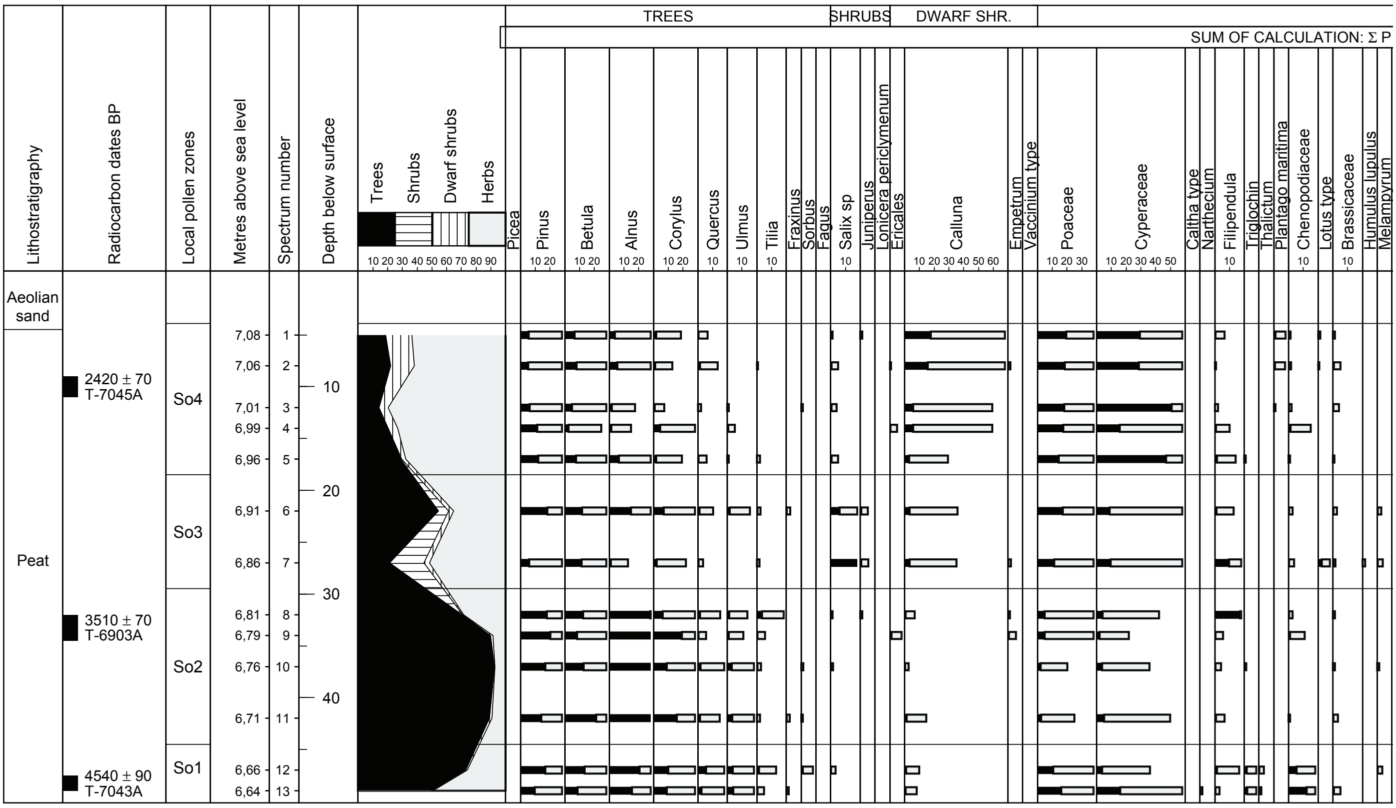
Five local PAZs (So1-So5) are recognised in the peat layer.

*Poaceae-Triglochin-Chenopodiaceae*, local PAZ So1
The zone is characterised by high Chenopodiaceae representation. Records of *Triglochin, Urtica, Filipendula* and Apiaceae pollen, poor shrub representation, and tree pollen at 50 % and 73 %, suggest the presence of nutrient-demanding vegetation, which was still under the influence of marine conditions. This is also confirmed by the low loss-on-ignition values, indicating that sand was supplied by waves and wind.

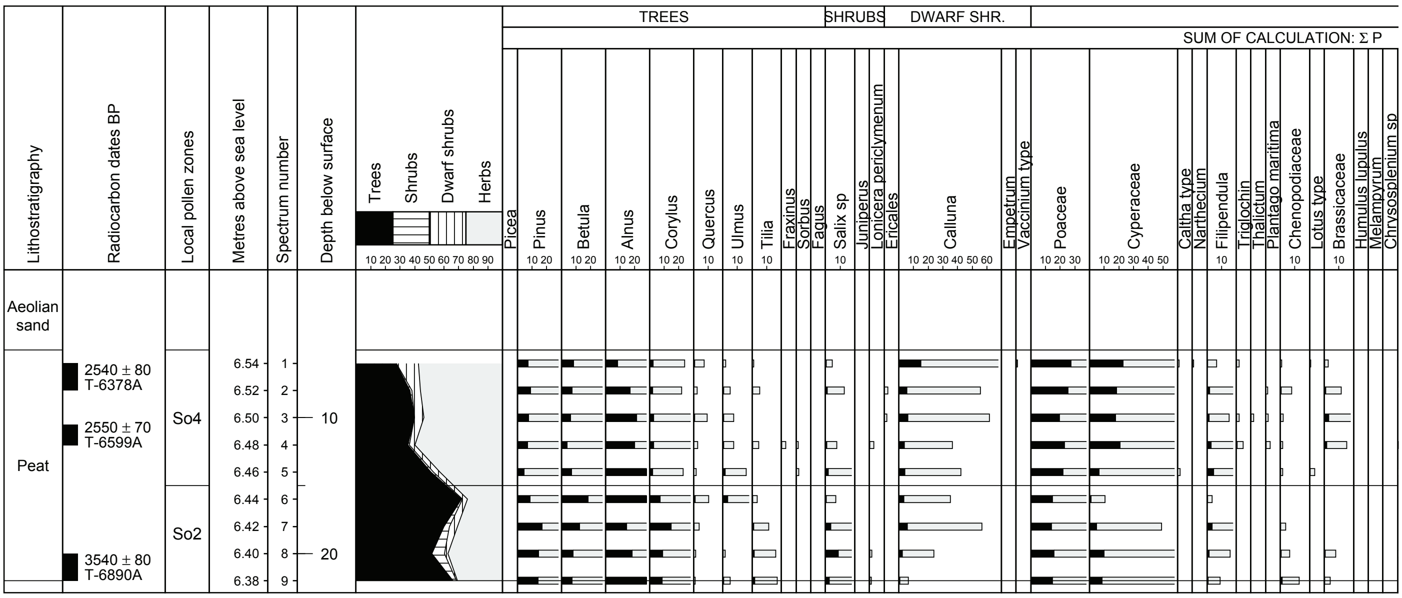
*Alnus-Polypodiaceae*, local PAZ So2
Tree pollen values are between 60 and 90 %, with *Alnus* at 20-50 %. Polypodiaceae have also increased, at the expense of herbs. *Plantago lanceolata* is recorded in the upper part of this zone, its first appearances being dated to 3510±70 yrs BP (3871-3695 cal yrs BP, T-6903A) and 3450±90 yrs BP (3835-3592 cal yrs BP, T-6903B), respectively. Its presence probably reflects the first husbandry at this site.

*Salix-Poaceae-Cyperaceae*, local PAZ So3
Tree pollen values decrease below 40 % and the Polypodiaceae curve decreases to a minimum of 4 %. Trees are partially replaced by shrubs, herbs, grasses and sedges. This local PAZ represents a purely local vegetation development that might be the result of agricultural influence. Tall ferns are sensitive to trampling, which may explain the decrease in Polypodiaceae. Otherwise, the pollen records indicate a rich seashore meadow.

## Stavanger Airport, Sola, Rogaland, Norway
**Profile B, 90x/100y**




## Stavanger Airport, Sola, Rogaland, Norway
**Profile B, 120.75x/138y**



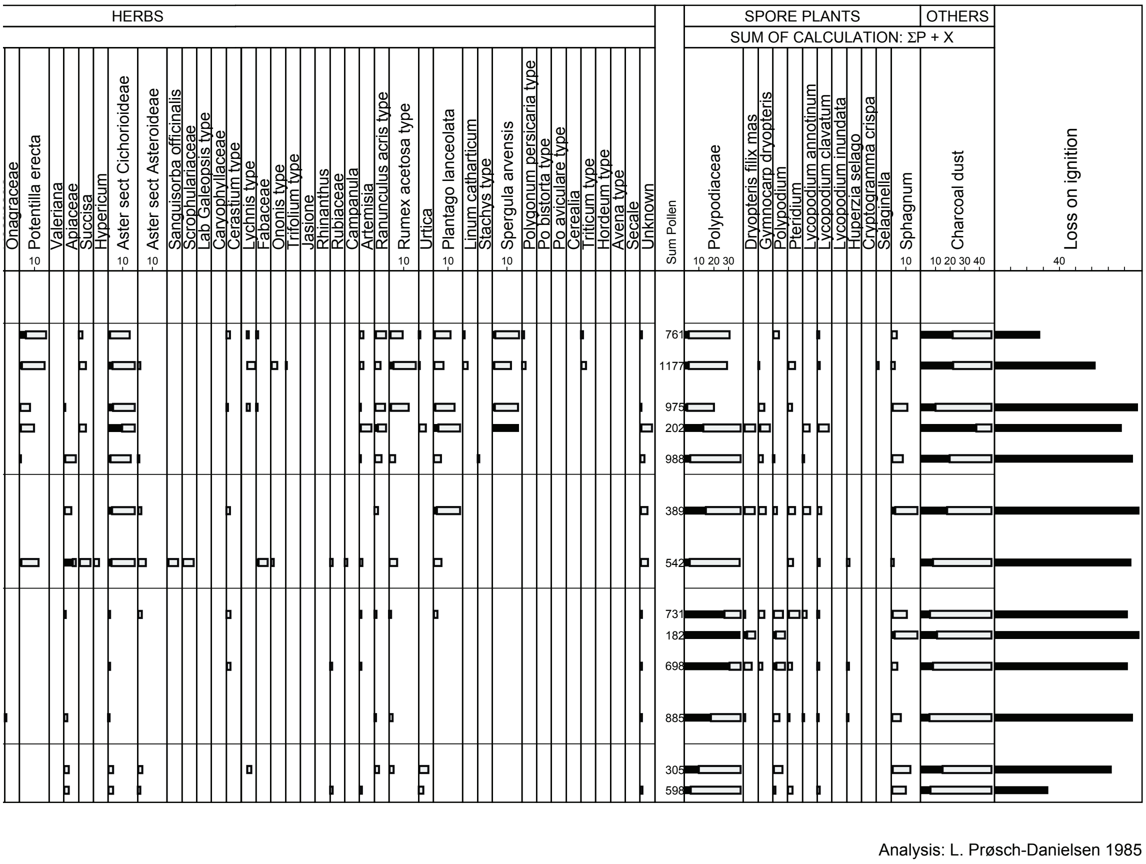



*Fig. 29. Percentage pollen diagram, pollen site 1 (90x/100y) from Stavanger Airport (Prøsch-Danielsen 1993: Fig. 9).*

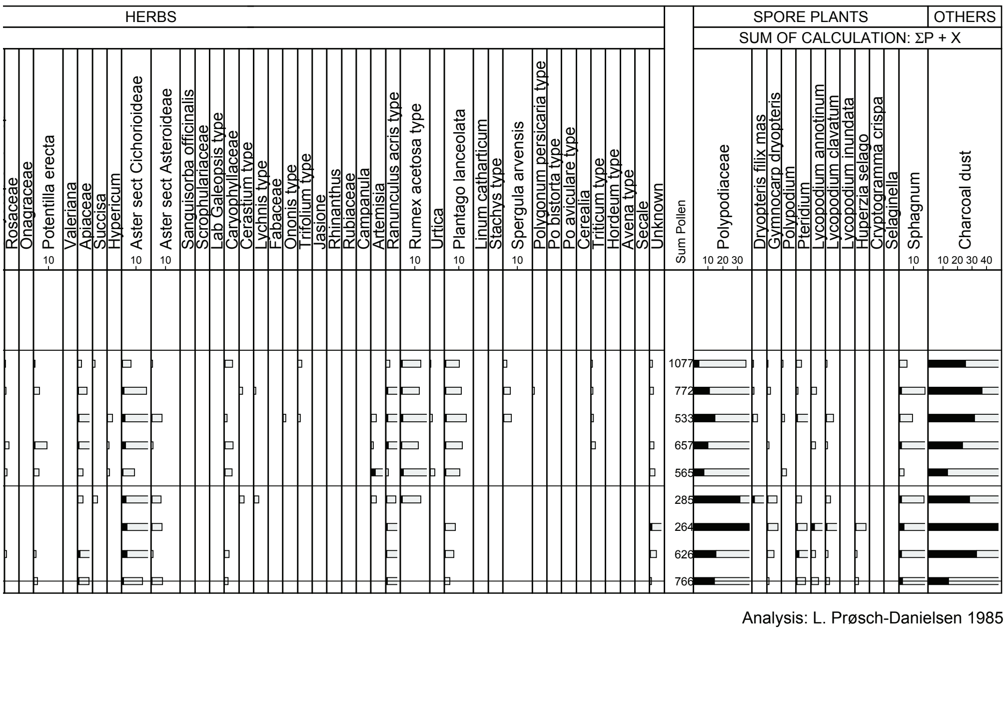



*Fig. 30. Percentage pollen diagram, profile B (120.75x/138y) from Stavanger Airport (Prøsch-Danielsen 1993: Fig. 10).*

## Stavanger Airport, Sola, Rogaland, Norway

**N area, 114.67x/142y**

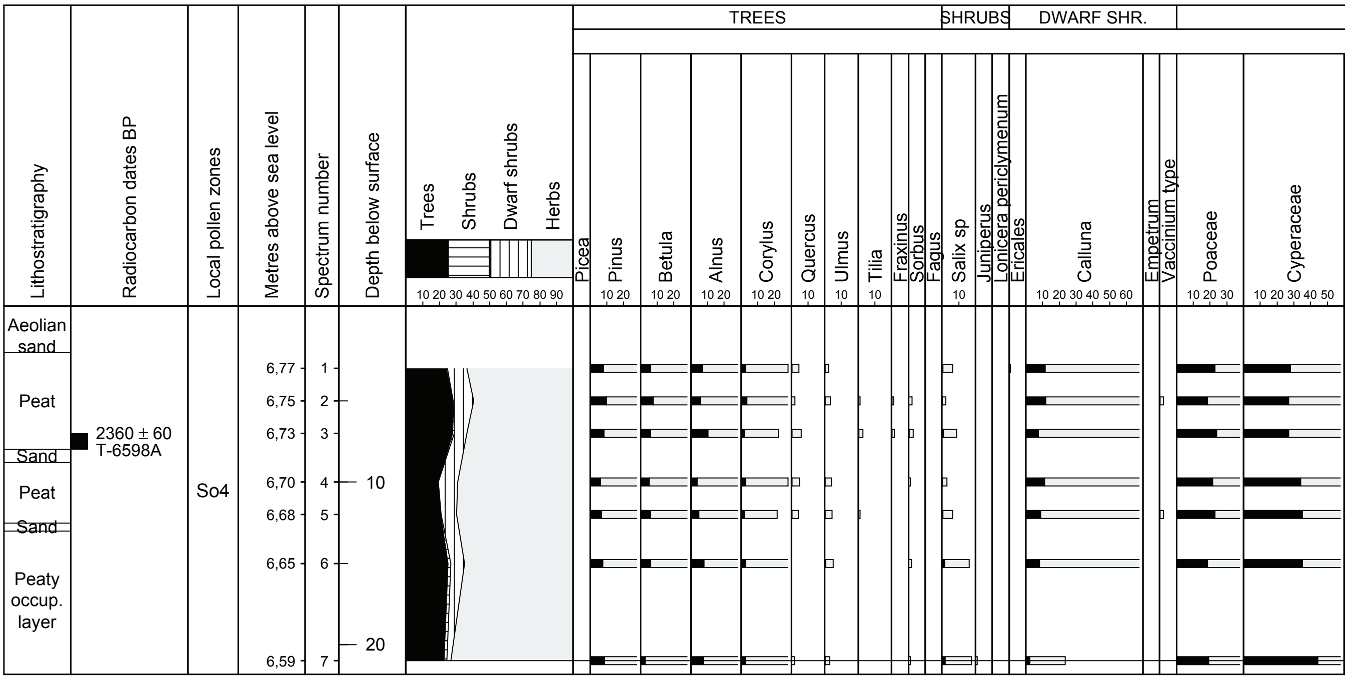
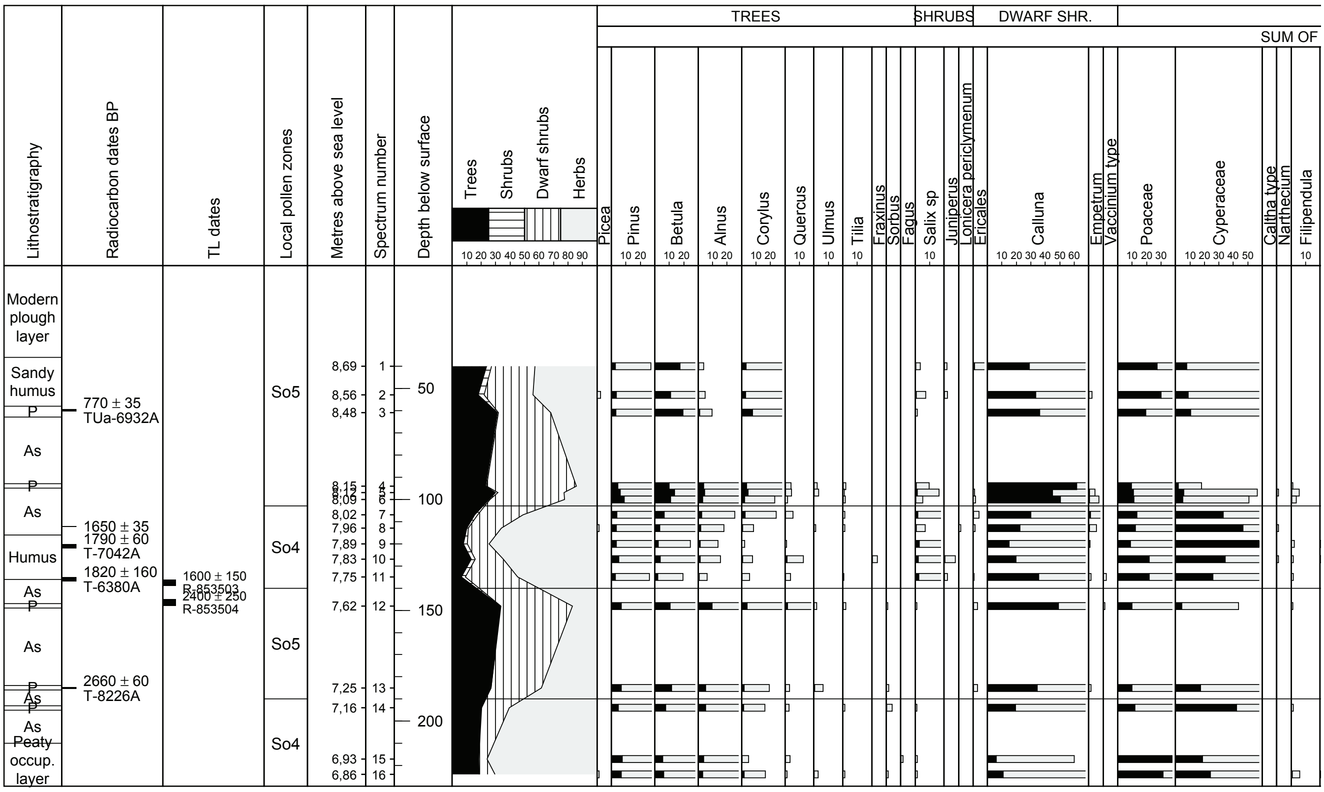
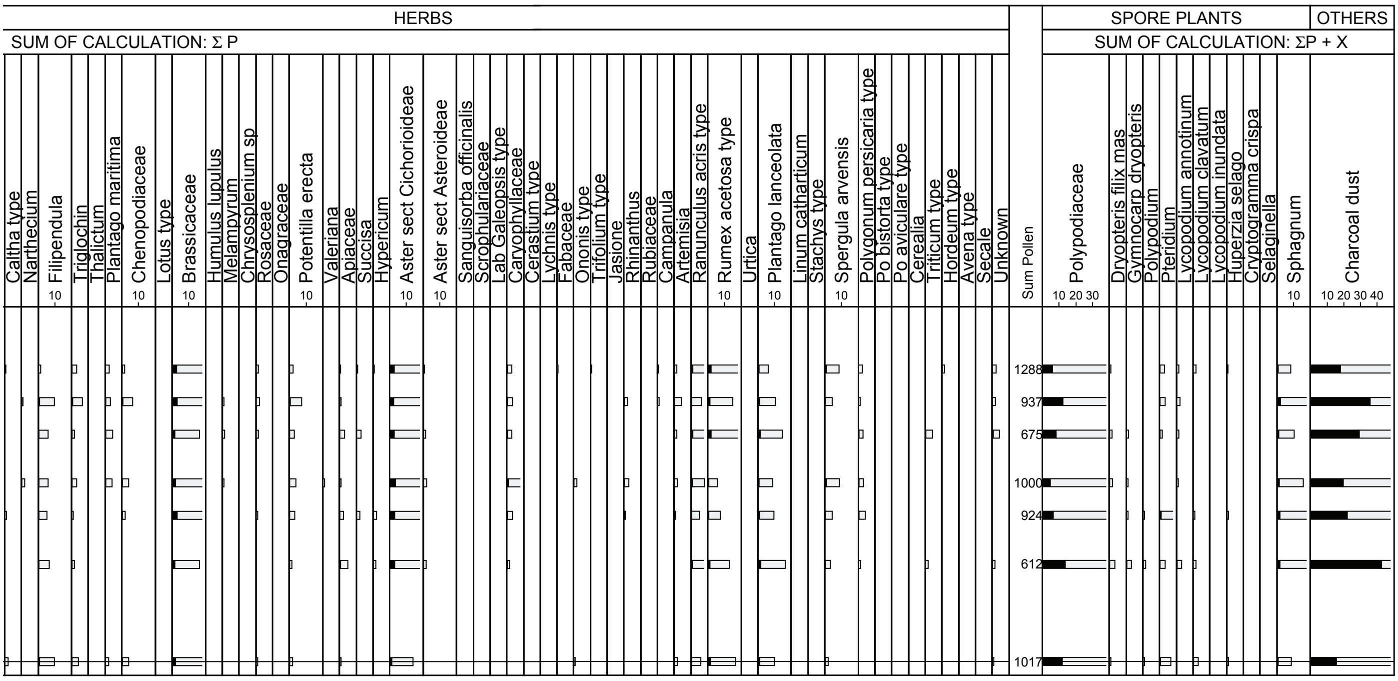


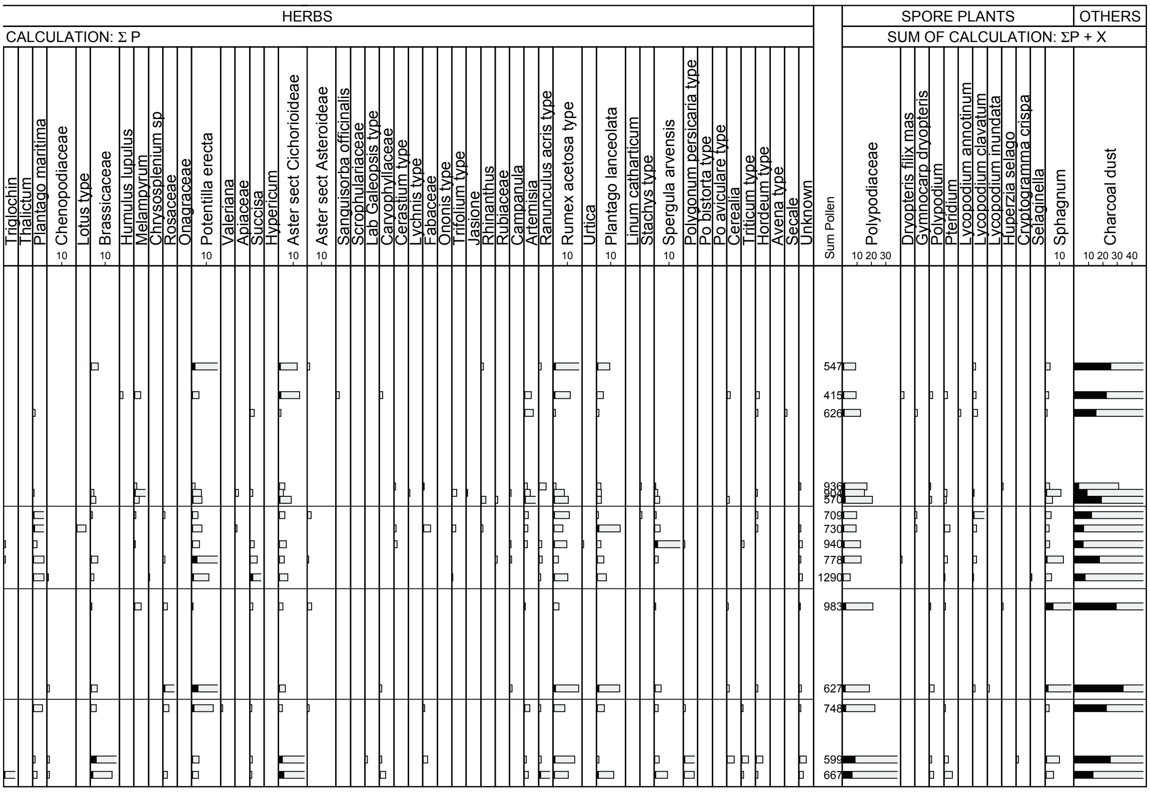

*Fig. 31. Percentage pollen diagram, northern area (114.67x/142y) from Stavanger Airport (Prøsch-Danielsen 1993: Fig. 10).*

**Profile A, 99.75x/155.75y and 98.35x/155.75y**



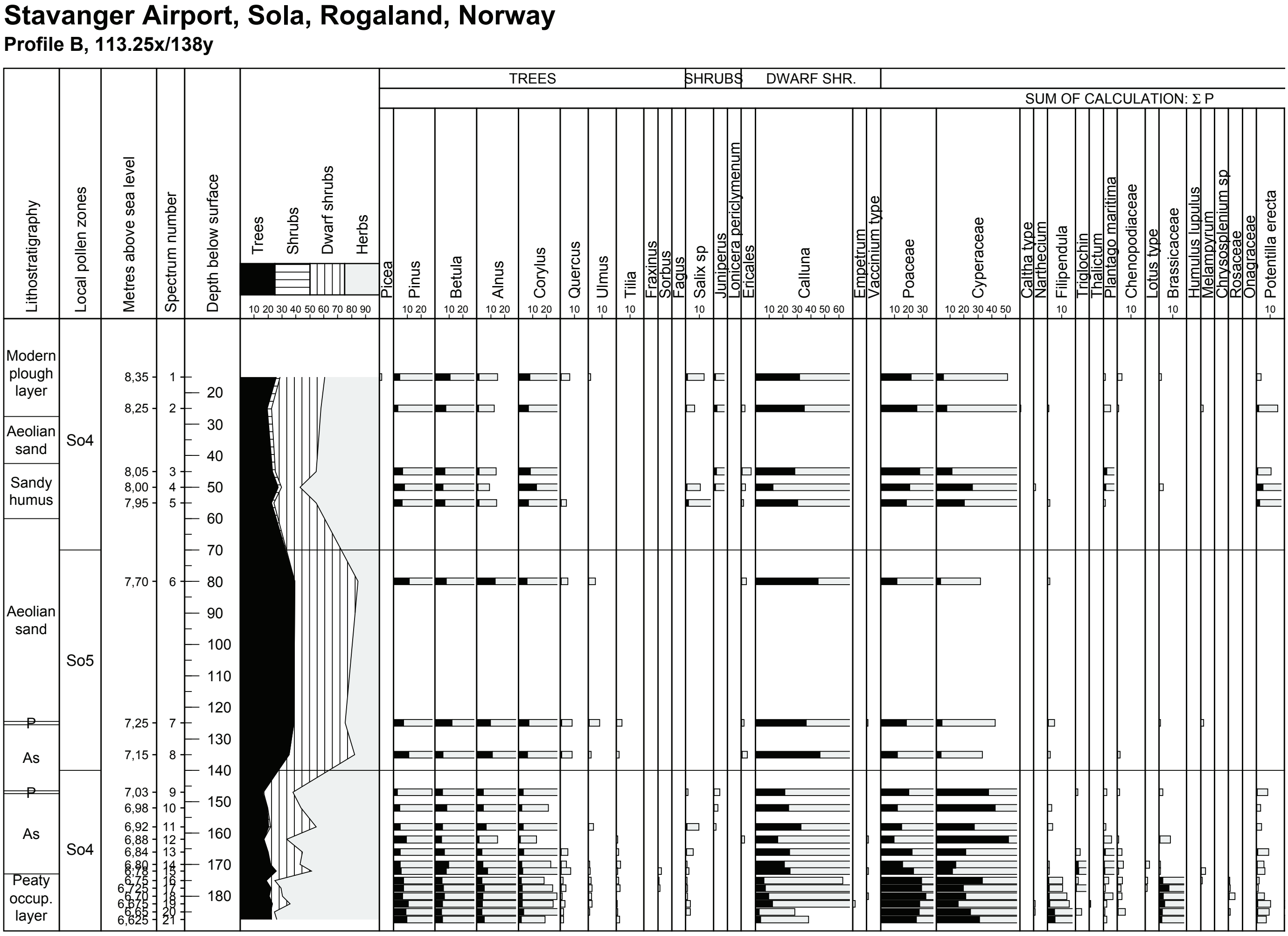



Analysis: L. Prøsch-Danielsen 1985




Analysis: L. Prøsch-Danielsen 1985

*Fig. 32. Percentage pollen diagram, profile A (99.75x/155.75y and displaced section 98.35x/155.75y) from Stavanger Airport (Prøsch-Danielsen, unpublished).*




*Poaceae-Cyperaceae, local PAZ So4*

*NAP,* mainly Poaceae and Cyperaceae, dominate the vegetation. Tree pollen values decrease, while dwarf shrubs (here mainly *Calluna*) increase to a maximum of 20 %. So4 represents a treeless community and marks the onset of heath vegetation at the site. Husbandry is still recorded, indicated by pollen of *Plantago lanceolata* and *Rumex acetosa* type. Cereal cultivation is recorded by pollen of *Triticum* type and *Hordeum* type, and by the appearance of pollen from weeds like *Spergula arvensis* (up to 18 %) and *Polygonum persicaria*.

Two local PAZs are recognised in the palaeosols/peat within the aeolian sand deposit.

The seven lowermost palaeosols and the thick palaeosol/peat layers within the aeolian sand of layer 7 have a pollen assemblage in accordance with the *Poaceae-Cyperaceae* local PAZ So4, but with increasing *Calluna* in the uppermost palaeosols and the modern plough layer. The agricultural activity, including husbandry and cereal cultivation, is especially seen in the lowermost palaeosols. However, there is no indication of cereal cultivation in the thick palaeosol/peat layer in profile A.

*Calluna-Poaceae-Cyperaceae*, local PAZ So5

Dwarf shrubs, here represented by *Calluna* (up to 50 %), dominate the local pollen assemblage in the middle palaeosols of the aeolian deposit. *Sphagnum* dominates among the spore plants. There is an approximately 20 % increase in tree pollen values from local PAZ So4 to local PAZ So5. Pollen taxa representing agricultural activity are almost absent in the zone.

*Sea-level fluctuation*

The sediment studies at the Stavanger Airport site and associated $^{14}$C dates have formed the basis for constructing the sea-level fluctuation curve for the area (Fig. 34). This curve was thoroughly described by Prøsch-Danielsen (2006a), and only features relevant to the present paper will be referred to below.

The Late Weichselian (Younger Dryas age) transgression forms the marine limit (ML) in the area and

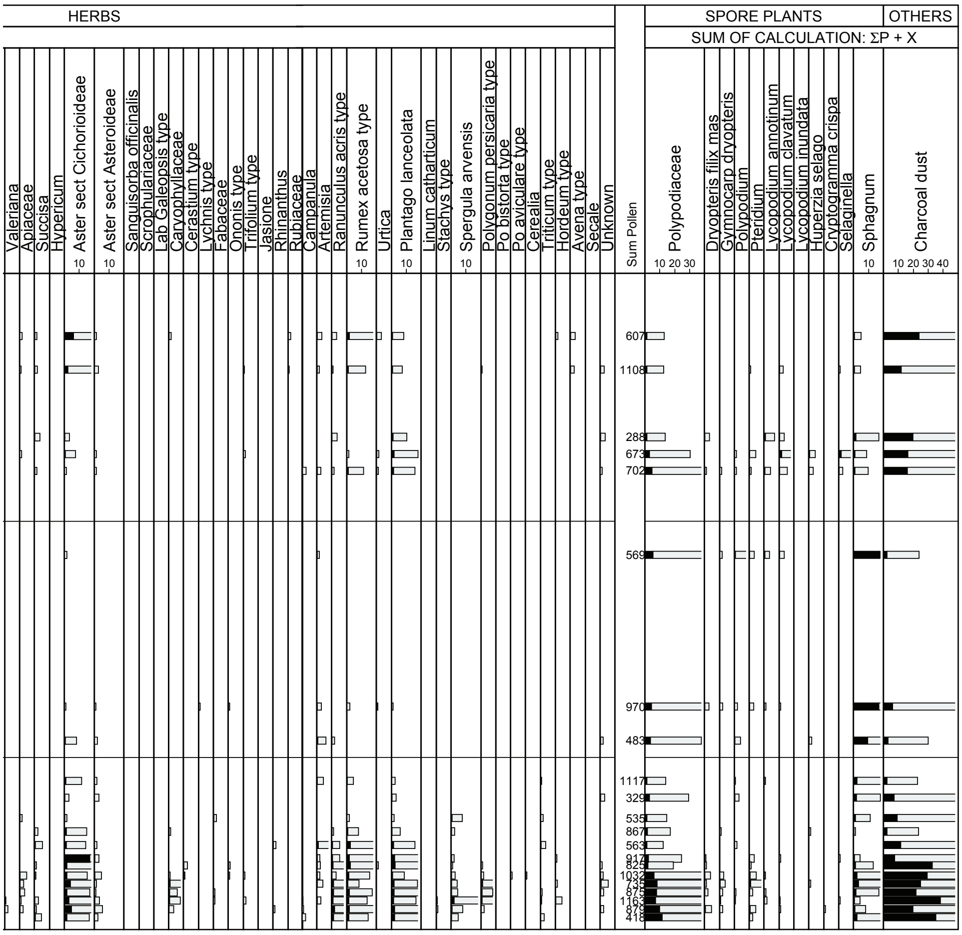



*Fig. 33. Percentage pollen diagram, profile B (113.25x/138y) from Stavanger Airport (Prøsch-Danielsen, unpublished). Analysis: L. Prøsch-Danielsen*

reached 19-20 m above present sea-level. The sea-level dropped below the 5 m level, probably to -2 m, during the Holocene regression minimum in the late Preboreal and early Boreal chronozones.

The Tapes transgression is double-peaked (Prøsch-Danielsen 2006a). Layer 2 (gravel with stones) represents a marine event (probably the Storegga event, Bondevik *et al.* 1997a, 1997b) prior to 7130 yrs BP (7960 cal yrs BP). The marine gyttja (layer 3) that contains marine molluscs and Late Mesolithic artefacts was deposited during the first Tapes transgression phase, ranging in time from 7130±100 yrs BP (8040-7837 cal yrs BP, T-7022) to 5480±90 yrs BP (6396-6191 cal yrs BP, T-6893A). The gyttja indicates shallow water and a sheltered location. A gravely layer that separates the marine gyttja into two units was deposited sometime between these dates (probably around 6500 yrs BP, 7430 cal yrs BP) and the depositional environment demands a high-energy pulse of water (e.g. a strong current). This situation could be achieved during the first peak (up to 9 m asl). At that time, seawater flowed in a sound from Solavika into Hafrsfjord, and build up a beach ridge at Stangeland in the south (Rein 1973).

A regression phase followed the first Tapes transgression, allowing *Alnus* to colonise the shore margins that emerged. The sea-level regressed below the present-day 6.10 m contour line. However, a terrestrial sequence is absent from the marine gyttja layers. The erosional discordance between layer 3 (marine gyttja) and layer 4 (marine gravel) indicates that deposits were eroded. The marine gravel must have been deposited in a strong current flowing through the area, a situation that also requires that the barriers or thresholds towards the sea had been broken. It is therefore suggested that a new, short-lived marine episode or transgression took place about 4900-4800 yrs BP (5620-5540 cal yrs BP). Layer 4 deposits are found up to 9 m asl in the investigated area (Selsing 1987).

The sand layer (layer 5) was deposited near or on the beach during the preceding regression phase. T-7043A shows that the sea-level was below 6.6 m asl for a short time before 4500 yrs BP (5170 cal yrs BP). Accumula-

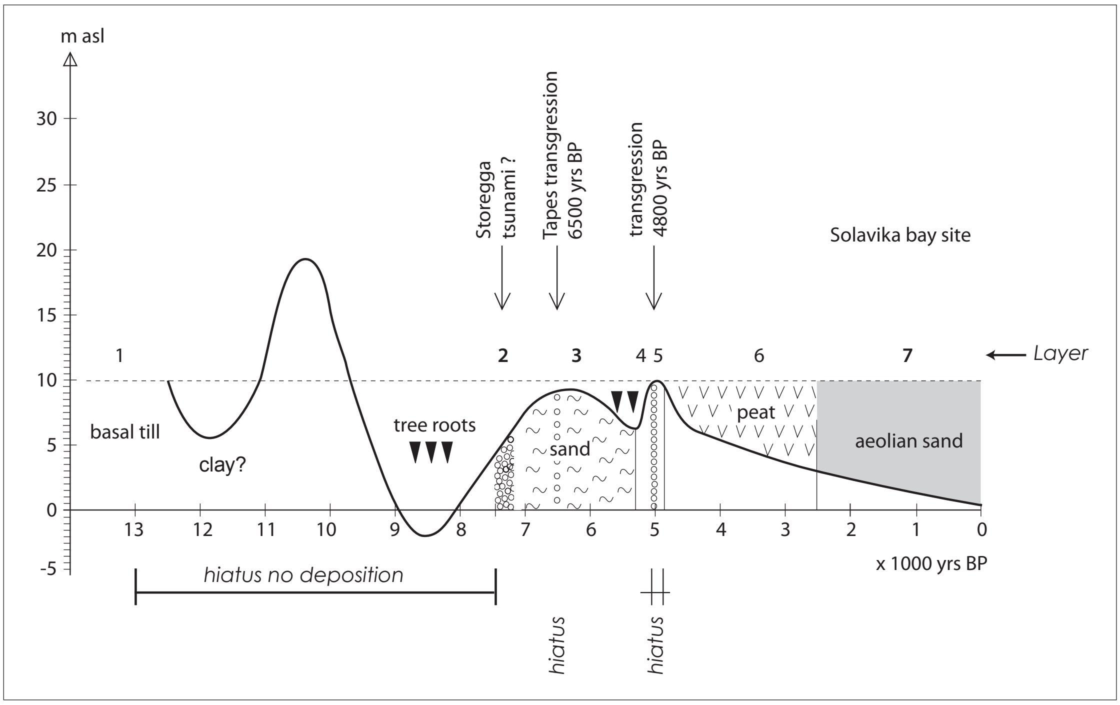



*Fig. 34. The sea-level displacement curve for Stavanger Airport in northern Jæren. Modified from Prøsch-Danielsen (2006a: Fig. 56).*

tion of terrestrial peat started soon after. Charcoal associated with Middle Neolithic artefacts (Skar 1985a) at the base of the peat layer is dated to 4890±100 yrs BP (5744-5479 cal yrs BP, T-6600), implying that the second Tapes peak was of short duration before the sea finally regressed.

*Discussion and conclusion*

The sand (layer 5) is of marine origin and was deposited during the Tapes transgression and regression phases (Rein 1973, Selsing & Mejdahl 1994, Prøsch-Danielsen 2006a). Rein (1972, 1973) concluded that this marine sand totally covered the lower parts of the aeolian plain and was the source for the aeolian deposits (layer 7). The geotechnical investigations also showed that seawater flowed in a sound from Solavika into Hafrsfjord, and build up a beach ridge at Stangeland in the south (Rein 1973). This implies that large areas of sand were exposed during the regression and were constantly moving (Rein 1973).

A peat layer (layer 6) resting on the marine sand has been observed nearly all over the plain. It varies in thickness from 20 cm to 3.5 m in the southern part. Palynological analysis of samples from the bottom (local PAZ So1) of the peat layer indicates a pioneer vegetation of shore-meadow plants. In local PAZ So2, alder swamps are locally dominant with a field layer of ferns and tall herbs. This plant community demands a certain amount of humus. The accumulation of the peat, the age of which is between 4890±100 yrs BP (5744-5479 cal yrs BP, T-6600A) and 4540±90 yrs BP (5430-5045 cal yrs BP, T-7043A) started soon after the sea regressed. Deforestation (PAZ So3) started locally around 3500 yrs BP, the transition between the Late Neolithic and the Early Bronze Age, immediately after the first record of husbandry in the area. It accelerated throughout the Bronze Age, and heathland developed. From about 2550-2200 yrs BP (2730-2230 cal yrs BP), cereal cultivation with weed-rich crops of *Hordeum* and *Triticum* took place (local PAZ So4). A series of intersecting plough marks penetrating into the marine sand may indicate that the peat layer was ruptured by a plough (an ard). The topsoil and vegetation were removed, at least in places with a thin peat cover, which allowed soil erosion and thus sand drift to accelerate. This is also revealed by the decrease in the loss-on-ignition curve in the upper part of the peat.

It cannot be excluded that some of this eroded soil may have been intercalated in aeolian sand (layer 7) as palaeosols at sites where deposition of aeolian sand had already begun. The lowermost palaeosols are dated to 2660±60 yrs BP and 2190±80 yrs BP (2844-2742 cal yrs BP and 2300-2152 cal yrs BP). This provides a *terminus ante quem* for the cessation of peat accumulation and the minimum age for the start of aeolian activity in the area. In local PAZ So5 from palaeosols in the middle part of the aeolian deposit, the pollen assemblage mainly reflects expanding heath vegetation. The humic bands reflect local vegetation consisting mainly of *Sphagnum* and Poaceae and Cyperaceae species. The thick peat layer at site A in the middle part of the aeolian deposit reflects a stable phase of 200-300 years that allowed a humic vegetation cover to develop. Livestock trampling resulted in new aeolian activity. The palaeosols and peat are thought to have formed during periods with continuous vegetation that protected the soil surface. The aeolian sand accumulated during periods with discontinuous vegetation. Thus human impact was reduced because the area was useless.

There is good agreement between nearly all the radiocarbon ages and age information based on archaeological typology and sea-level changes, and also the thermoluminescence dates (Selsing & Mejdahl 1994). This indicates that the samples giving ages deviating from the proposed age may consist of material which may have been reworked (e.g. eroded by wind and/or livestock trampling). Two dates of palaeosols (T-6929A and T-6930A) are too old for the proposed age (see Table 1). These discrepancies may be caused by erosion of old peat and soil deposits which were then blown and deposited elsewhere, probably close to the erosion site.

A combination of arable land and grazing animals in the sensitive phase of deforestation (phase 3), combined with large areas of unprotected marine sand, may have caused the aeolian activity. A concentration of aeolian sand in the south suggests that it was mostly dry northerly and easterly winds that aided this transport (Rein 1973).

## 5. Solavika

The Solavika site, about 1 km west of Stavanger Airport and 500 m from a bay named Solavika, is located on a gently sloping hillside stretching from the Sola Beach


*Fig. 35. Aerial view of the Solavika site 500 m upslope from the sandy beach at the head of the bay (Solavika). The Sola Beach Hotel is in the foreground. Photo: County Governor of Rogaland.*

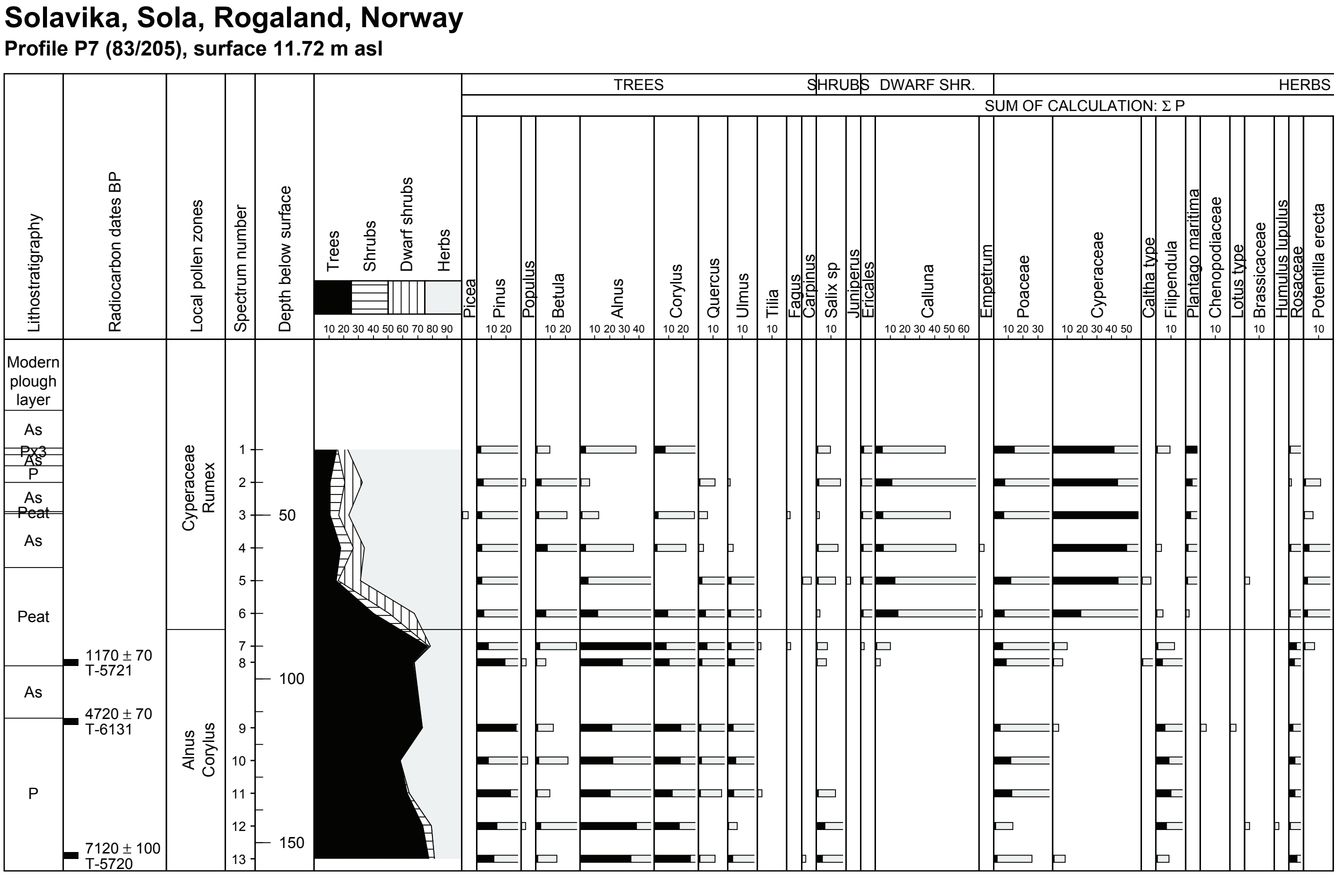



*Fig. 36. Percentage pollen diagram, profile P7, from Solavika (Ugland 1984). Drawing: L. Prøsch-Danielsen.*

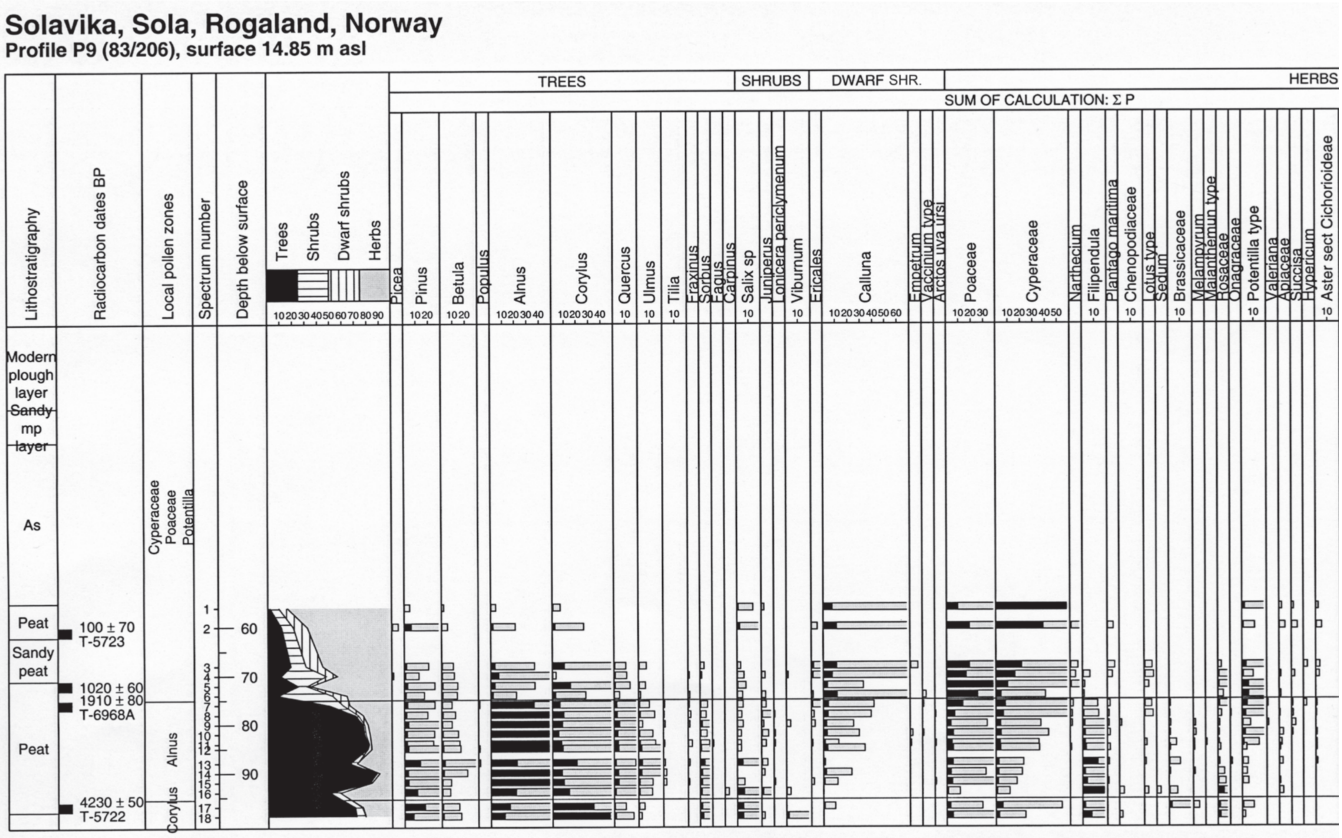
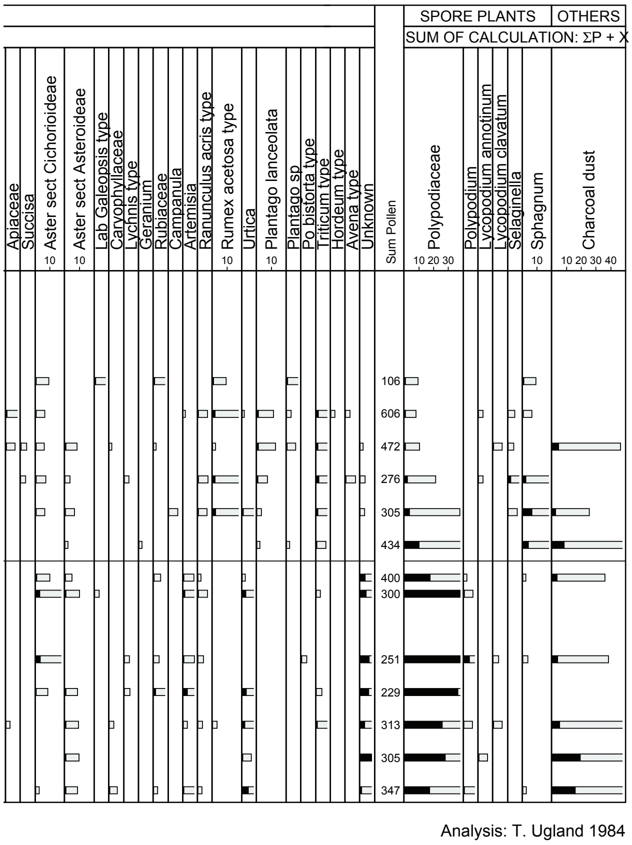
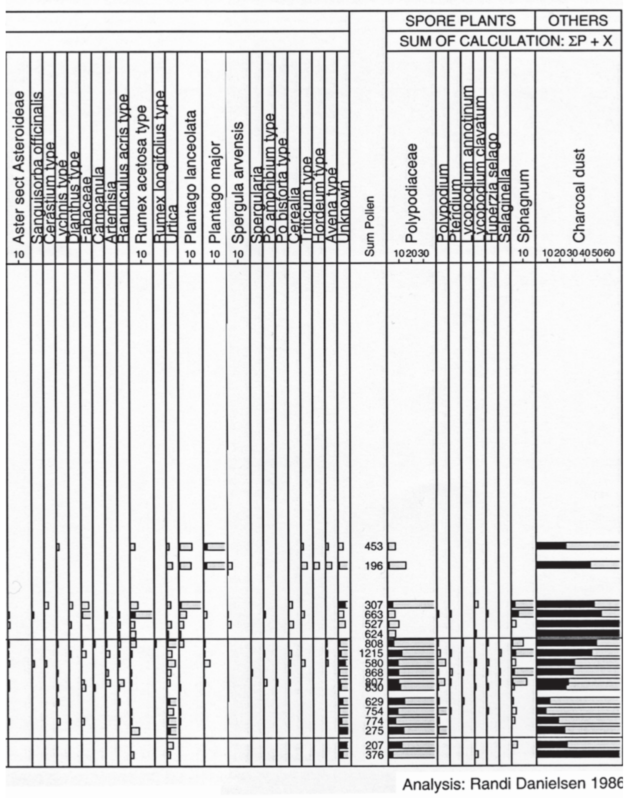



*Fig. 37. Percentage pollen diagram, profile P9, from Solavika (Danielsen 1986). Drawing: L. Prøsch-Danielsen.*




Hotel north-eastwards to the ruins of the Sola medieval church (Figs. 23 and 35).

In 1983, the hotel needed a new sewer. A mechanical excavator dug a trench down the slope to Solavika, and this unearthed a Mesolithic locality dating back to 8500±240 yrs BP (9882-9131 cal yrs BP, T-5321) (hazelnut shell fragments) situated beneath a thick pile of alternating layers of peat and aeolian sand (Haraldsen 1984). The site was investigated by a team composed of Tom Haraldsen (archaeology), and Per Blystad and Trond Ugland (Quaternary geology and palynology).

Three profiles located from 11.72 m to 14.85 m asl were sampled with emphasis on the age, genesis and origin of the aeolian deposits (Ugland 1984, Danielsen 1986, Selsing & Mejdahl 1994). Two sites (P7 and P9), where organic material was intercalated in sand, were radiocarbon dated. The central part of the Mesolithic locality was situated close to P9. In 1986, a supplementary and more detailed palynological analysis of P9 was performed (Danielsen 1986). This was funded by Sola Borough Council as part of an investigation of the ruins of the Sola medieval church to reconstruct the vegetation history of the area during the Viking Period and in medieval times.

*Lithostratigraphy and chronology*

The lithostratigraphy was described by Ugland (1984) and Danielsen (1986). Radiocarbon dates are given in Table 1. The two profiles are situated 60 m apart, P7 on the 12 m contour line and P9 further up on the 15 m contour line. These differences in height above sea-level, though small, do in fact explain the variety in the profiles. Both localities, however, are situated above the maximum Tapes transgression (Fig. 34).

Profile P7 (from 11.72-10.12 m asl):
Layer 4: modern plough layer (18 cm thick)
Layer 3: sand with palaeosols (48 cm thick)
Layer 2: terrestrial carr peat with an aeolian sand layer (94 cm thick)
Layer 1: gravel and sand (20 cm thick)

Profile P9 (from 14.85-13.85 m asl):
Layer 4: modern plough layer (22 cm thick)
Layer 3: aeolian sand (33 cm thick)
Layer 2: terrestrial carr peat (40 cm thick)
Layer 1: gravel and sand (more than 10 cm)

Layer 1 – The gravel and sand layer is believed to be of marine origin because of the height above sea-level (Haraldsen 1984, Ugland 1984). Artefacts are embedded in this layer.

Layer 2 – In P7, the terrestrial carr peat is separated into two sequences by an aeolian sand layer. The oldest sequence has a lower boundary dated to between 7120±100 yrs BP (8030-7831 cal yrs BP, T-5720) and 4720±70 yrs BP (5580-5326 cal yrs BP, T-6131), and the youngest sequence has a lower boundary dated to 1170±70 yrs BP (1174-985 cal yrs BP, T-5721). In P9, the peat sequence started to grow at 4230±50 yrs BP (4854-4652 cal yrs BP, T-5722), and growth continued until AD 1850, 100±70 yrs BP (265- -3 cal yrs BP, T-5723). Sand particles were recorded in the peat shortly after 1020±60 yrs BP (1048-801 cal yrs BP, T-6130).

Layer 3 – The aeolian sand includes five thin palaeosols, none of which are dated.

The source material for the aeolian deposits is probably marine shore deposits and perhaps till, with both the dominating wind directions.

*Palynological analyses*

Palynological analyses were carried out on profiles P7 (Ugland 1984) and P9 (Ugland 1984, Danielsen 1986) (Figs. 36-37). In general, two local PAZs are recognised throughout the sections.

*Alnus-Corylus*, local PAZ

The zone is characterised by tree pollen (AP) values of between 60 and 85 % ΣP, with *Alnus* values ranging up to 50 %. *Alnus* swamps dominated locally, confirmed by finds of tree stumps in the sediments, with their characteristic red colour. *Pinus* and *Corylus* are also present, but probably grew further up, on the hilltop. Finds of hazelnut shell fragments at the Mesolithic locality confirm the presence of hazel in the vicinity. The field layer comprised sedges and tall herbs like *Filipendula ulmaria*, Rosaceae (probably *Geum*), *Urtica* and ferns (Polypodiaceae). This local PAZ can be traced back to at least 7100 yrs BP (7940 cal yrs BP) and lasted until 1200 yrs BP (1130 cal yrs BP) (Viking Period) at P7 and approximately 1900 yrs BP (1850 cal yrs BP) (Roman Iron Age) at P9.

Human impact can be traced back to shortly after 4230±50 yrs BP (4854-4652 cal yrs BP, T-5722) by the appearance of *Plantago lanceolata*, which is normally regarded as an indicator of pasture and mowing (Behre 1981, Groenman-van Waateringe 1986) but may also reflect seashore meadows. However, since *P. lanceolata* pollen is not recorded here in the samples from P7, which is situated closer to the seashore, its presence probably reflects the first husbandry in the Middle Neolithic at the site. Furthermore, there is a rise in anthropogenic indicators around 3000 yrs BP (3200 cal yrs BP, interpolated), verified by pollen of Cerealia and weeds as well as an increase in *Rumex acetosa* type, *Potentilla* type, *Artemisia*, *Plantago major* and charcoal dust. *Triticum* pollen was recorded in P7 (Ugland 1984), but these records interpolated to 6000 yrs BP (6840 cal yrs BP) must be looked upon with some doubt. Human impact accelerates throughout the zone and there are simultaneous heath vegetation (*Calluna vulgaris*) and light-demanding species like *Potentilla erecta*. The human impact suddenly causes a collapse of the alder swamp sometime between 1900 and 1200 yrs BP (1850-1130 cal yrs BP).

*Cyperaceae-Rumex* or *Cyperaceae-Poaceae-Potentilla*, local PAZ

The lower zone boundary is characterised by a sudden drop in the AP curve to about 10-20 % ΣP, a drop in Polypodiaceae and a rise in Cyperaceae, Poaceae and *Potentilla*. The area became treeless. Cyperaceae dominates at P7, on the lower, more humid part of the slope. On the upper part of the slope (P9), sedges competed with dry- and light-demanding herbs. Husbandry and cereal cultivation took place throughout the zone.

*Discussion and conclusion*

The Mesolithic locality, dated to 8500±240 yrs BP (9882-9131 cal yrs BP, T-5321), is embedded in the gravel and sand layer (layer 1), believed to be of marine origin, near the 13-14 m contour line. This is in a period when the sea-level had regressed to a minimum (probably -2 m) in the area. The Tapes transgression followed this event. The freak Storegga tsunami event happened during the early part of the Tapes transgression, around 7200 yrs BP (8000 cal yrs BP, see the discussion in Prøsch-Danielsen 2006a:85-86). This disaster probably eroded older sediments along the coast. Soon after,


*Fig. 38. Aerial view of the outlet of the River Figgjo (see also Fig. 39). Photo: Norsk fly og flyfoto.*

a marine gyttja (layer 3) dating back to 7080±90 yrs BP (7997-7799 cal yrs BP, T-6894) was deposited between the +5 and +6 m levels at the Stavanger Airport site, and on the slopes near the Solavika site peat accumulated when the groundwater rose due to the ongoing transgression, initially on the lower part of the slope (P7) around 7100 yrs BP (7940 cal yrs BP) and about 3000 calendar years later, 4230 yrs BP (4830 cal yrs BP), on the upper part of the slope (P9). As humus accumulated, this peat layer gradually developed into swampy carr peat with *Alnus*.

The continuous peat sequence at Solavika, 10.12 m asl, confirms the lithostratigraphy and chronology at the Stavanger Airport site. The base of the peat layer at Solavika has been dated to 7120±110 yrs BP (8030-7831 cal yrs BP, T-5720), which implies that neither the Tapes transgression nor "freak" events reached the 10 m contour line later than 7100 yrs BP (7940 cal yrs BP) in this area (Prøsch-Danielsen 2006a).

The Tapes transgression here was double-peaked, the first peak being dated to around 6500 yrs BP (7430 cal yrs BP) and the second and highest one to around 4800 yrs BP (5540 cal yrs BP). Large areas were eroded and flooded, and marine sand (layer 5 at the Stavanger Airport site) covered parts of the flat, low-lying Sola plain below the present 10 m level. When the sea regressed, large areas were exposed to wind and waves before vegetation became established, and the result was sand drift. This aeolian sand layer is only recorded above the peat sequence (layer 2) in the lower profile, P7, and has a maximum date of 4720±70 yrs BP (5580-5326 cal yrs BP, T-6131) corresponding closely to the second Tapes peak. When the sand drift ceased, the alder carr recovered. The pollen record contains no indications of deforestation or human impact at this time. This sand layer is thus a good example of aeolian activity caused by a combination of wind and exposed sediments brought about by a transgression.

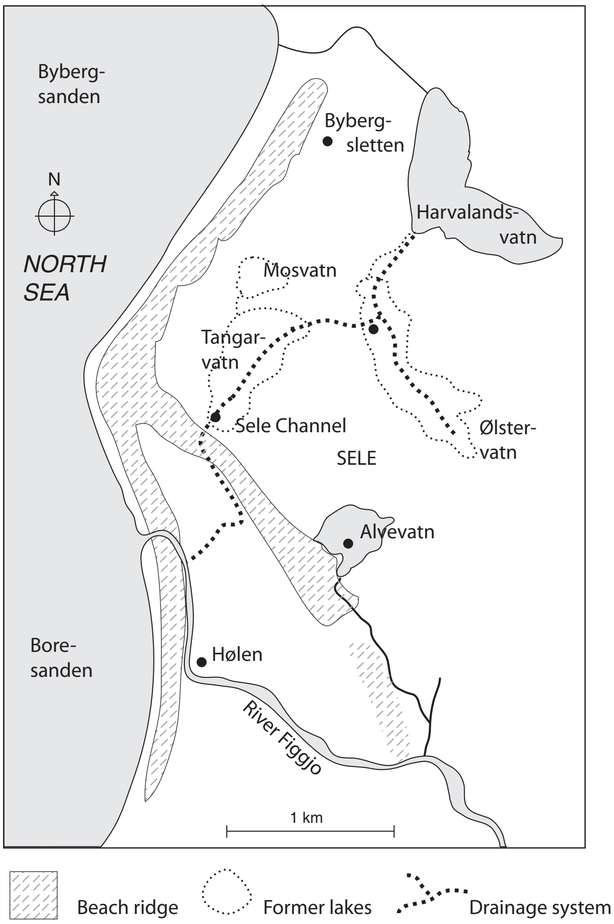



*Fig. 39. The sites investigated near the River Figgjo. Map redrawn from Thomsen (1983) and Prøsch-Danielsen (2006a: Fig. 57).*

The first indication of husbandry in the area is recorded in the pollen diagram shortly after 4230±50 yrs BP (4854-4652 cal yrs BP, T-5722) and the first records of Cerealia followed by a rise in charcoal dust particles are estimated to appear about 3000 yrs BP (3200 cal yrs BP, 85 cm level in P9). However, the activities bringing these about did not affect the local *Alnus* swamp on the hill slope until 1910±80 yrs BP (1941-1736 cal yrs BP, T-6968A). Simultaneously, Poaceae in combination with anthropogenic indicators like *Plantago lanceolata* and *Rumex acetosa* type increased. This anthropogenic impact had considerably accelerated by around 1020±60 yrs BP (1048-801 cal yrs BP, T-6130). Trampling and cereal cultivation had damaged the soil cover, resulting in incipient sand drift, which continued here until the present day, only interrupted by short standstills that allowed a peat layer or palaeosol to recover.

**Localities 6-10: The mouth of River Figgjo**

The Figgjo is a river flowing westwards through Klepp in central Jæren to enter the North Sea at Honnsvika (Boresanden) (Figs. 1, 38 and 39). Several lakes close to the coast from Hellestø in the north to Reve in the south have been dammed by beach ridges or are greatly affected by movements in unconsolidated deposits. They have had a complex evolution, but must be regarded as a single, closely linked, geographical entity (Prøsch-Danielsen 2006a).

This landscape has been subjected to changes throughout the Holocene, especially since the 1860s. Several lakes have had their water level lowered (Harvalandsvatn and Alvevatn) and some have been entirely drained (e.g. Tangarvatn/Selevatn, Mosvatn and Bybergsvatn/Ølstervatn) (Bang-Andersen 1986) (Figs. 21, 22 and 39). Some used to drain northwards, but now drain southwards.

In 1982, the Museum of Archaeology, Stavanger surveyed prehistoric sites near a former lake named Ølstervatn in connection with intermunicipal plans to extend waste-disposal sites and construct new ones near the mouth of the Figgjo. In connection with this survey, Thomsen (1983) studied the lithostratigraphy along several transects to reconstruct the past topography and sea-level fluctuations in different periods (Fig. 40). However, already in the late-1930s, Fægri had made a particular study of this area in his classical work on Jæren (Fægri 1940). Both these works are also important in connection with investigating aeolian activity in prehistoric times and more recently. One of Fægri's localities, Alvevatn, was re-investigated in 1995 to study human impact and soil erosion in the area (Prøsch-Danielsen & Simonsen 2000a, Prøsch-Danielsen & Sandgren 2003).

This area is of great interest in terms of both geology and archaeology. Several archaeologists have pointed out that it was probably the most densely populated part of Jæren in the Mesolithic and Neolithic (e.g. Gjessing 1920, Lillehammer 1988, Møllerop 1989, Bang-Andersen 1999). Several Mesolithic habitation sites have been discovered and some of those along the River Figgjo have been excavated (Bang-Andersen 1995). In the Late Mesolithic, Sele was a large wetland with favourable conditions for water birds, fish and seals. Some of the richest sites, called the "Sele flint-fields" (Gjessing 1920), are found from the mouth of the River Figgjo northwards across Tangarhaug and along the banks of the former lake, Tangarvatn/Selevatn. Artefacts ranging in age from the Mesolithic to the Iron Age have been found in the area.

Drillings were carried out by using a 54 mm auger piston corer on the low-lying plain north of the River Figgjo in 1982 (Thomsen 1983). Several transects were drilled near the northern border of Ølstervatn, along the old and new channel at Sele and over the entire aeolian plain of Bybergsletten. Three of these sediment profiles, Sele Channel, Bybergsletten and Ølstervatn, which are relevant to the problem of sand drift, will be referred to in this paper. They have been analysed for pollen and diatoms, and have been radiocarbon dated. Thomsen (1983) stressed that the results had to be looked upon as preliminary and that new samples were necessary to be able to draw well-founded conclusions. After a thorough discussion of her results, we find the sediment studies reliable. However, the result of the analyses of some pollen samples and radiocarbon dates do not fit into the general chronological pattern and must be looked upon critically. Sampling from sediment profiles would have been preferable for this study. Some material might have been moved upwards or downwards by the auger piston during coring, causing serious dating problems and preventing us from reconstructing the past vegetation at the site. Consequently, the pollen diagrams can only be divided into reasonable local PAZ with caution.

In the mouth of the River Figgjo, southeasterly winds may have moved the thick marine and glaciofluvial deposits, while the sand moved by northwesterly winds may have originated in older marine shore deposits.

## 6. Sele Channel

A drainage channel at Sele is located 1 km from the sea. A total of eight cores from two transects were investigated there. Coring point no. 1, near the southern border of a former lake, Tangarvatn, was chosen for more detailed studies (Fig. 39).

*Lithostratigraphy, palynological analysis and chronology*

The lithostratigraphy was described and discussed by Thomsen (1983) and is shown in the pollen diagram (Fig. 41). The site was also discussed by Prøsch-Danielsen (2006a). Radiocarbon dates are given in Table 1.

A 700 cm sequence of sediments was recorded. The sequence (top 7.35 m asl) is as follows:

Layer 5: aeolian sand with thin palaeosols containing charcoal (0-600 cm)
Layer 4: dark-brown peat/gyttja with charcoal (600-612 cm)
Layer 3: upper gyttja with sand and gravel (612-655 cm)

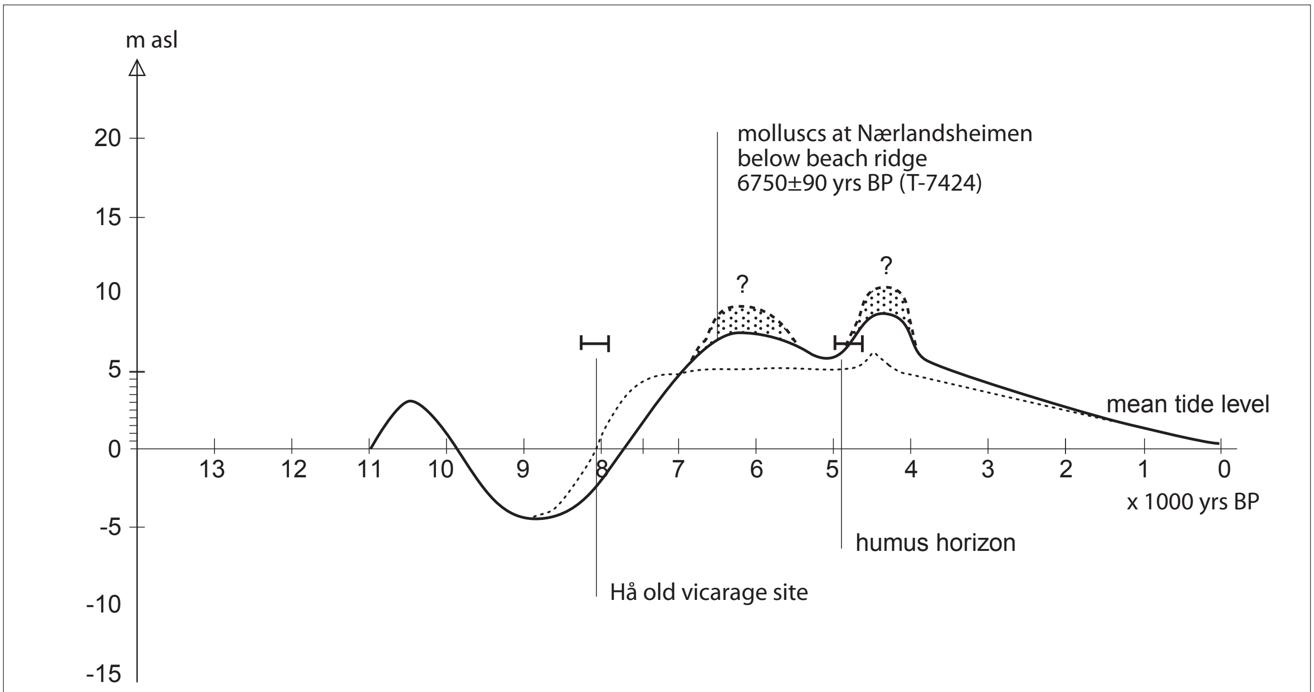



*Fig. 40. The sea-level displacement curve for the area near the outlet of the River Hå in central Jæren (Prøsch-Danielsen 2006a: Fig. 70, modified from Bang-Andersen & Thomsen 1993).*

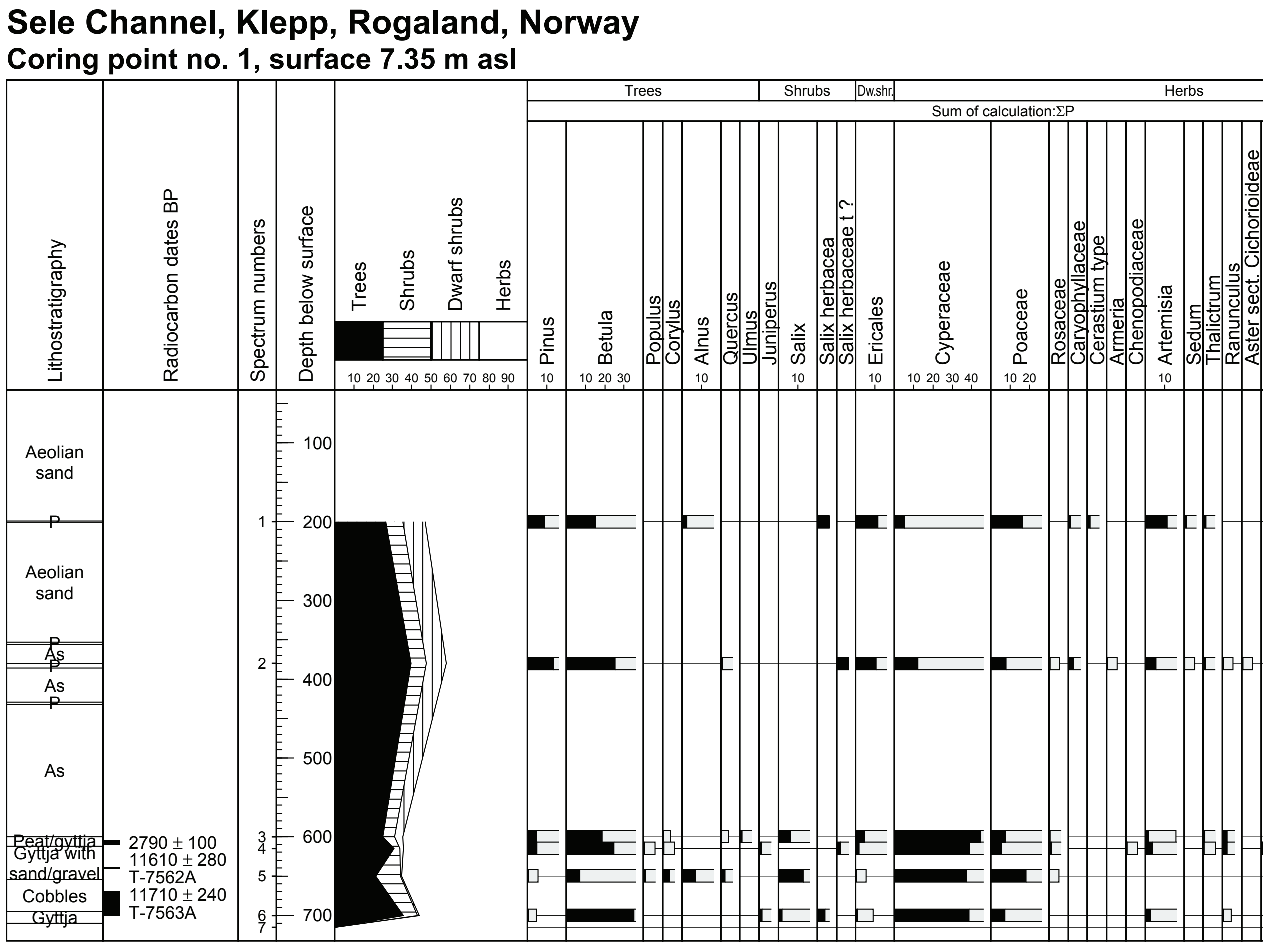



*Fig. 41. Percentage pollen diagram from Sele Channel (Thomsen 1983). Drawing: L. Prøsch-Danielsen.*

Layer 2: rounded pebbles and cobbles (655-695 cm)

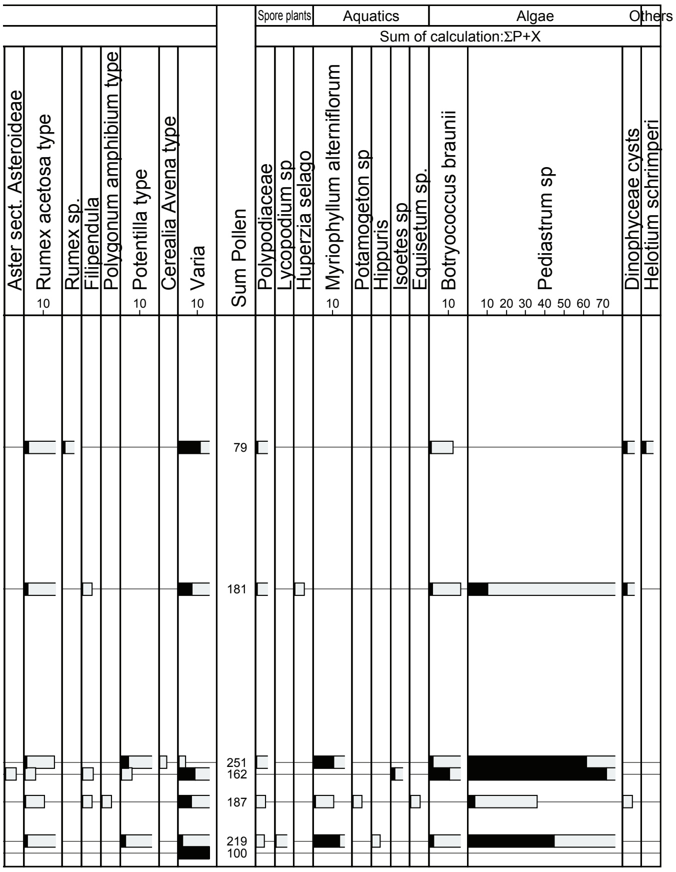
Layer 1: lower gyttja (695-715 cm)

Layer 1 – The lower gyttja has been dated to 11,710±240 yrs BP (13,784-13,321 cal yrs BP, T-7563A) and 12,110±300 yrs BP (14,601-13,645 cal yrs BP, T-7563B) at a depth of 700 cm. The only pollen sample which was analysed reflects a treeless Late Weichselian flora. The gyttja layer is lacustrine.

Layer 2 – Rounded pebbles and cobbles (up to 40 cm thick). No dates.

Layer 3 – The upper gyttja with sand and gravel is 43 cm thick. The middle of this layer has been radiocarbon dated to 11,610±280 yrs BP (13,749-13,225 cal yrs BP, T-7562A) and 11,990±230 yrs BP (14,135-13,569 cal yrs BP, T-7562B). Two pollen samples have been analysed; the lower one includes taxa from thermophilous trees like *Corylus*, *Alnus* and *Quercus* which are probably redeposited, while the upper one reflects a Late Weichselian flora.

Layer 4 – The dark-brown peat/gyttja layer is approximately 12 cm thick. The uppermost pollen sample contains pollen of tree species associated with a warmth-demanding flora and species associated with open heath vegetation, charcoal particles and pollen of Cerealia, probably *Avena*. Cyperaceae dominate and record a rather humid site. The lowermost pollen sample, which Thomsen (1983) described as gyttja, lacks the warmth-demanding flora. Unfortunately, two radiocarbon dates from this layer differ greatly, being 2790±100 yrs BP (3003-2772 cal yrs BP, T-6783) and 11,750±160 yrs BP (13,756-13,431 cal yrs BP, T-6782A), respectively. This indicates a disturbance in the lower layers. It also reveals a hiatus between layers 3 and 4. Nevertheless, the youngest date gives the maximum age of the sand drift at this site.




Analysis: Hanne Thomsen 1983. Redrawn: L. Prøsch-Danielsen 2007

Layer 5 – The aeolian sand is up to 600 cm thick and includes four palaeosols, two of which have been analysed for palynomorphs. These samples record open, treeless vegetation (AP<40 %) dominated by herbs with an increasing component of shrubs and dwarf shrubs (Ericales) upwards. Some pollen taxa, Rosaceae, Caryophyllaceae, *Artemisia*, *Sedum*, *Thalictrum, Filipendula* and *Rumex acetosa* type, indicate a seashore meadow or that the locality was close to the sea. Cereal cultivation (*Avena*) is recorded.

The maximum date of the sand drift at this site is 2790±100 yrs BP (3003-2772 cal yrs BP, T-6783) at this site. This event took place after deforestation in an open, cultivated landscape in the middle of the Bronze Age.

**7. Bybergsletten**

Bybergsletten is now a flat aeolian plain situated 9 m asl (Fig. 39). A total of 16 cores in three transects were investigated (Thomsen 1983). Coring point no. 8, near Sandmarka and south of Harvalandsvatn, is situated just inside the Late Weichselian beach ridge. This point was chosen for further studies.

*Lithostratigraphy, palynological analysis and chronology*

The lithostratigraphy was described and discussed by Thomsen (1983) and is shown in the pollen diagram (Fig. 42). The site was also discussed by Prøsch-Danielsen (2006a). Radiocarbon dates are given in Table 1.

Layer 6: aeolian sand with palaeosols and a peat layer (0-175 cm)
Layer 5: peat (175-275 cm)
Layer 4: peat (4a) and sand (4b) with palaeosols and wood (275-375 cm)
Layer 3: coarse marine sand grading into fine sand downwards (375-495 cm)
Layer 2: silt (495-650 cm)
Layer 1: silt, clay and gravel (650-? cm)
Bottom: gyttja?

Layers 1 and 2 – These layers are found between 4.8 and 2.5 m asl. In the lower part of the silt layer, the auger piston corer encountered an "impermeable" layer of silt, clay and gravel. This impediment prevented sampling further downwards. However, it was possible to penetrate the layer by using a smaller sounding stick. Layer 1 rested on "soft" gyttja, at least 4.5 m thick, which reveals the existence of a depression, maybe a fjord or a lagoon, prior to the deposition of layers 1 and 2.

The pollen content in a sample from layer 1 is rather sparse and dubious. The sample contains pollen of species indicative of a cold, mid-Younger Dryas flora, such as *Salix herbaceae*, *Betula* (probably *B. nana*), *Artemisia, Ranunculus* and *Sedum* (Thomsen 1983, Prøsch-Danielsen 2006a) as well as pollen of the warmth-demanding tree, *Alnus*, and spores of *Sphagnum*. The absence of typical Preboreal species like *Corylus, Filipendula* and the early immigrant in Rogaland, *Quercus*, supports the interpretation of a Late Glacial flora and implies that this layer consists of re-deposited till brought into the former basin. This most probably happened during the Younger Dryas transgression when the Late Weichselian beach ridge was built up and large areas were flooded and reworked. The input of *Alnus* and *Sphagnum* might be the result of contamination

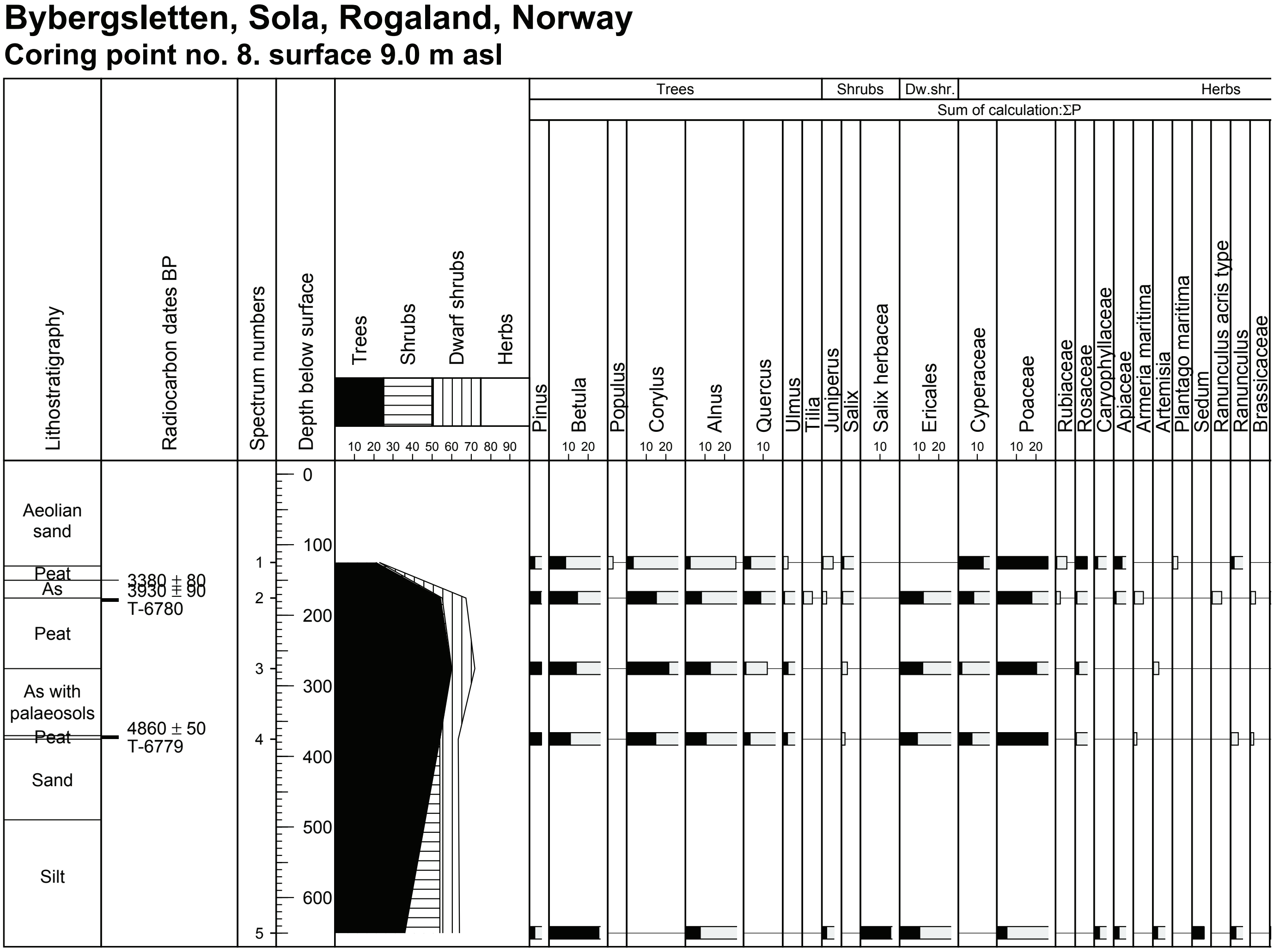


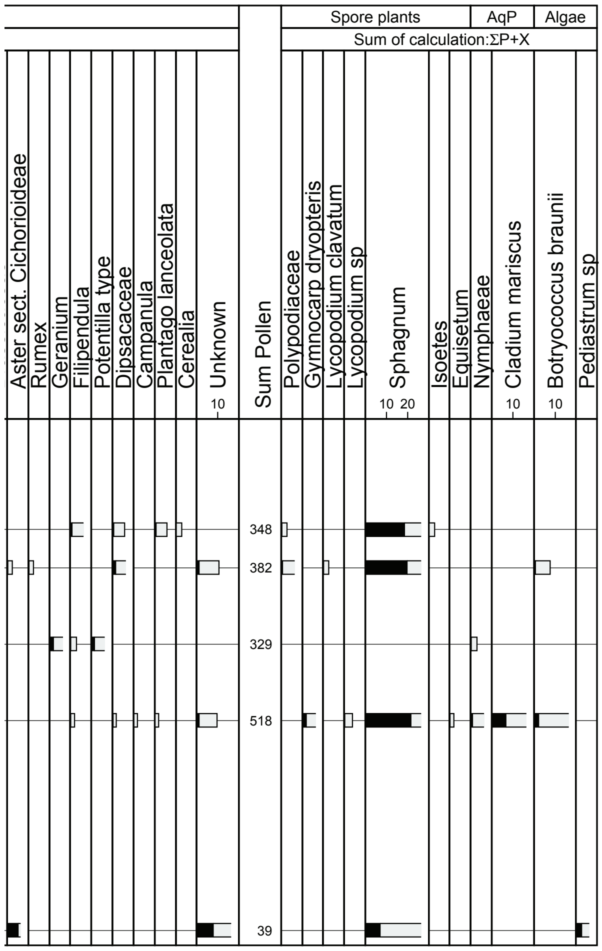

Fig. 42. Percentage pollen diagram from Bybergsletten (Thomsen 1983). Drawing: L. Prøsch-Danielsen. Analysis:

from younger sediments. The immigration of *Alnus* into this area is dated to about 8200 yrs BP (9170 cal yrs BP, see Alvevatn) and both *Alnus* and *Sphagnum* suggest local, humid vegetation.

Layer 3 – This coarse sand is older than 4860±50 yrs BP (5651-5490 cal yrs BP, T-6779). It was probably deposited during the Tapes transgression and is of marine origin.

Layer 4 – This layer consists of alternating peat (4a) and sand layers (4b). Some twigs have been recorded. The lowermost peat layer has been dated to 4860±50 yrs BP (5651-5490 cal yrs BP, T-6779). The pollen assemblage represents open forest vegetation (mixed oak forest) (AP>50 %) with pollen from light-demanding dwarf shrubs and herbs like *Calluna vulgaris, Poaceae, Campanula* and *Plantago lanceolata*. The numerous finds of pollen from the aquatic plants, *Nymphaea* and *Cladium mariscus*, as well as spores of *Equisetum*, indicate the presence of a nearby water body, probably Harvalandsvatn (a lake 500 m to the southeast). Layer 4 obviously represents a terrestrial unit. It is interesting to note that these alternating peat and sand layers developed soon after the regression from the second Tapes peak, dated to around 4800 yrs BP (5540 cal yrs BP, Prøsch-Danielsen 2006a) (Fig. 40). In that period, large unprotected areas were exposed to wind and waves that might have resulted in sand drift. The presence of *Plantago lanceolata* in the pollen record may also indicate that husbandry was introduced into the area, causing increasing grazing pressure.

Layer 5 – This layer represents a period of stability allowing a thick peat cover to develop. The upper boundary is dated to 3930±90 yrs BP (4516-4239 cal yrs BP, T-6780). AP has increased to about 60 %, *Plantago lanceolata* is absent, but otherwise the pollen assemblage




Hanne Thomsen 1983. Redrawn: L. Prøsch-Danielsen 2007

(two spectra) is similar to that in layer 4.

Layer 6 – The uppermost unit of the sediment sequence contains aeolian sand with palaeosols of varying thickness. The sand drift began around 3930±90 yrs BP (4516-4239 cal yrs BP, T-6780). This date corresponds to the second forest clearance period at the transition between the Middle Neolithic II and the Late Neolithic I (Prøsch-Danielsen & Simonsen 2000a, 2000b). In Jæren, the following deforestation was progressive and massive (Simonsen & Prøsch-Danielsen 2005). Already nearly 800 calendar years later at 3380±80 yrs BP (3715-3483 cal yrs BP, T-7564A), the pollen assemblage reveals a treeless landscape dominated by Cyperaceae and Poaceae where both husbandry and cereal cultivation (*Avena*) were introduced.

To conclude: The sand layer (4b) at Bybergsletten, sandwiched between the two peat layers (4a and 5), is another example (cf. Solavika P7) of aeolian activity brought about after a regression (after 4800 yrs BP, 5540 cal yrs BP) when large areas were exposed to sand drift. The uppermost unit of aeolian sand containing palaeosols reflects unstable soil conditions due to massive deforestation around 3800 yrs BP (4190 cal yrs BP), with subsequent husbandry and cereal cultivation. This agricultural practice led to sand drift. Holmsen (1922) and Thomsen (1983) pointed out that this sand drift was intense and subsequently dammed Harvalandsvatn, resulting in a rise in the water level.

## 8. Ølstervatn

A beach ridge built up during the Younger Dryas chronozone dams Ølstervatn (Fig. 39). The lake surface was originally 7.1 m asl, but has now been lowered to 5.6 m asl. A 550 cm sequence of sediments was recorded, described and discussed by Thomsen (1983). Radiocarbon dates are given in Table 1.

*Lithostratigraphy, palynological analysis (including diatom analysis) and chronology*

The diatom flora from Ølstervatn, recorded from the base upwards, shows a marine-lacustrine to brackish-marine sequence of Late Weichselian age followed by a lacustrine Holocene sequence (Thomsen 1983: Fig. 18). The Late Weichselian sequence is of great value for sea-level studies and was described by Prøsch-Danielsen (2006a). Only features from the lacustrine Holocene sequence are relevant as regards sand drift (Fig. 43).

Layer 4: fine detrital gyttja (0-77 cm)
(no more information available)
Layer 3: algal gyttja with sand lenses
(77-105 cm)
Layer 2: gyttja with twigs (105-150 cm)
Layer 1: detrital gyttja with sand (150-170 cm)
Below: sandy gyttja

Layer 1 – Following its isolation from the sea, a body of seawater became a freshwater lake (detrital gyttja layer with sand) 10,160±220 yrs BP (12,143-11,341 cal yrs BP, T-7565A) (1.67 cm depth). At this level, there is an abrupt rise in such lacustrine algae as *Botryococcus braunii* and *Pediastrum*, and marine indicators are not present. The lower part of this layer shows the early-Preboreal chronozone sequence that is well known in

Rogaland; first a *Betula-Empetrum-Poaceae* LPAZ, then a *Betula-Pinus* LPAZ and finally a rise in *Corylus*. A disturbance has been recorded in one spectrum (no. 13) in the lower part, as seen from the *Corylus avellana* pollen curve. The influx of *Corylus* pollen suddenly ceases and the sediments seem to have been mixed or disturbed. Thomsen (1983) assumed that this was a local feature. The sand in the sediment is probably due to in-wash from the lake borders and not of aeolian origin.

Layer 2 – This consists of algal gyttja that contains a layer of twigs and hazelnut shell fragments at 135-125 cm. Thomsen (1983) did not record any sand. The lower boundary corresponds with the rise in *Alnus*, about 8200 yrs BP (9170 cal yrs BP). Layer 2 includes the *Alnus* LPAZ and the younger *Quercus-Corylus* LPAZ, which marks the growth of mixed oak forest and the development of the climax forest. It also includes a decrease in AP from 90 to 50 %, shown by the pronounced decreases in *Corylus*, *Quercus* and *Ulmus*. There is a simultaneous increase in pollen from the light-demanding tree, *Tilia,* and agricultural indicators like *Rumex acetosa* type and *Plantago lanceolata* represent the introduction of husbandry, dated at 125 cm to 4560±150 yrs BP (5461-4977 cal yrs BP, T-6784A). This vegetation development agrees with the results from Alvevatn, discussed in more detail below. At Alvevatn, sand drift is recorded some hundred years after the first appearance of *Plantago lanceolata,* i.e. the introduction of husbandry, and the earliest sand particles were recorded at 4315±65 yrs BP (4968-4835 cal yrs BP, TUa-1598A).

Layer 3 – Sand lenses are recorded in the upper freshwater algal gyttja. Thomsen (1983) assumed that they marked the start of aeolian activity in the area. This level has not been radiocarbon dated, but an age between 4300 and 3800 yrs BP (4850-4190 cal yrs BP) is suggested. Biostratigraphically, the lower boundary of the layer corresponds to the local *Calluna* LPAZ, the age of which is dated to about 3800 yrs BP (4190 cal yrs BP) in this area (Prøsch-Danielsen & Simonsen 2000a, 2000b).

To conclude, the aeolian activity at Ølstervatn was caused by deliberate forest clearance with the subsequent establishment of heathland about 4300-3800 yrs BP (4850-4190 cal yrs BP). The sand drift was delayed

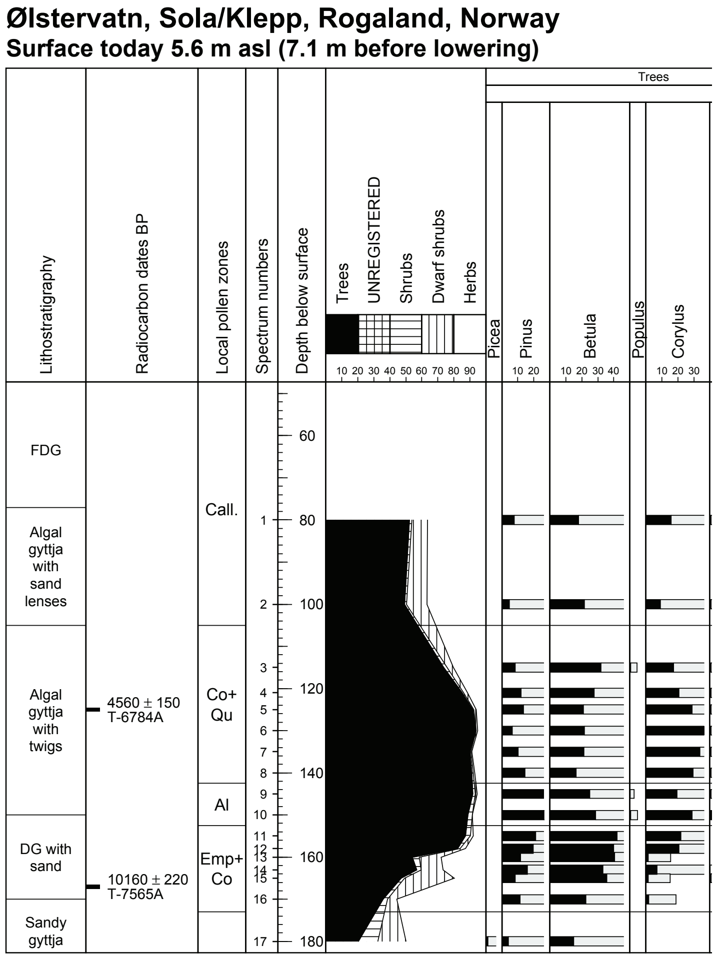
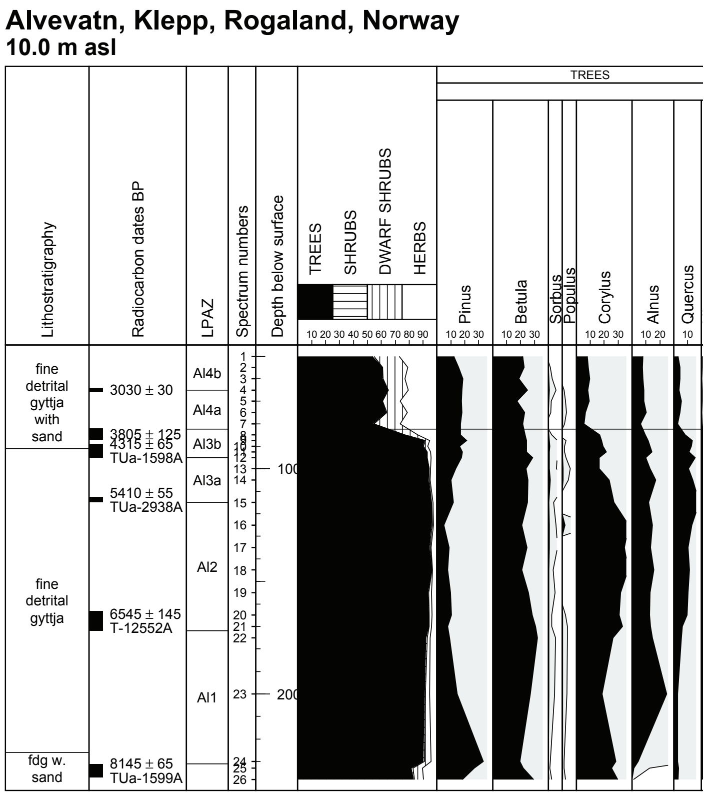
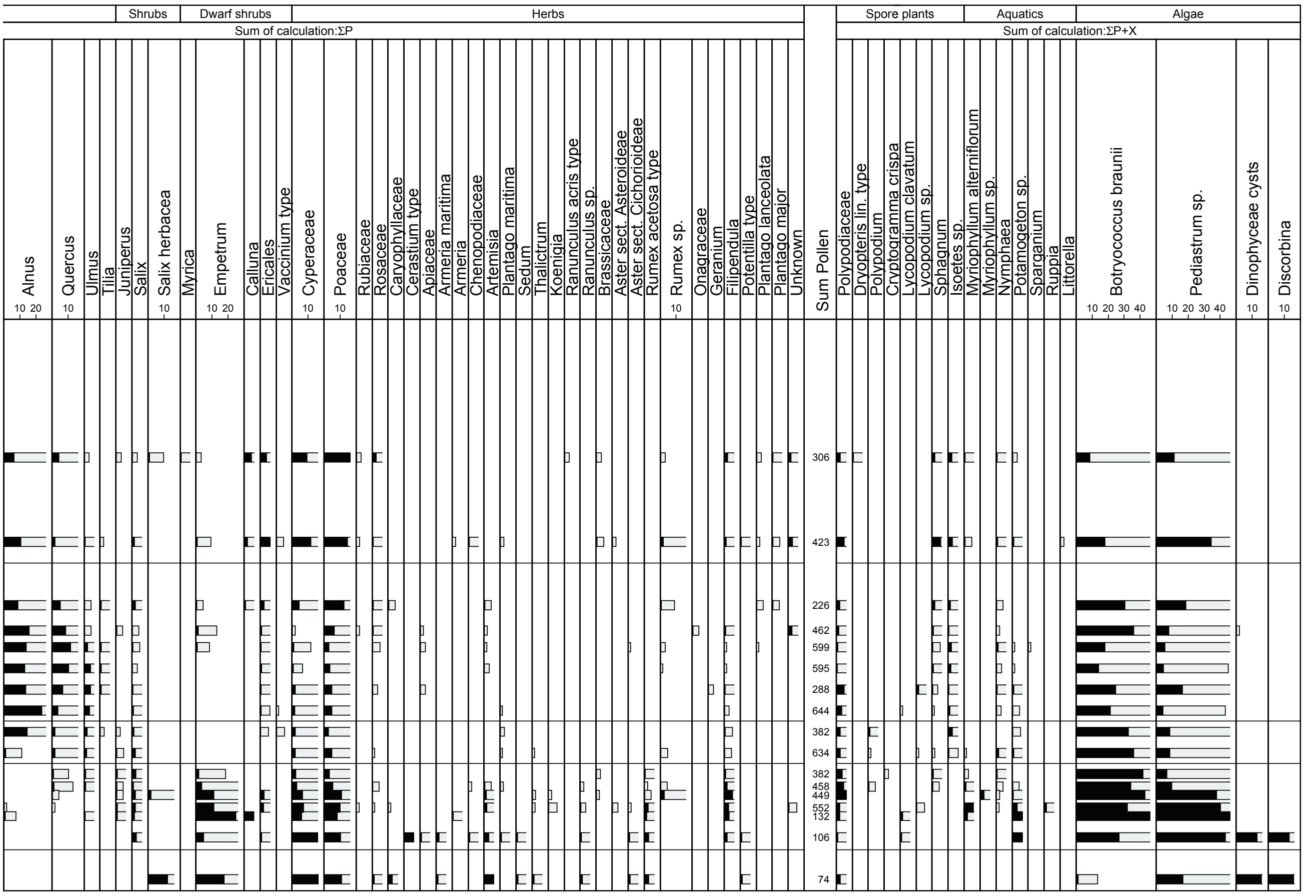


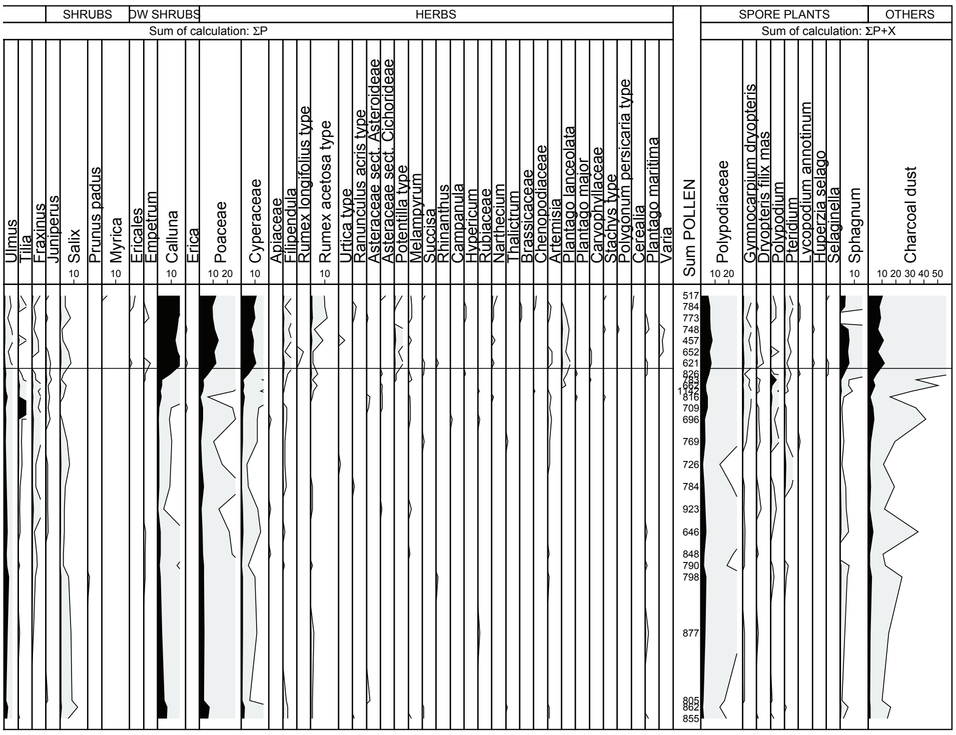

*Fig. 43. Percentage pollen diagram from Ølstervatn (Thomsen 1983).*






Analysis: Hanne Thomsen 1983. Redrawn: L. Prøsch-Danielsen 2007

*Drawing: L. Prøsch-Danielsen.*




Analysis: Lisbeth Prøsch-Danielsen 1995

*Fig. 44. Percentage pollen diagram from Alvevatn (Prøsch-Danielsen & Sandgren 2003: Fig. 5).*

by probably 200-500 calendar years compared to indications of husbandry. The thick brown soil cover, developed during the mixed oak stage, resisted erosion due to low grazing pressure for a long time in the Neolithic.

## 9. Alvevatn

Alvevatn is a small lake situated 10.2 m asl, approximately 1 km east of the coastline and the mouth of the River Figgjo (Fægri 1936, 1940, Thomsen 1983) (Fig. 39). The threshold is now located at 9.4 m asl. The lake originally covered approximately 60,000 m$^2$. It is dammed in the south by a Late Weichselian beach ridge, and the area further south has active and inactive dunes and marine shore deposits.

As mentioned earlier, Prøsch-Danielsen re-investigated Alvevatn by palynological analysis in 1995 to determine the history of deforestation and heath establishment in the area (Prøsch-Danielsen & Simonsen 2000a). Later, magnetic susceptibility analysis was used to record soil erosion in the area (Prøsch-Danielsen & Sandgren 2003) and study how the lake sediments responded to changes in the vegetation cover arising from natural causes like wind erosion and fluctuations in sea and lake levels, and from anthropogenic activity in the catchment basin.

*Lithostratigraphy and chronology*

Sediments were collected down to 270 cm below the

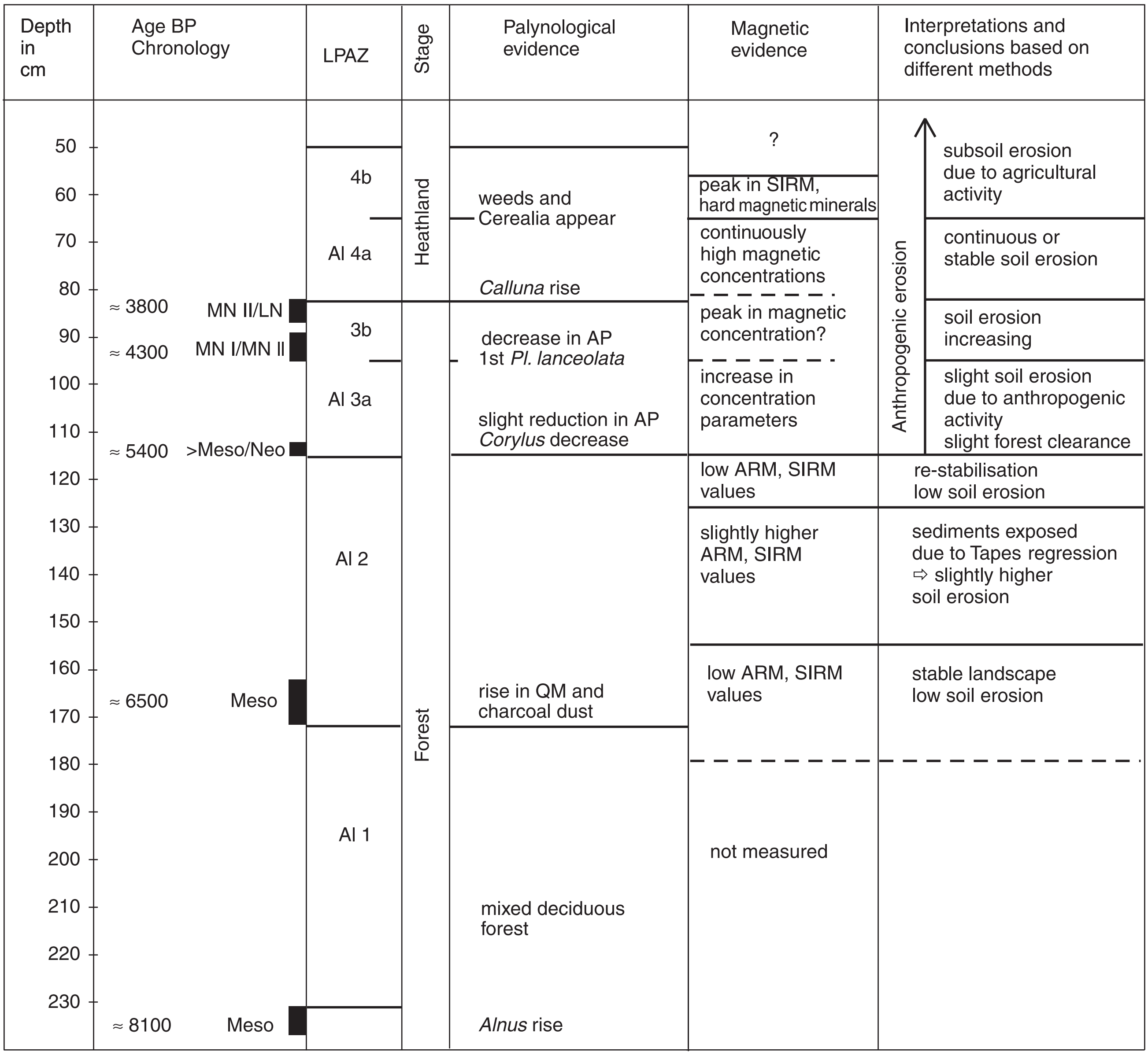



*Fig. 45. Interpretation of the palynological and magnetic susceptibility analyses from Alvevatn (Prøsch-Danielsen & Sandgren 2003: Fig. 7).*

surface using a 10 cm diameter Russian peat corer operated from a raft. The sediments started 50 cm below the water surface. The sequence showed nearly homogeneous detrital gyttja resting on a basal layer of sand and silt. Minerogenic particles were recorded in the upper and lower parts of the fine detrital gyttja and in the interval between 226 and 235 cm. Radiocarbon dates are given in Table 1.

Layer 4: fine detrital gyttja with sand (50-91 cm)
Layer 3: fine detrital gyttja (91-259 cm) (sand at 226-235 cm)
Layer 2: fine detrital gyttja with sand (259-265 cm)
Layer 1: sand and silt (265-270 cm)

Layer 1 – The sand and silt layer was probably deposited during the Late Weichselian, in a period when the sea-level was at least 10 m higher than today. It is thus most probably of marine origin.

Layer 2 – The fine detrital gyttja with sand was deposited prior to 8100 yrs BP (9020 cal yrs BP), during the Younger Dryas/Preboreal regression phase when large sandy areas lacking a protective vegetation cover became prone to wind erosion. Sand drift is recorded.

Layer 3 – This layer was deposited between >8145±65 yrs BP (9236-9007 cal yrs BP, TUa-1599A) and 4315±65 yrs BP (4968-4835 cal yrs BP, TUa-1598A).

Layer 4 – The upper fine detrital gyttja contains sand particles and was deposited from 4315±65 yrs BP (4968-4835 cal yrs BP, TUa-1598A) up to the present day.

*Palynological analysis*
The diagram (Fig. 44) is divided into four local pollen assemblage zones (LPAZ Al1-Al4). A radiocarbon dating at 231-237 cm (8145±65 yrs BP, 9236-9007 cal yrs BP, TUa-15599A) indicates that it covers a time span from the Mesolithic up to the present time (Prøsch-Danielsen & Simonsen 2000a, Prøsch-Danielsen & Sandgren 2003).

*LPAZ Al1*: 231-172 cm
(c. 8100-6500 yrs BP, 9015-7430 cal yrs BP)
The AP percentages are high throughout the zone (>90 %). The zone records a mixed, densely forested landscape dominated by *Pinus* and the deciduous forest species, *Alnus*, *Corylus* and *Betula*, along with shrubs and dwarf shrubs like *Salix* and *Calluna*. The lower boundary is determined by the immigration and rise of *Alnus*. The *Alnus* forest expands throughout the zone and probably replaces *Filipendula*, growing on wet, well-developed humic soils. The pollen record contains few taxa. The presence of *Plantago maritima* and Rubiaceae pollen confirms the near-shore location.

*LPAZ Al2*: 172-115 cm
(c. 6500-5400 yrs BP, 7430-6240 cal yrs BP)
The zone is characterised by high AP values (95 %). Its lower boundary can be distinguished by the rise in *Corylus*, *Quercus* and *Fraxinus,* and a slight decrease in the values for *Betula* and *Alnus*. The zone is characterised by the luxurious growth of mixed oak forest and the development of the climax forest. *Betula* and *Alnus* forest probably occupied the lake borders. Herbaceous types of pollen are less frequent in this zone than in the other zones. The lower boundary has been dated to 6545±145 yrs BP (7569-7323 cal yrs BP, T-12552A). Human impact has not been recorded.

*LPAZ Al3*: 115-82.5 cm
(c. 5400-3800 yrs BP, 6240-4190 cal yrs BP)
The AP/NAP ratio decreases throughout the zone, but is still high (AP values are 95-90 %). It represents a more open forest phase than the previous periods. The zone is characterised by the highest values of the mixed oak forest constituents, regular occurrences of *Betula* (25 %) and *Alnus* (15 %) and a stepwise decrease in *Corylus*.

A slight increase in microscopic charcoal particles and a more marked increase in herbaceous types of pollen are recorded. The vegetation development can be separated into two steps, which reflect two episodes of human impact starting at 115 cm and 95 cm, respectively.

The first episode is marked by the decrease in *Corylus* followed by the rise in *Tilia*. Slight forest clearance or human interference may have given the shade-tolerant *Tilia* an advantage. This event is dated to 5410±55 yrs BP (6288-6130 cal yrs BP, TUa-2938A), shortly before the transition from the Mesolithic to the Early Neolithic. The increase in microscopic charcoal particles indicates fires in the vicinity.

The second episode started 4315±65 yrs BP (4968-4835 cal yrs BP, TUa-1598A) at the transition between the Middle Neolithic periods I and II. This opening up of the previous densely wooded area can be seen by an increase in pollen from light-demanding vegetation, like Poaceae, *Rumex acetosa* type, *Plantago lanceolata, P. major* and *Stachys* type. The occurrences of *Plantago lanceolata* and *P. major* marks the first agricultural activity in the area, as these species are closely linked with areas grazed by domesticated animals.

*LPAZ Al4*: 82.5-50 cm
(c. 3800 yrs BP- present?, 4190 cal yrs BP- present?)
This zone is determined by an abrupt decline in tree pollen to approximately 60 %, and a rapid rise in pollen of *Calluna vulgaris* to 20 %, Cyperaceae, Poaceae, *Sphagnum* and charcoal dust particles. Heathland began to replace the local woodland. The increase in charred particles and the presence of anthropogenic species like *Plantago lanceolata* show that heathland expansion is a result of regular grazing and deliberate burning. It is also verified by the increase in, or presence of, species (pollen types) that are characteristic of wet and dry heaths and regularly burnt heather in this region, like Poaceae, Cyperaceae, *Narthecium, Succisa* and *Potentilla* type. This form of land use can be dated to 3805±125 yrs BP (4408-4006 cal yrs BP, T-12550A) at the transition between the Middle Neolithic II and Late Neolithic periods at this locality.

Indications of cereal cultivation occur at a depth of 65 cm through the appearance of pollen of Cerealia type, *Polygonum persicaria* type, Brassicaceae, *Stachys* type, *Ranunculus acris* type and an increase in Asteraceae, *Rumex acetosa* type and Chenopodiaceae. This event is dated to 3030±30 yrs BP (3325-3209 cal yrs BP, TUa-7254A).

*Magnetic susceptibility analysis*
The results of the palynological analysis and the magnetic susceptibility analysis (only the upper 180 cm) have been compared (Prøsch-Danielsen & Sandgren 2003) (Fig. 45). During the Mesolithic (LPAZ Al1 and Al2), very low magnetic concentrations occurred, indicating a stable environment with little or no soil erosion during the older, densely forested periods. However, from around 6000 yrs BP (6840 cal yrs BP) there is a period (depth 155-126 cm) with slightly higher ARM and SIRM values, suggesting somewhat increased erosion, but this occurs so early (Late Mesolithic) that traditional agrarian activity is precluded as a likely explanation as far as we know today. During the Tapes transgression, large areas close to the lake were flooded, and they became prone to wind erosion during the subsequent regression phase as they lacked a protective vegetation cover. The enhanced magnetic concentrations in this period can most probably be explained as a result of moderate aeolian activity before the soil was restabilised by a new vegetation cover, represented by the lower magnetic concentrations above (125-115 cm).

At Alvevatn, modest human interference (LPAZ Al3a, c. 5400 yrs BP, 6240 cal yrs BP) or slight agricultural activity (LPAZ Al3b, c. 4300 yrs BP, 4850 cal yrs BP) are recognised by a marked rise in the magnetic concentration, even in the forest stage. Sand particles are recorded from 4300 yrs BP (4850 cal yrs BP) onwards. However, the transition from closed woodland to man-made heathland, LPAZ Al3/LPAZ Al4, is paralleled by the most prominent fluctuations in the magnetic mineral parameters (seen by rising ARM and ARM/SIRM values and a rise in SIRM values), interpreted as topsoil erosion in the catchment basin. A period of cereal cultivation recognised in the pollen record, LPAZ Al4b, led to subsoil erosion during the heathland stage. This is recorded in the magnetic mineral analyses as an increase in backcoercivity values due to the presence of a hard magnetic component, most probably as a result of ploughing penetrating and exposing the subsoil.

Two events resulting in sand drift have been recorded at Alvevatn during the last 7400 calendar years. The first took place between c. 6500 yrs BP (7430 cal yrs BP) and c. 5400 yrs BP (6240 cal yrs BP) due to the exposure of nearby sediments during the Tapes regression. The second event was caused by anthropogenic erosion starting with slight forest clearance in the Late Mesolithic, c. 5400 yrs BP (6240 cal yrs BP), resulting in sand drift at c. 4300 yrs BP (4850 cal yrs BP) and escalation at c. 3800 yrs BP (4190 cal yrs BP) due to deforestation with the subsequent establishment of heathland. Subsoil erosion is recorded in the upper layers at 3030±30 yrs BP (3325-3209 cal yrs BP, TUa-7254A).

## 10. Hølen

Fægri (1940) investigated a sediment section at Hølen, immediately behind the Tapes beach ridges approximately 500 m from the coast and upstream from the mouth of the River Figgjo (Fig. 39). The stratigraphy showed a gyttja layer between a lower fluvial sand layer and overlying aeolian sand. The top of the section was 4.6 m asl (Fig. 46). The Tapes beach ridge system (about 8.7 m asl) is now broken by the River Figgjo, which separates Selesanden and Boresanden. A lagoon formed inside this system at some time in the past.

Pollen and diatom analyses of the gyttja layer disclosed a lower brackish phase and an upper marine phase separated by a freshwater phase (Fig. 47). This double-peaked Holocene transgression recorded by Fægri (1940) was confirmed by Prøsch-Danielsen (2006a), who dated the first marine phase to about 6500 yrs BP (7430 cal yrs BP) and the second, short-lived, one to about 4800 yrs BP (5540 cal yrs BP). The second peak took place at the same time as the formation of the beach ridges (Fægri 1940).

The environment when the sea-level changes occurred was capable of triggering aeolian activity, but this is only recorded after the regression following the second peak. The sand drift is younger than 1985±25 yrs BP (1985-1896 cal yrs BP, TUa-7251A). Large sandy plains without a vegetation cover were then exposed to wind (and waves) from the North Sea.

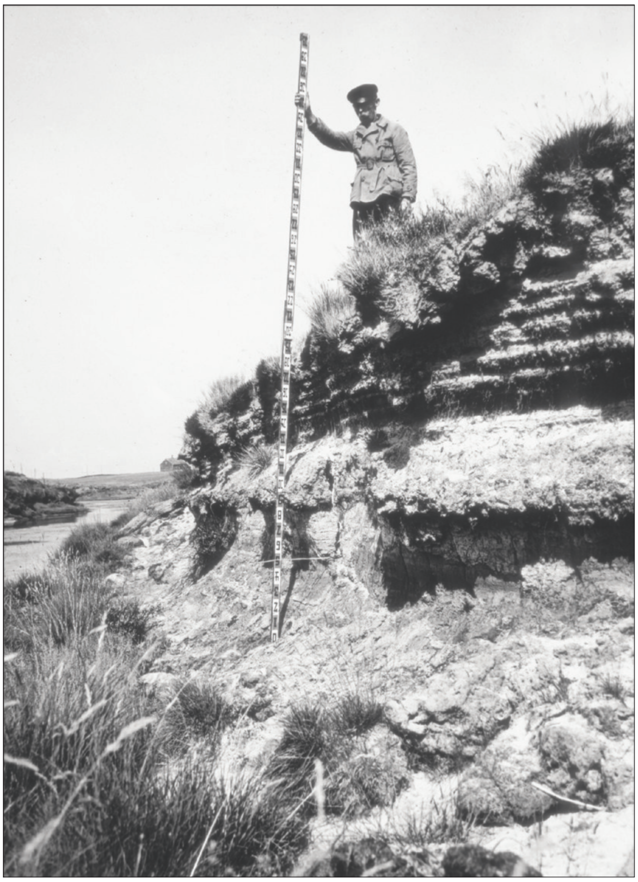


*Fig. 46. Sediment section from Hølen about 500 m upstream and to the south of the outlet of the River Figgjo (Fægri 1940: Fig. 22).*

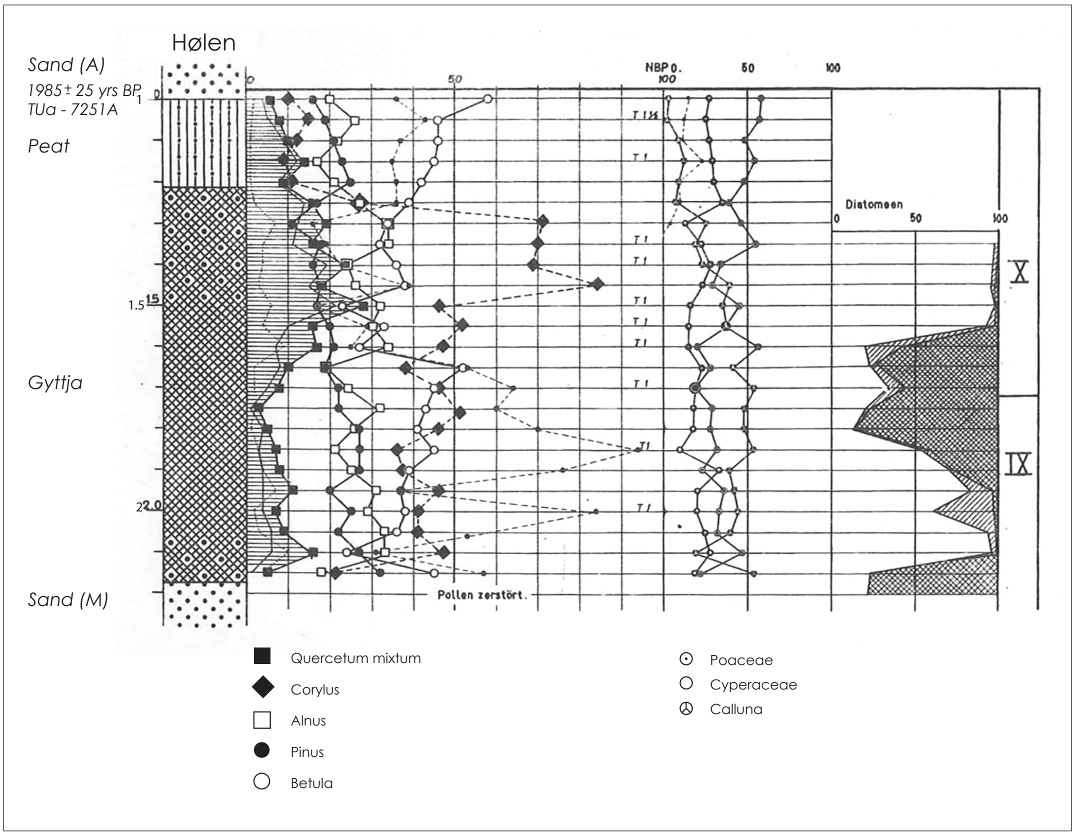



*Fig. 47. Percentage pollen diagram from Hølen about 500 m upstream and to the south of the outlet of the River Figgjo (Fægri 1940, with a new radiocarbon date added).*


*Fig. 48. Aerial view of the bay at Ognasanden. Photo: Norsk fly og flyfoto.*

## Area C

Coastal areas classified as sandy beaches are also encountered in area C. The sandy beaches in the Ogna area constitute the southern fringe of the Jæren Landscape Protected Area. Otherwise, the Dalane coast is dominated by exposed bedrock and almost lacks Quaternary sediments. The topography at Ogna marks an abrupt shift from the low-lying parts of Jæren with their thick Quaternary deposits to the north and northwest (area B) and the rocky Dalane area (area C) to the south (Figs. 48 and 49). There are no sandy beaches between the Ogna area and Lista on the south coast.

In the Ogna area, there are no indications of the original material for the aeolian deposits when southeasterly winds blew because bedrock dominates in that direction today. With both of the main wind directions, the aeolian deposits in this area may have originated from the shore, from the till to the north of the area or from older sand deposits.

**11. Slettabø**

The archaeological site at Slettabø in Ogna (Figs. 50 and 51) has occupation layers from the Stone Age and Bronze Age sandwiched in aeolian sand. An amateur archaeologist, Emelankton Aadnesen, discovered the site, which was later excavated by Arne Skjølsvold during the summers of 1963, 1965, 1966 and 1968 (Skjølsvold 1972, 1977:266). The investigation was financed by the Research Council of Norway (NFR). Asbjørn Simonsen (unpublished pollen diagrams from 1974 and 1976) carried out the pollen investigation. The site was reinterpreted by Indrelid (1974), Myhre (1979), Bruen-Olsen (1992) and Glørstad (1996).

*Fig. 49. Ognasanden to the south of Jæren, looking northeast (Fægri 1940:80, Fig. 6).*

The Ogna district has many prehistoric sites, especially from the Stone Age. Slettabø is located in the sand dunes near the mouth of the River Ogna (Skjølsvold 1977:14 ff). Aeolian sand and rock outcrops dominate the area. The site stands 5-9 m asl on the southeast side of a rock about 300 m from the sea and is protected from the prevailing northerly and northwesterly winds. The two pollen sampling sites are located approximately east and northeast of the archaeological site (Skjølsvold 1977:19-21, Plate 1).

The coast off Slettabø is now almost devoid of skerries and is exposed to the North Sea. The maximum height of the Holocene sea-level displacement curve during the second Tapes peak was about 5.5 m asl, and was attained about 5200-4800 yrs BP (5930-5540 cal yrs BP) (Bird & Klemsdal 1986) (Fig. 52). In the Early and Middle Neolithic, the shoreline was close to the archaeological site, which was probably on an island (Skjølsvold 1977:19, 187-188) (Fig. 50). At that time, the area had many small islands and sheltered inlets with good living conditions for hunter-gatherers who also engaged in fishing and trapping. This is confirmed by the osteological material determined by Håkon Olsen (in Skjølsvold 1977:68 ff) from occupation layers I-III and by bone artefacts, including decorated bone fragments, fishhooks and harpoons (occupation layer II) (Skjølsvold 1977:66-67, Plate 25). The occupation layers also contained bones from red deer (*Cervus elaphus*), various species of cod, marine mammals like seals (*Phocidae*) and the common porpoise (*Phocaena phocaena*), and various seabirds, as well as white-tailed eagles (*Haliacetus albicilla*). Large numbers of cow (*Bos taurus*) bones were found in occupation layers I and II.

*Lithostratigraphy and chronology*

Skjølsvold (1977:27 ff) described the lithostratigraphy at the archaeological site(s) (Fig. 53), which was characterised as a sand accumulation area. If erosive forces had dominated, the site could have resulted in deflation of artefacts, termed a "flint field" in older Norwegian archaeological literature. The generalised stratigraphy from top to bottom was:

Layer 8: fine-grained, light-grey aeolian sand
Layer 7: greyish-brown aeolian sand mixed with weathered material
Layer 6: greyish-black occupation layer I, organic layer 3 (0-50 cm, average 30-40 cm), Bronze Age (2900-2400 yrs BP, 3030-2400 cal yrs BP)
Layer 5: greyish-yellow aeolian sand
Layer 4: greyish-black occupation layer II, organic layer 2, Middle and Late Neolithic (3800-4700 yrs BP, 4190-5400 cal yrs BP)
Layer 3: yellowish-brown aeolian sand
Layer 2: greyish-brown occupation layer III, organic layer 1 (sometimes two thin layers intercalated with light-coloured aeolian sand, average 10 cm), Early and Middle Neolithic (4800-4400 yrs BP, 5540-4960 cal yrs BP)
Layer 1: light-coloured sand with a flake of charcoal and dust (4800 yrs BP, 5540 cal yrs BP)

Skjølsvold (1977:182) distinguished three (perhaps four) habitation periods:

- The oldest occupation layer III can be dated to the Early Neolithic period C and Middle Neolithic I (a short pre-ceramic period at the transition from the Early Neolithic period C to the Middle Neolithic I or the last part of the Early Neolithic period C). However "the archaeological material does not contain any demonstrably Neolithic elements, and the settlement is assumed to belong to a purely Mesolithic hunter's culture" (Skjølsvold 1977:267).
- The middle occupation layer II was from the transition between the Middle and the Late Neolithic (MN IV-V and LN), a more intense and longer period than the oldest period.
- The youngest occupation layer I was dated to the Early Bronze Age. This habitation lasted longer than the two previous ones. The site was possibly also in use during the Late Bronze Age.

The radiocarbon dates from Slettabø (Nydal *et al.* 1972, Skjølsvold 1977:175-182, Gulliksen *et al.* 1978, Glørstad 1996, this volume) (Table 1) give maximum and minimum ages for the aeolian activity at the site. The radiocarbon dates of occupation layers II and III obtained

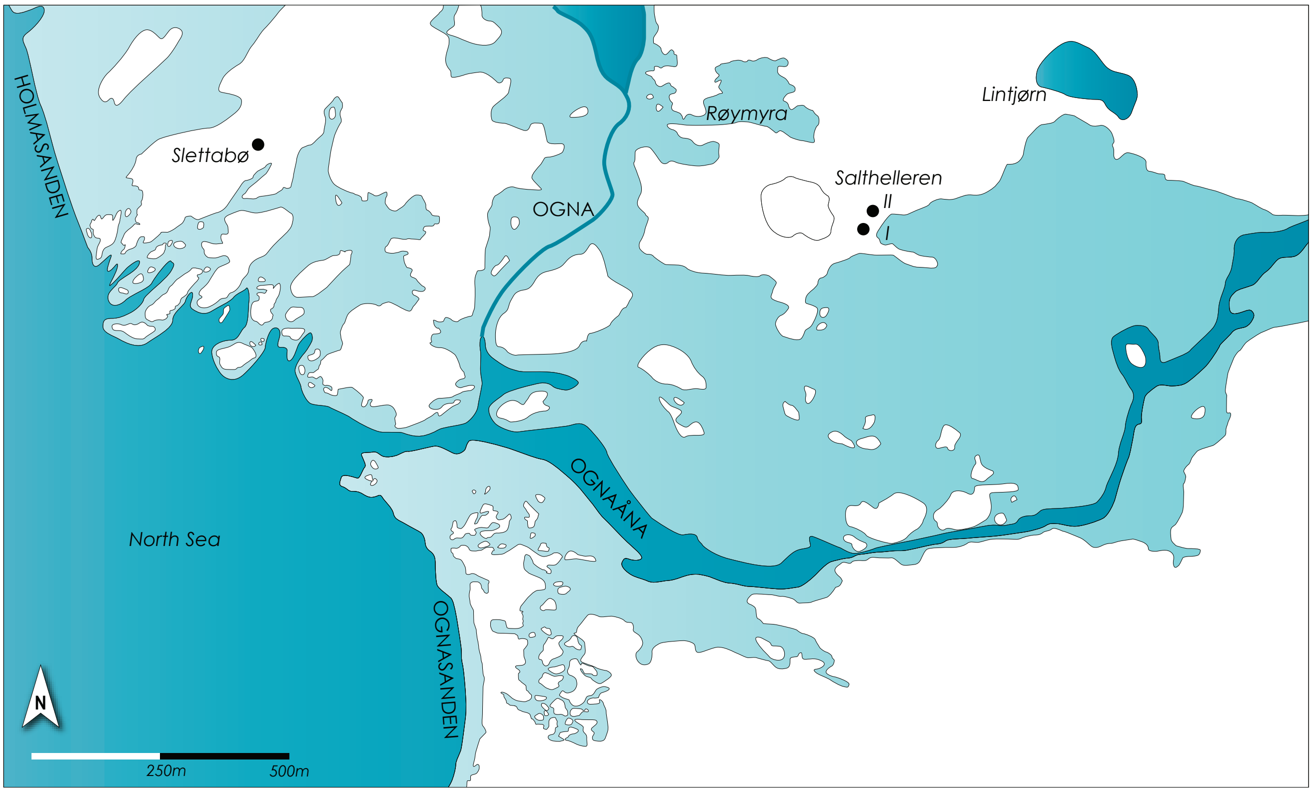



*Fig. 50. The palaeogeography of Ognasanden during the Holocene Tapes maximum transgression when the sea-level was 5 m higher than today (light grey). Redrawn from Skar Christiansen (1985: Fig. 6a).*

*Fig. 51. The Slettabø archaeological site looking west-southwest, The North Sea in the background (Skjølsvold 1977: Fig. 4).*

by Glørstad (1996) from food remains in pottery give older ages than the dates on charcoal (Skjølsvold 1977) (see Table 1). If the food remains consisted of marine organisms the reservoir effect might be a plausible explanation for this gap in radiocarbon dates (see Philippsen 2009). Thus Glørstad's dates might be a little too old. Skjølsvold's (1977) dates, from occupation layer II, have a range of 3970±100 yrs BP (4568-4247 cal yrs BP) to 3790±70 yrs BP (4290-4009 cal yrs BP), while Glørstad's (1996) dates from the same layer range from 5080±65 to 4190±60 yrs BP (5906-5748 to 4837-4627 cal yrs BP). The dates from occupation layer III have a range of 4820±180 to 4470±120 yrs BP (5740-5319 to 5299-4966 cal yrs BP) according to the charcoal dates of Skjølsvold (1977) and a range of 5305±80 to 4940±65 yrs BP (6188-5955 to 5727-5602 cal yrs BP) according to the dates of food remains (Glørstad 1996). The relation between occupation layers II and III has been the subject of debate. Glørstad (1996) reinterpreted the ceramic chronology as being older than presumed by Skjølsvold. Occupation layer III and the lower part of occupation layer II are most probably from the same settlement period, dated to Early Neolithic and/or early Middle Neolithic. This is based on one deviating radiocarbon date from occupation layer II (T-561), the radiocarbon dates of Glørstad (1996) and new results from the ceramic chronology in western Norway (Bruen-Olsen 1992 from Glørstad 1996).

Artefacts in the upper part of occupation layer II have been dated to the late Middle Neolithic or early Late Neolithic. Finally, the Bronze Age settlement is recorded by the upper occupation layer I (Glørstad 1996:59).

These dates imply that the aeolian sand layer (layer 3) wedged between occupation layers II and III could have

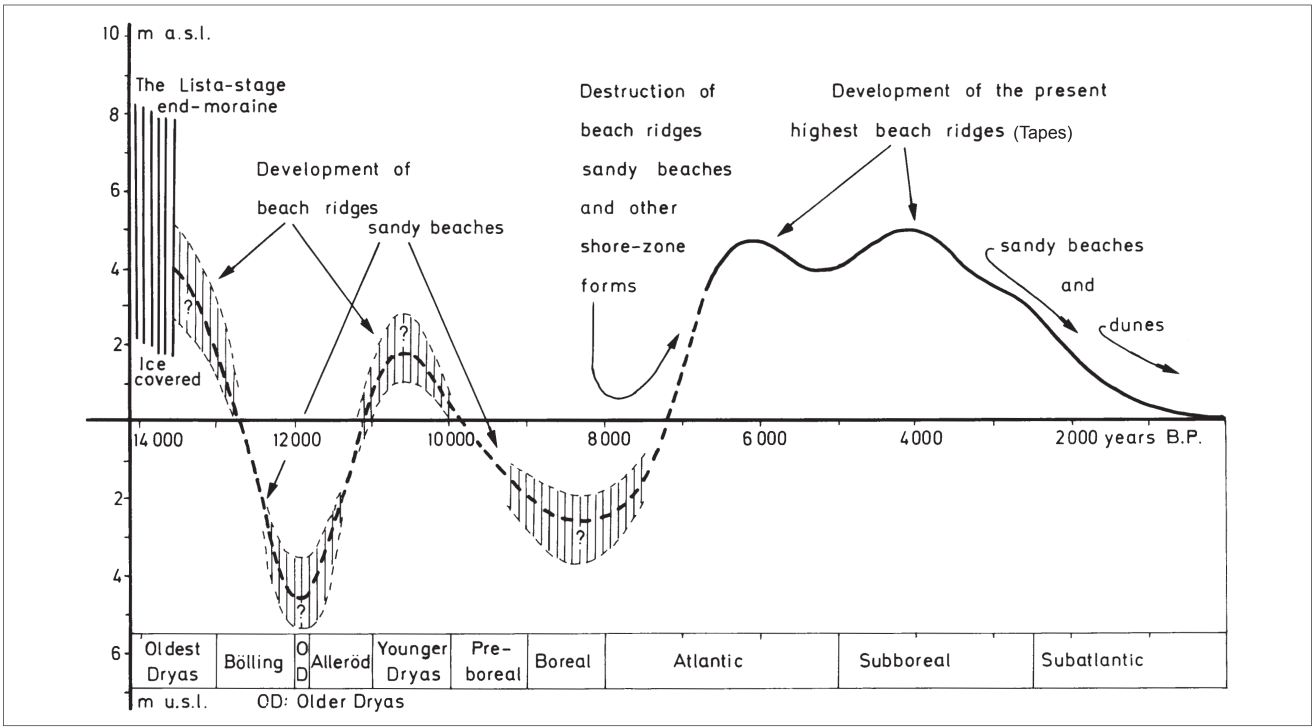



*Fig. 52. Probable sea-level displacement curve for the Brusand area in the southern part of Jæren (Bird & Klemsdal 1986).*

been deposited during a very short period sometime in the Early Neolithic and early Middle Neolithic, as suggested by Glørstad (1996:35).

*Palynological analysis*

Asbjørn Simonsen carried out the palynological analysis on samples from two sediment profiles 50 m to the east (1974) and 60 m to the northeast (1976) (Figs. 54 and 55) of the archaeological site.

The lithostratigraphy of the 1974 site from top to bottom was:

Layer 5: aeolian sand with thin palaeosols from 25-35 cm (0-120 cm)
Layer 4: peat (120-125 cm)
Layer 3: aeolian sand with accumulations of sesquioxides (Fe) (125-170 cm)
Layer 2: peat (170-175 cm)
Layer 1: aeolian sand (175-230 cm)

Palynological analyses were carried out on layers 4 and 5 of the five organic layers intercalated in the sand (A. Simonsen, unpublished) (Fig. 54).

*Pinus-Cyperaceae,* local PAZ Sl1

The lower peat layer (2) showed dominance of a field layer consisting mainly of Cyperaceae. Arboreal pollen (45 %) is dominated by *Pinus.* Pollen of *Plantago lanceolata* is recorded, indicating that the area was used for grazing. The pollen record in local PAZ Sl1 is in accordance with Fægri's results from the Ogna district (Fægri 1940): Røyrmyra, Lintjørn and Helgåvatn. In this part of Jæren, *Pinus* dominated in the bare, nutrient-poor inner areas throughout the Subboreal and Subatlantic periods. This pine dominance is also reflected in local LPAZ Sl1, but it probably only represents scattered stands. The upper part of the peat layer is dated to 1740±90 yrs BP (1775-1540 cal yrs BP, T-2000), i.e. the Roman Iron Age. The presence of *Plantago lanceolata* indicates anthropogenic use of the area. According to Skjølsvold (1977), husbandry was intensified in the Early Bronze Age, while an economy based on mixed farming started later.

*Myrica-Poaceae-Cyperaceae,* local PAZ Sl2

In the three spectra from the youngest peat layer (4), the tree pollen values decreased to ≤15 % compared to PAZ Sl1. The zone represents a treeless community with pollen from species associated with sub-oceanic wet heaths. These species are: *Calluna vulgaris, Myrica gale, Succisa pratensis, Narthecium ossifragum, Potentilla erecta* and species in the families Poaceae (probably *Molinia caerulea*) and Cyperaceae (probably *Trichophorum caespitosum*) (Steinnes 1988, Prøsch-

Danielsen 2001:43). Husbandry is recorded by pollen of *Plantago lanceolata* and *Rumex acetosa* type and cereal cultivation by *Avena*.

The palynological analysis of local PAZ Sl2 shows a deforested area where the heath has expanded. In this area, forest clearance mostly concerned pine (Simonsen & Prøsch-Danielsen 2005:41). The peat layer has been dated to 820±100 yrs BP (900-670 cal yrs BP, T-2001) and 840±110 yrs BP (904-677 cal yrs BP, T-2002), a time with indications of both pasturing and growing of cereals.

The lithostratigraphy of the 1976 site from top to bottom was:

> Layer 5: raw humus (0-20 cm)
> Layer 4: aeolian sand (20-35 cm)
> Layer 3: peat (35-45 cm)
> Layer 2: aeolian sand with a palaeosol from 67-70 cm (45-80 cm)
> Layer 1: carr peat (80-? cm)

Palynological analysis was carried out on three pollen samples from the carr peat and the peat layer (A. Simonsen, unpublished) (Fig. 55).

*Myrica-Poaceae-Cyperaceae,* local PAZ Sl2
The pollen records correspond to the local PAZ Sl2 from the 1974 site, but cereal cultivation is not recorded.

The top of the carr peat (layer 1) is dated to 665±25 yrs BP (666-567 cal yrs BP, TUa-7252) and the palaeosol in layer 2 is dated to 435±25 yrs BP (514-492 cal yrs BP, TUa-7253A).

*Discussion and conlusion*
The lowest sand layer is of aeolian origin, deposited before occupation layer III about 1 m above the Tapes maximum of 5.5 m above present sea-level. Occupation layer III is dated in the time interval between c. 5300 and 4500 yrs BP (6090-5170 cal yrs BP). Bearing in mind the first Tapes maximum at 6500 yrs BP (7430 cal yrs BP) and the succeeding regression, this implies that large, flat, sandy areas without vegetation were exposed to strong winds from the North Sea. This was probably what triggered the first recorded sand drift in this area, between the two Tapes peaks.

The second period of aeolian activity at this site was recorded as a sand wedge in the oldest settlement phase (between occupation layers III and II). The youngest

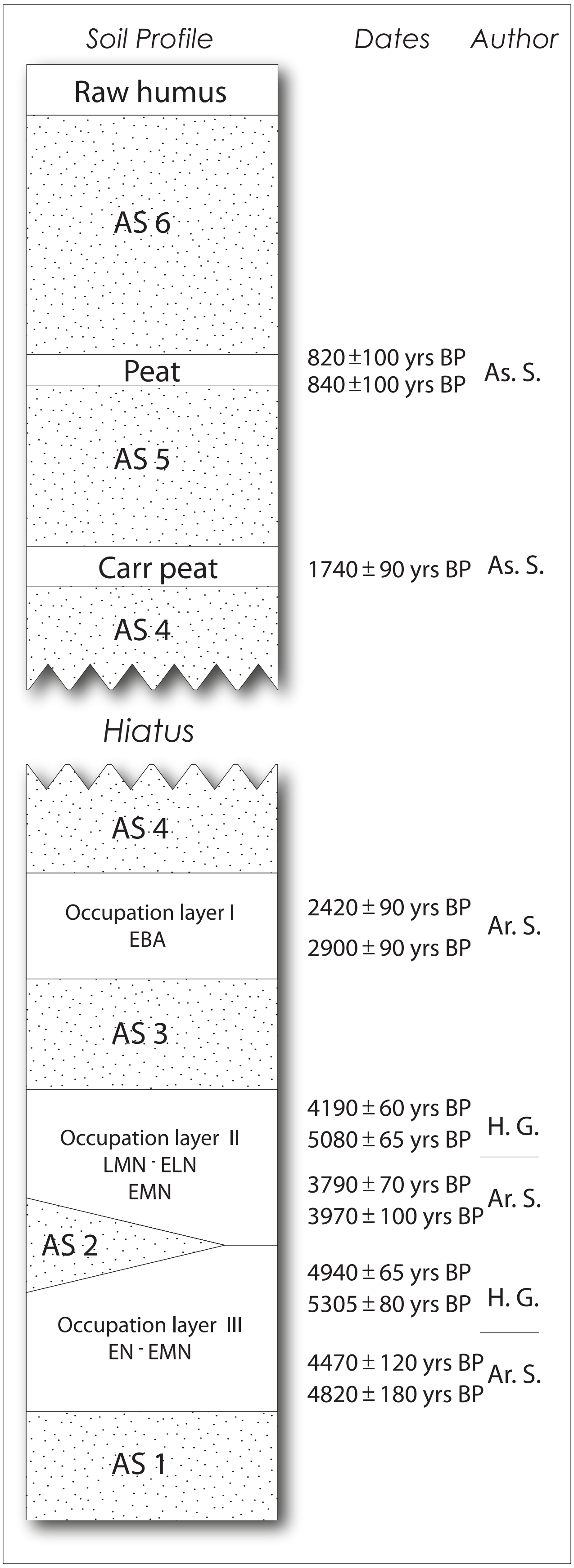



*Fig. 53. A stratigraphical outline of the Slettabø archaeological site compiled from information in Skjølsvold (1977:27ff), Glørstad (1996) and A. Simonsen (unpublished). Drawing: Lotte Selsing.*

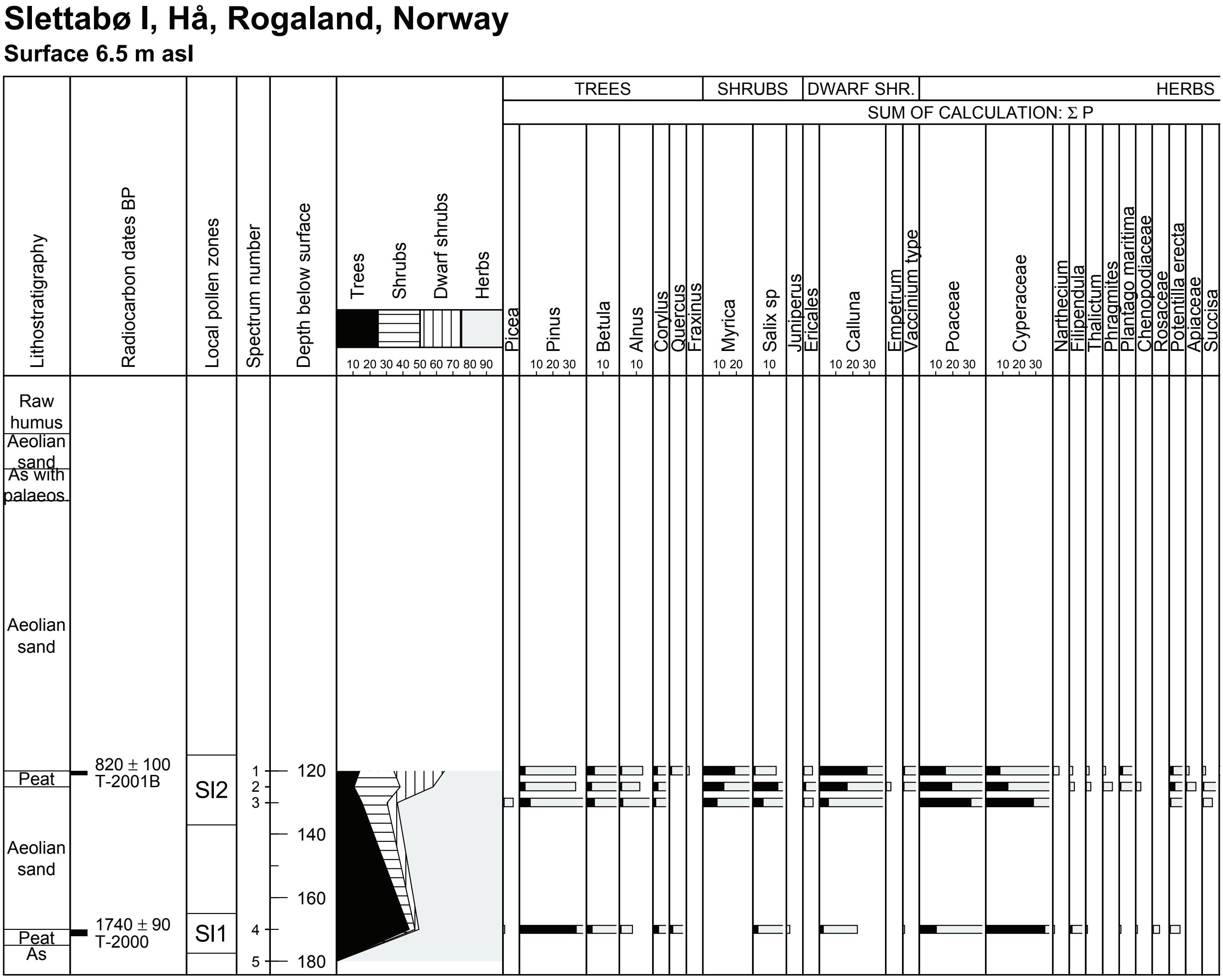


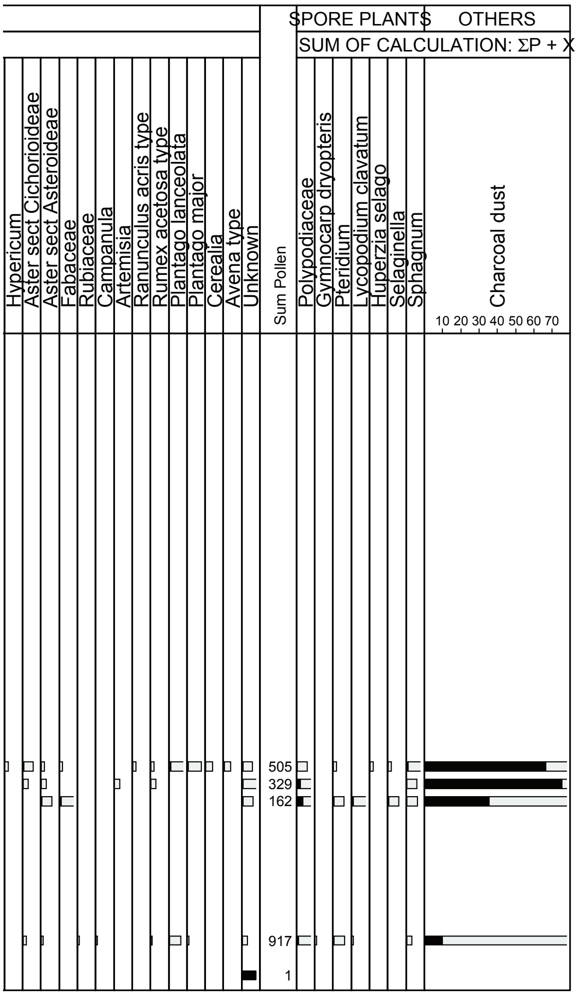

*Fig. 54. Percentage pollen diagram from Slettabø I (A. Simonsen, unpublished). Drawing: L. Prøsch-Danielsen.*

Analysis:

date of occupation layer III is 4470±120 yrs BP (5299-4966 cal yrs BP, T-1780) and the oldest date of occupation layer II is 5080±65 BP yrs (5906-5748 cal yrs BP, TUa-650). However, as the exact locations of these samples compared to the lithostratigraphy are not known they do not necessarily date the sand wedge. Nevertheless, these dates imply that the aeolian sand layer could have been deposited during a very short period sometime in the Early Neolithic (EN) and early Middle Neolithic (EMN), as suggested by Glørstad (1996:35). This probably means that this aeolian phase occurred in a short period during the second Tapes maximum (5200-4800 yrs BP, 5930-5540 cal yrs BP) or the following regression phase. The thickness of the aeolian sand (5-20 cm, average 8-10 cm) also confirms a short period of aeolian activity.

The third aeolian sand layer was sandwiched between occupation layers II and I. The youngest date of occupation layer II is 3790±70 yrs BP (4290-4009 cal yrs BP, T-739) and the oldest date of occupation layer I is 2900±90 yrs BP (3205-2898 cal yrs BP, T-562). Pasturing was recorded at the site in occupation layer II, indicated by bones of cow (*Bos taurus*). This is in accordance with Skjølsvold (1977) who pointed out that husbandry intensified during the Early Bronze Age. The environmental pressure increased and the regression of the sea was still in progress. The area was more sensitive to aeolian stress and aeolian activity was triggered.

The fourth aeolian phase was recorded between occupation layer I (the youngest date 2420±90 yrs BP, 2697-2350 cal yrs BP, 750-400 BC, T-740) and a peat layer (1740±90 yrs BP, 1775-1540 cal yrs BP, AD 175-410, T-2000). Coastal heaths were established in the Ogna area during this phase. At Bø in Ogna, heath was estab-




A. Simonsen 1974. Redrawn: L. Prøsch-Danielsen 2008

lished 2825±60 yrs BP (3057-2851 cal yrs BP, 1050-912 BC, TUa-1945) and at Røyrmyra 2270±80 yrs BP (2350-2154 cal yrs BP, 410-227 BC, TUa-1575A) (Prøsch-Danielsen & Simonsen 2000a, 2000b). The Slettabø site is located 4 km south-southeast of Bø and 1 km west of Røyrmyra. The establishment of the heathland confirms that this aeolian phase started around 2400 yrs BP (2400 cal yrs BP). This implies that the habitation represented by occupation layer I ended between the heathland establishment at Bø and Røyrmyra.

In the Jæren area (B), heath was generally established 900-700 BC (c. 2750 yrs BP, (2850 cal yrs BP), while the general pattern in area C is about 200 BC (2150 yrs BP, 2140 cal yrs BP) (Prøsch-Danielsen & Simonsen 2000a, 2000b). This implies that the landscape at Ogna, the transition between the flat, low-lying Jæren area and the rocky Dalane area to the southeast, is mirrored by land-use practice that included heathland management. The factors triggering this sand drift are a combination of regular, intense burning of the heathland, increased grazing and strong onshore winds blowing over sand.

The fifth aeolian phase was in the period between 1740±90 yrs BP (1775-1540 cal yrs BP, T-2000) and 840±110 yrs BP (904-677 cal yrs BP, T-2002). The same factors as encountered in phase four triggered the sand drift.

The sixth aeolian phase occurred after 820±100 yrs BP (900-670 cal yrs BP, T-2001) and 840±110 yrs BP (904-677 cal yrs BP, T-2002), following a period of stable vegetation cover which resulted in the development of a peat layer. Land use involving heathland management and cereal growing was practised and may have accelerated sand drift after the stable period.

The seventh aeolian phase started 665±25 yrs BP (666-567 cal yrs BP) with a short standstill at 435±25 yrs BP (514-492 cal yrs BP).

It is worth noting that the occupation layers with artefacts also consist of aeolian sand intermixed with the organic material. This confirms that the aeolian activity in this area lasted continuously from 6500-5300 yrs BP (7430-6090 cal yrs BP) until the present day, with varying intensity depending on sea-level changes, exposed sand, strong onshore winds and changes in land use involving husbandry and, in the last 800 calendar years, also cereal cultivation.

### 12. Salthelleren

The investigation at Salthelleren was required under the terms of the Cultural Heritage Act. The name Salthelleren refers to a rock shelter situated 500 m northeast of Ogna railway station, about 1.5 km from the coast and about 1.5 km east of Slettabø (Figs. 50 and 56). Birgitte Skar Christiansen, Guro Fredriksen and Olle H. Hemdorff excavated a Late Mesolithic site in 1979 and Lotte Selsing carried out the pollen investigation (Fredriksen 1979, Syvertsen 1979, Hemdorff 1980, Skar Christiansen 1985, Selsing & Mejdahl 1994). In the early 20th century, Brøgger (1911) and Gjessing (1920:86-87) described open Stone Age dwelling sites with occupation layers at Salthelleren, which extended to the surrounding sandy plain. The lowest observation of flint artefacts in 1920 was about 4 m asl (Gjessing 1920:86).

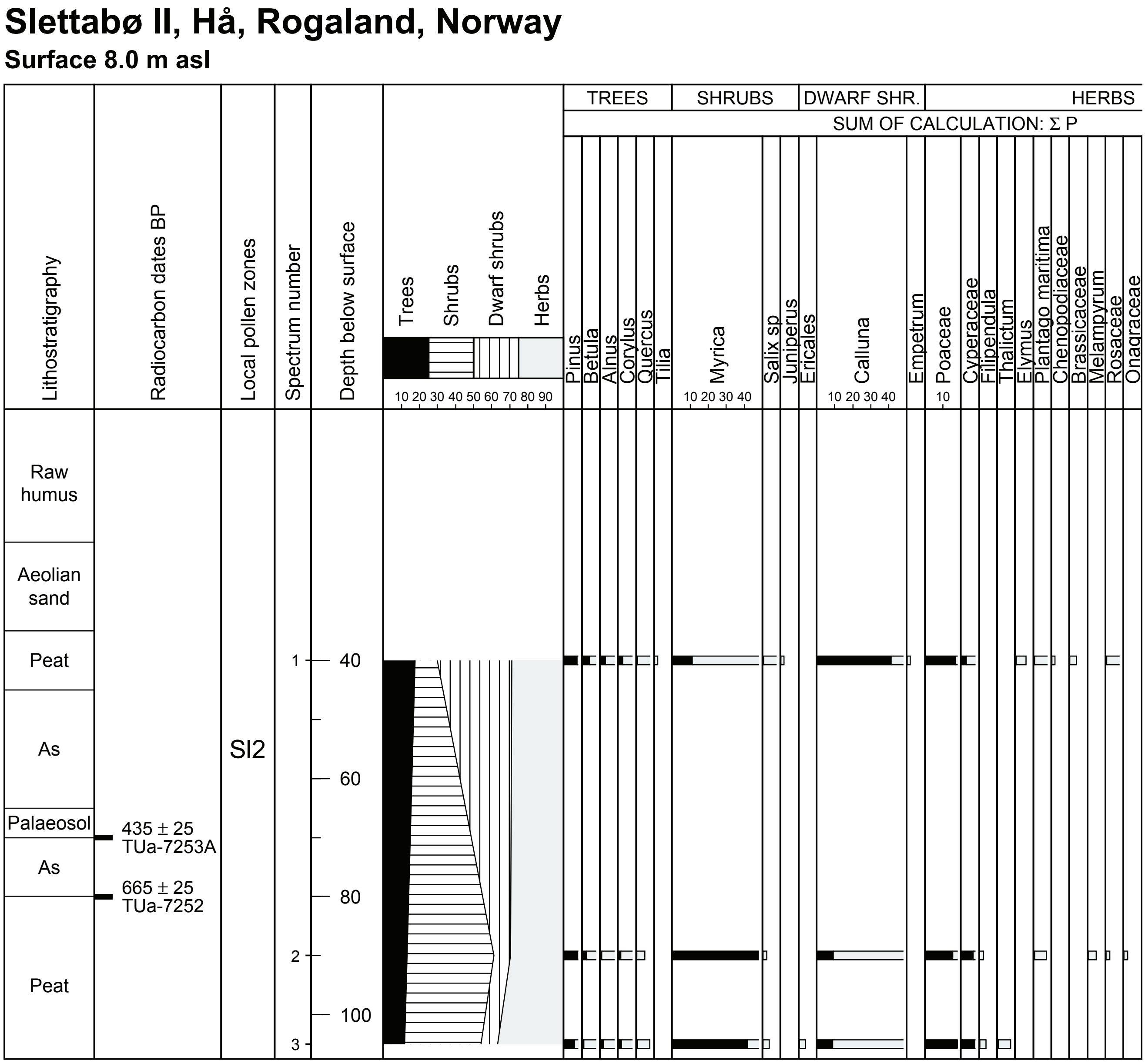


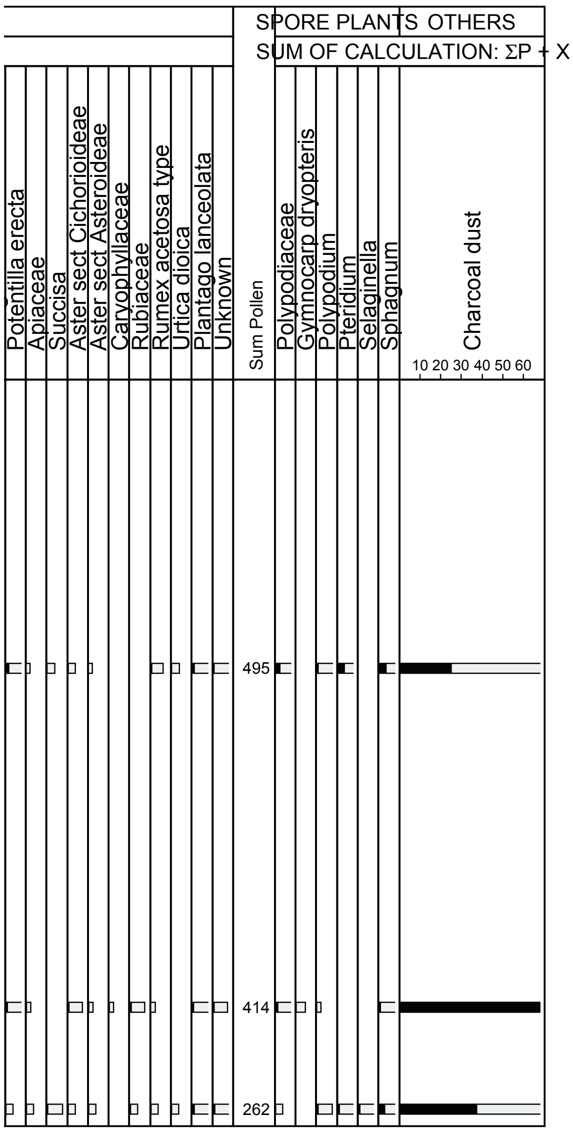

*Fig. 55. Percentage pollen diagram from Slettabø II (A. Simonsen, unpublished). Drawing: L. Prøsch-Danielsen.*

The bedrock in the area is anorthosite belonging to the Egersund Complex (Michot 1966). Anorthosite is resistant to degradation and poor in plant nutrients. This is the main cause of the poor soil and vegetation cover in the area (Skar Christiansen 1985:19). The Quaternary sediments are till and glaciofluvial deposits covered by sand and peat. The topography is characterised by rock outcrops surrounded by plains of aeolian sand that cover the older sediments, and narrow valleys stretching inland.

In 1979, two Late Mesolithic sites, Salthelleren I and II, were recorded, but only site II was excavated. The two sites are separated chronologically and in space (35 m apart). Salthelleren II is situated 6.0-9.0 m asl on the eastern side of the rock outcrop, where it meets a sloping sandy plain (Gjessing 1920, Skjølsvold 1977, Skar Christiansen 1985:18). It covers more than 200 m$^2$ and is sealed by up to 2 m of aeolian sand (Fredriksen 1979:330). The site was on the shore in the Late Mesolithic.

*Sea-level changes*

A sea-level displacement curve was constructed for the area (Fig. 52) (Bird & Klemsdal 1986). This curve is based on geomorphological studies in the area and information in Fægri (1940), Andersen (1960), Simonsen




Simonsen 1976. Redrawn: L. Prøsch-Danielsen 2008

(1982, pers. comm.), Sjulsen (1982) and Thomsen (1982b). "*The oldest sequence, from c. 13,500 yrs BP to c. 8000 yrs BP, shows shore features varying from +7 m to -5 m. This implies that nearly all littoral forms produced during this time interval were destroyed during the following Tapes transgression, and that the surviving littoral forms originate from the Tapes transgression and the following regression phase. Based on field observations and available data they constructed a double- peaked Tapes transgression with one peak around 6500 yrs BP, while the second one was put around 4000 yrs BP. The authors did not radiocarbon date the two marine events. Anyway, their sea-level curve demonstrates a double-peaked Tapes transgression*" (Prøsch-Danielsen 2006a). In 2006, the maximum of the second Tapes peak was put at 5200-4800 yrs BP (5930-5540 cal yrs BP) (Prøsch-Danielsen 2006a). A beach ridge 8.8 m asl dams up Lintjørn, a lake c. 500 m northeast of Salthelleren II. This may appear too high compared with the sea-level fluctuation curve outlined above. However, already in 1940, Fægri suggested that beach ridges might be built up 2-3 m above average sea-level.

*Lithostratigraphy and chronology*

Skar Christiansen (1985:50-52) described the general stratigraphical record at the archaeological site from the top to the bottom (Fig. 57, see Table 1 for radiocarbon dates):

Layer 5: aeolian sand
Layer 4: upper occupation layer (1) made up of sand
Layer 3: beach sand
Layer 2: lower occupation layer (2) made up of sand
Layer 1: till

Layer 2 – The lower occupation layer (2) comprises sand with artefacts and charcoal. The lower part has been radiocarbon dated to 6470±100 yrs BP (7460-7279 cal yrs BP, T-3591), the middle part to 6110±90 yrs BP (7156-6891 cal yrs BP, T-3590) and the upper part to 5460±90 yrs BP (6395-6128 cal yrs BP, T-3589). These dates were obtained on charcoal of *Pinus* and/or *Quercus*. As these species can grow for a very long time, the dates may give older ages than expected compared to the time of burning. However, they become younger upwards and match the artefacts based on typology (Skar Christiansen 1985:56). They show that the Late Mesolithic settlement lasted some 1100 calendar years (Skar Christiansen 1985:56).

Layer 3 – The beach sand rests on beach ridge deposits on the lower part of the slope (see the profile in Fig. 57) and on occupation layer 2 on the upper part of the slope. The beach ridge was probably deposited during the first Tapes peak dated to c. 6500 yrs BP (7430 cal yrs BP) in this area. Beach sand (documented by granulometric analyses, Selsing 1984) covered parts of the settlement during the following regression phase, around 5400 yrs BP (6240 cal yrs BP).

*Fig. 56. The archaeological excavation at Salthelleren was carried out in 1979. Photo: Guro Fredriksen.*

Layer 4 – The upper occupation layer (1) was located on top of the lower occupation layer (2), except towards the southeast where layer 3 separated them. It has been dated to 5470±130 yrs BP (6406-6026 cal yrs BP) (Skar Christiansen 1985b:56), which corresponds to the upper part of the lower occupation layer (2). This indicates continuous settlement from the lower to the upper occupation layer, with no hiatus. On the other hand, the beach sand between the two layers may indicate a time lag between them, but this may be very short. Skar Christiansen (1985:56) calculated that the settlement represented by the upper occupation layer (1) lasted about 300 years.

Layer 5 – The granulometric analyses of the sand in and above the upper occupation layer (1) indicate that the sediment is of aeolian origin (Selsing 1984). The date of the upper occupation layer (1) gives a maximum age of the aeolian activity, which is c. 5400 yrs BP (6240 cal yrs BP), i.e. between the two Tapes peaks.

No marine beach sediments linked with the second Tapes peak have been recorded at the site perhaps because unconsolidated deposits accumulated further west prevented them being deposited there. The second Tapes peak was c. 1 m higher than the first one from Hå in the northwest (Bang-Andersen & Thomsen 1993, Bang-Andersen 1995, modified by Prøsch-Danielsen 2006a) to Eigerøy in the southeast (Prøsch-Danielsen 2006a based on Simonsen 1972, 1975, 1982, 2005). However, the Salthelleren site is sheltered and located leeward more than 1 km from the seashore and therefore protected from both strong onshore winds and waves. At Slettabø, we recorded continuous aeolian activity from about 6500 yrs BP (7430 cal yrs BP). As a consequence, large aeolian deposits, interrupted by rocky knolls, possibly formed a barrier against the North Sea soon after 6500 yrs BP (7430 cal yrs BP).

The palaeogeography in the Late Mesolithic differed from the present landscape because of the sea-level changes and the later redeposition of sediments, mostly sand. During the Mesolithic, a bay stretched eastwards from the open North Sea. The Late Mesolithic site II at Salthelleren stood on the east-facing shore of this sheltered bay (Skar Christiansen 1985: 22). Older sediments were eroded and redeposited. From about

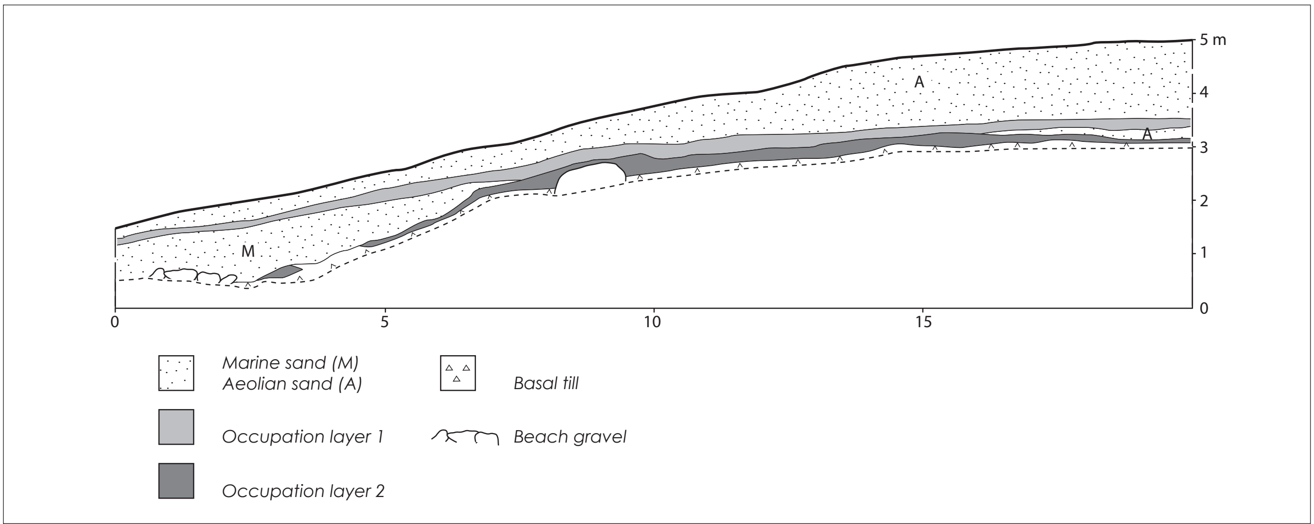



*Fig. 57. The stratigraphy at the Late Mesolithic site at Salthelleren in 1979 (modified from Skar Christiansen 1985:51, Fig. 18).*

6500 yrs BP (7430 cal yrs BP), marine deposits were deposited on the seabed at Bjørvatnet (Brusand), Ogna (Ognasanden) and Ognasletten. Sand drift began later.

*Palynological analysis*

Palynomorph analyses were performed at two sites at Salthelleren, the first randomly from the sandy occupation layer (2) at site II and the second throughout a peat section 3 m north of the excavation (Selsing & Mejdahl 1994:99).

*Lower occupation layer (2), Salthelleren II*

Thirteen samples from 0-5 cm in the upper part of the lower occupation layer were analysed for palynomorphs (Skar Christiansen 1985b:81-83, Fig. 26) (Fig. 58). Four samples held no palynomorphs. In the remaining samples, 5-40 % of the palynomorphs were unidentifiable because of bad preservation conditions in the sand. Three radiocarbon dates from the layer lie in the time interval of c. 6500 yrs BP to c. 5500 yrs BP (7430 cal yrs BP and 6300 cal yrs BP). However, the palynological samples correspond to the youngest date.

The AP values in the samples are generally between 40 and 60 %, and are dominated by *Betula* and *Alnus*. In two samples, *Calluna* pollen comprises more than 20 %; one of these samples has 19 % *Campanula*, the other 15 % *Melampyrum*. One sample is totally dominated by herbs (95 %): Rosaceae, *Potentilla* and Brassicaceae.

The palynomorphs in the samples from the lower occupation layer (2) were produced both regionally and locally. The palynomorph composition gives information about an environment without or with only a sparse forest cover. The high values of, for instance, Rosaceae and Brassicaceae (sample 79/107) indicate a location near the seashore and/or originate from selected herbs brought to the site by the Late Mesolithic people.

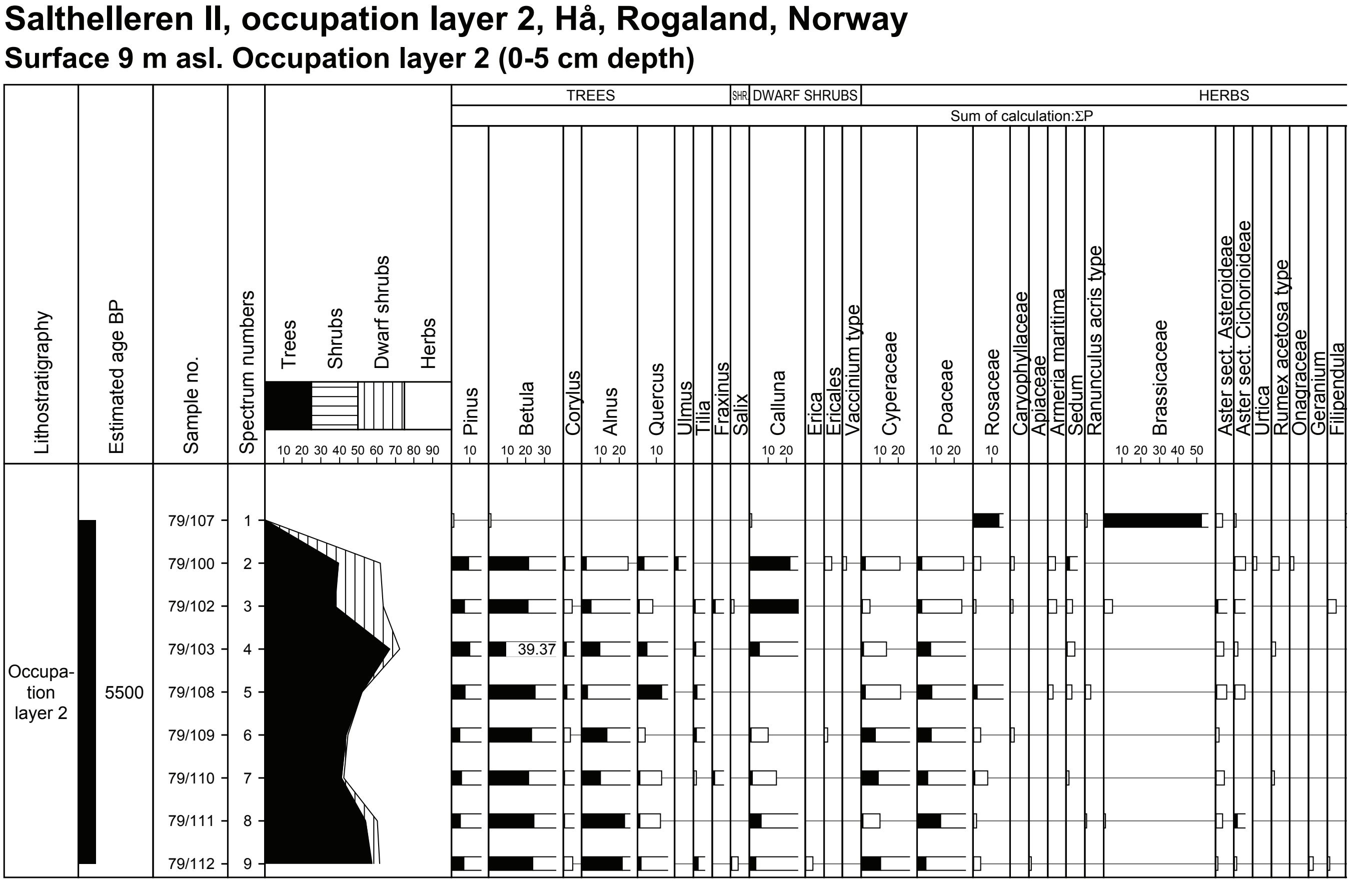
*A peat section 3 m north of the excavated area at Salthelleren II*

The site is located between two small rock outcrops, one of which separates the peat from the investigated archaeological site only 3 m to the south. The peat, occupying a depression, formed after the settlement was abandoned. Some metres northwest of the settlement site there was a spring that probably created favourable conditions for the growth of moisture-demanding plants which formed the peat. The lithostratigraphy is from top to bottom (Fig. 59):

Layer 3: aeolian sand (100-200 cm)
Layer 2: carr peat (30 cm)
Layer 1: aeolian sand with palaeosols
(40-150 cm)
Bedrock, anorthosite

The upper sediment section rests directly on the bedrock.

Layer 1 – The bedrock was covered by aeolian sand with mm-thin dipping palaeosols in the upper part. The radiocarbon age of these palaeosols is 4150±90 yrs BP (4825-4577 cal yrs BP, T-5116A). The loss on ignition is low (<10 %).




Layer 2 – The peat layer above the palaeosols had a small horizontal distribution. The ages of the lower and upper parts of the peat are 3430±80 yrs BP (3826-3585 cal yrs BP, T-5115A) and 2340±70 yrs BP (2652-2184 cal yrs BP, T-5114A), respectively. Loss on ignition rises in the lower part and has a relatively stable value of 60-80 % in the upper part of the zone. Loss on ignition decreases to 40 % in the uppermost part (corresponding to pollen spectrum 1).

Layer 3 – This aeolian sand layer varied in thickness between 100 and 200 cm.

Palynological analysis was carried out on one of the palaeosols in the lower aeolian sand (layer 1) and in the carr peat (layer 2). Three local PAZs are recognised in the pollen diagram (Fig. 60):

*Poaceae*, local PAZ Sa1
The palynomorph content of Sa1 (one spectrum) shows the presence of *Alnus, Corylus* and Quercetum mixtum with high *Tilia* values of 5.6 %. The herbs show dominance of Poaceae and relatively high values of pollen from near-shore species like *Sedum, Elymus, Campanula* and species in the families Rubiaceae, Rosaceae and Caryophyllaceae. The relatively high herb, shrub and dwarf shrub values (50 %) and the near-shore species reflect open vegetation. The pollen curves and the radiocarbon dates (T-5116A and T-5115A) indicate a hiatus between Sa1 and Sa2.

*Betula-Alnus-Quercus*, local PAZ Sa2
The palynomorph content of the lower part of Sa2 shows a decrease in *Corylus* and *Tilia* and a rise in *Alnus, Quercus* and *Betula*. Two maxima of *Betula* (52 % and 50 %) are intercalated by a maximum in *Quercus*. The herb, shrub and dwarf shrub pollen curves have low values. The curve of charcoal dust particles reached a maximum in spectrum four. At the same time, *Spergula arvensis*, a species associated with a weed flora and, thus, cereal cultivation, is recorded for the first time.

*Poaceae-Calluna*, local PAZ Sa3
Local PAZ Sa3 is recognised in the upper spectrum with a decrease in tree pollen values of *Betula, Alnus*

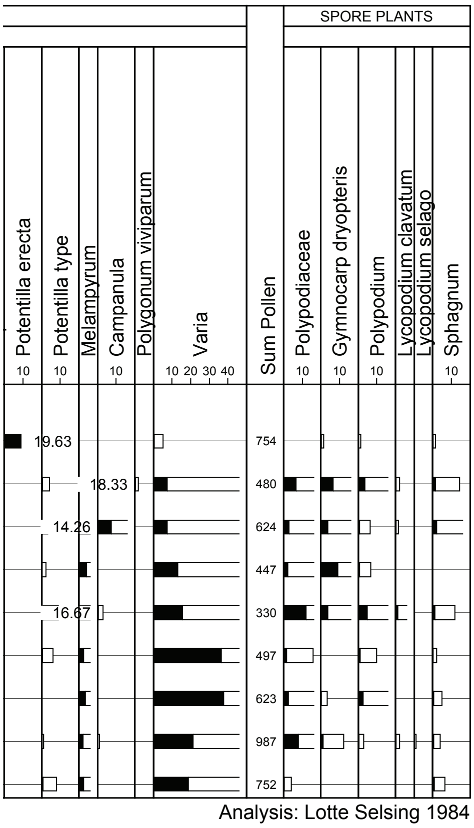



*Fig. 58. Percentage pollen diagram of thirteen samples from 0-5 cm in the upper part of the lower occupation layer at the Salthelleren archaeological site. L. Selsing (unpublished). Drawing: L. Prøsch-Danielsen.*

and *Quercus*. There is a rise in *Calluna* pollen and the number of herb species increases, especially reflected in a rise in meadow plants like *Artemisia, Ranunculus acris* type, *Rumex longifolius* type, *Campanula* and species in the families Poaceae, Apiaceae, Fabaceae and Asteraceae. *Spergula arvensis* is also recorded. At the same time, loss on ignition decreases. There is a peak in the curve of charcoal dust particles. The relatively stable value of the regional *Pinus* pollen in the upper part of the pollen diagram confirms that the decrease in tree pollen represents local anthropogenic deforestation resulting in the heathland establishment at 2340±70 yrs BP (2652-2184 cal yrs BP, T-5114A).

The pollen content in the layer below the peat section reflects open vegetation with a pronounced amount of near-shore pollen taxa. Later on, the local forest recolonises. The opposite is recognised in local PAZ Sa3 where human influence became significant, broke up the vegetation cover and started the aeolian activity.

*Discussion and conclusion*

Three of Fægri's classical sites, Lintjørn, Røyrmyra and Helgåvatn, are located in the Ogna area. They serve as a background for interpreting the general vegetation development in the area and are also good tools for understanding the sea-level displacement curve here. On the other hand, the palynological analyses of the peat and of samples from the Late Mesolithic site at Salthelleren II primarily show local conditions.

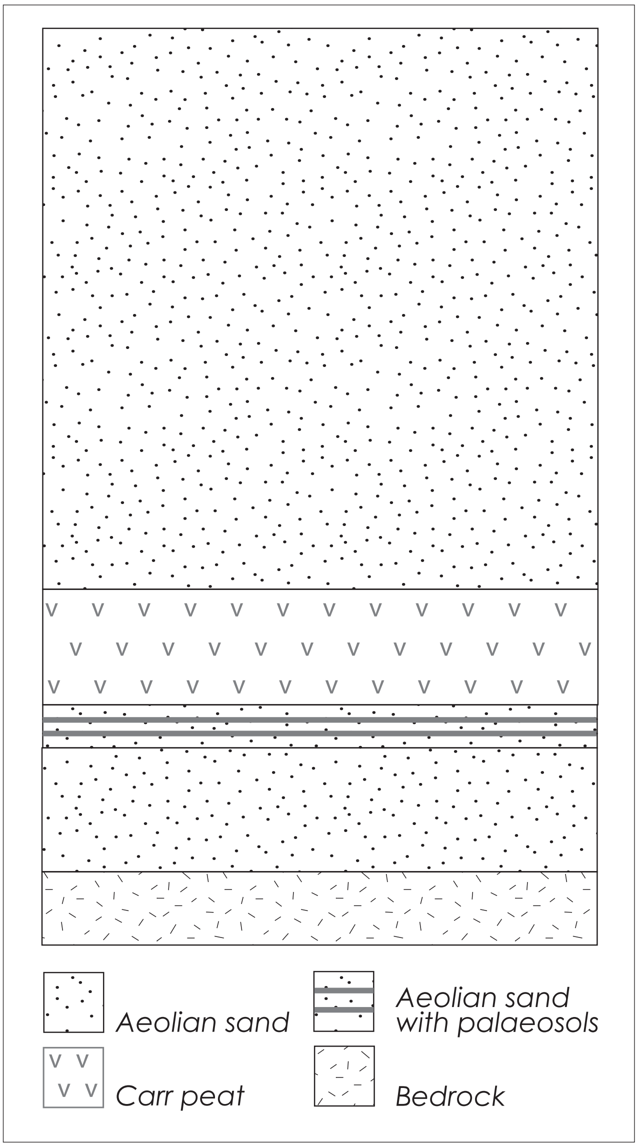



*Fig. 59. A stratigraphical outline of the peat section 3 m north of the archaeological site at Salthelleren. Drawing: L. Selsing.*

Aeolian activity in this area can be traced back to about 6500 yrs BP (7430 cal yrs BP), indicated by the aeolian sand in the occupation layers. The sand between the lower and upper occupation layers was interpreted as beach sand, but it is not unambiguously distinguishable from aeolian sand. This near-shore location is also confirmed by the pollen studies that reveal seashore meadow species in the upper part of

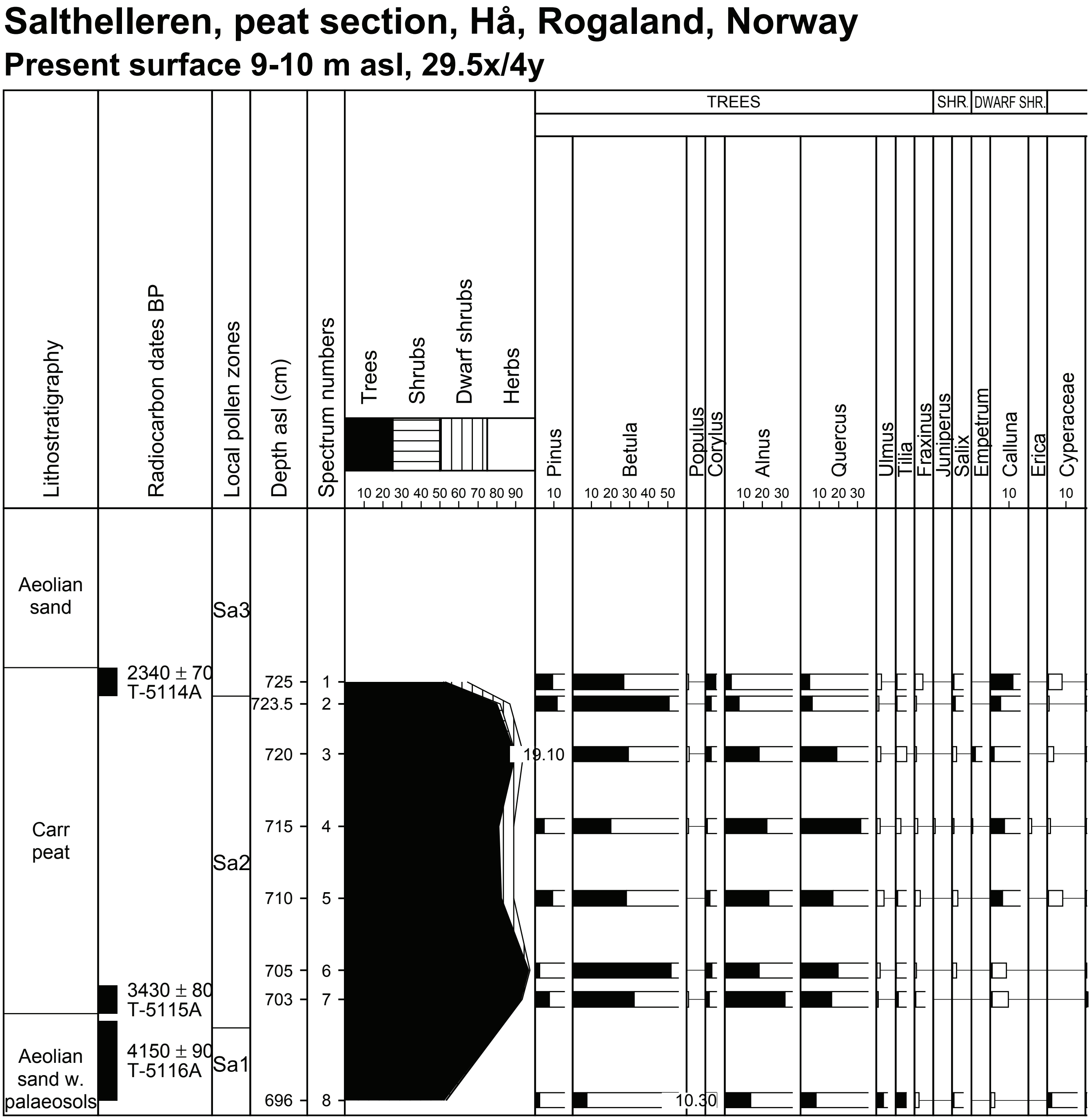
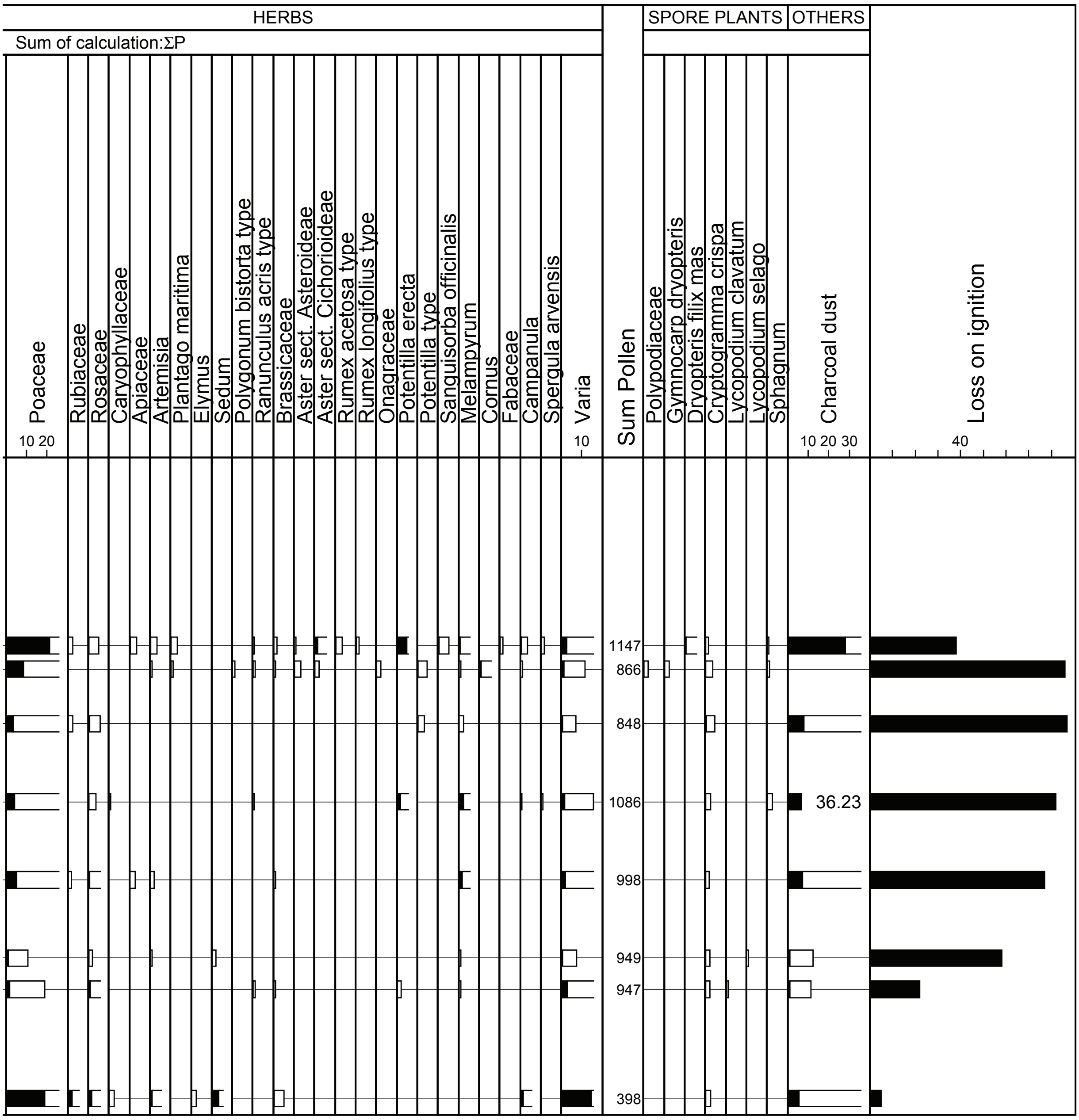



*Fig. 60. Percentage pollen diagram of the peat section 3 m north of the archaeological excavation site (29.5x/4y) at Salthelleren (L. Selsing, unpublished). Drawing: L. Prøsch-Danielsen.*

the occupation layer (2). The aeolian activity continued after Salthelleren II was abandoned about 5500 yrs BP (6300 cal yrs BP). The aeolian sand that covered the site is rather thick, more than 100 cm. This confirms that the aeolian activity lasted for a long period.

The lithostratigraphy of the peat section with a lower, up to 150 cm thick, sand layer shows that aeolian activity lasted a long time. A series of palaeosols indicates standstills in the sand drift before the drift totally ceased, allowing peat to form at the site. The upper palaeosol is dated to c. 4100 yrs BP (4660 cal yrs BP) and the bottom of the peat is dated to c. 3400 yrs BP (3660 cal yrs BP). This hiatus of about 1000 calendar years may mark a period of stabilisation or deflation in this time interval. The date of 2350±90 yrs BP (2685-2184 cal yrs BP) gives a maximum age of the next sand drift




Analysis: Lotte Selsing 1983

phase in the area, caused by human activity like burning, pasturing (establishment of heathland) and probably also cereal growing. Historical sources supplement the information about aeolian activity in this area in the 19th century until the 1930s (Grude 1914, Kastellet 1996, Kastellet *et al.* 1998).

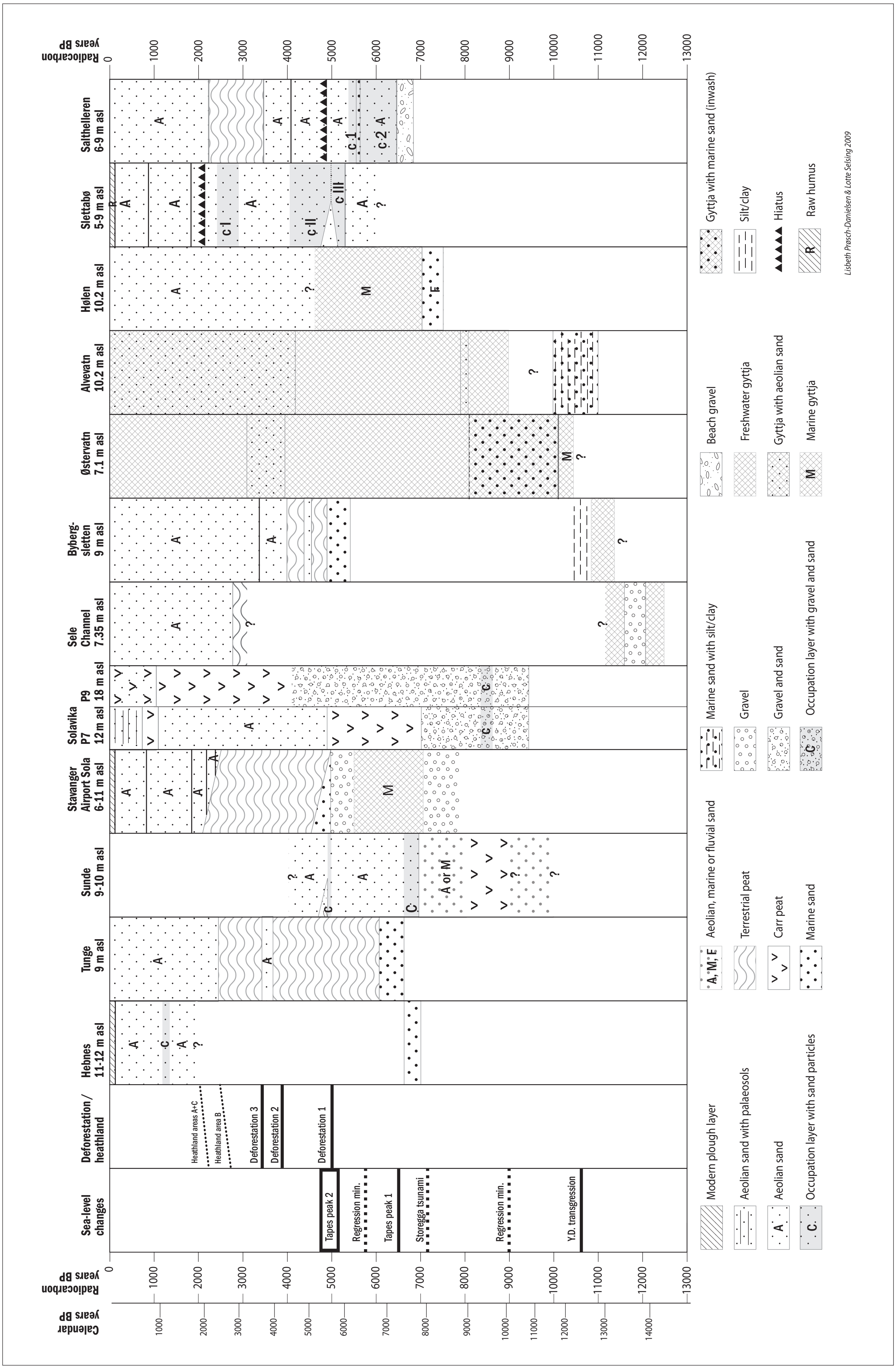



*Fig. 61. A compilation of the results of the investigation.*

# Discussion

The results of this investigation are compiled in Fig. 61. The schematic stratigraphies show brief and longer episodes of aeolian sedimentation during the Holocene. Most of the sites have been investigated due to legal requirements (the Norwegian Cultural Heritage Act) and not specifically to study sand drift. However, this does have some advantages, too, because the archaeological sites provide good stratigraphical sections and different kind of dates (e.g. artefacts and their typology, bones and charcoal) as exemplified, for instance, by the information from the former shore-bound sites of Sunde, Slettabø and Salthelleren.

Aeolian activity is triggered by natural factors, anthropogenic events or a combination of both. Many natural factors may help to trigger aeolian activity (e.g. patchy or absent vegetation cover, changes in sea-level, the water table and climate, periodic flooding along rivers and lakes, and tides). However, along the southwest coast of Norway, tides are less important for aeolian activity than differences caused by shifts from calm to stormy weather. Among anthropogenic events, the introduction of pasturing, cultivation and heathland management may accelerate sand drift. The most relevant factors are discussed below.

In our study area, there are no records of Late Weichselian aeolian activity. In contrast, aeolian activity in northwest Europe was recorded from the Late Weichselian well into the Holocene (Kolstrup 2007). In Drente, in the Netherlands, it lasted until the end of the Boreal (Cleveringa *et al.* 1977), in Lithuania to the Atlantic/Subboreal transition (Molodkov & Bitinas 2006) and in Denmark it took place periodically during the Late Weichselian into the earliest Holocene (Kolstrup 1991). In the cover sand area of the Veluwe in the Netherlands, forests prevented mass transport, but the vegetation never grew sufficiently dense to prevent sand drift completely (Polak 1968:33). Cleveringa *et al.* (1977:242) concluded that sand drift took place in the Netherlands during drier, colder periods and, to a lesser extent, moister, warmer periods, perhaps due to the presence of more open vegetation and possibly a windier climate. The vegetation cover became denser and aeolian activity decreased from the later part of the Preboreal. Sand deposition (and erosion) did not cease at least in the northern part of the Netherlands until the end of the Boreal or the beginning of the Atlantic period. By this time, a soil cover had developed and the vegetation cover had become closed. Furthermore, sand drift along the coastline of the southern isles of the Outer Hebrides of Scotland was recorded continuously from the Late Weichselian into the Early Holocene, with reworking and perhaps slope wash (Gilbertson *et al.* 1999).

Late Glacial aeolian activity has been recorded at inland sites in southern Norway (e.g. Romerike and Evjemoen, Holtedahl 1953:855 ff), but these deposits have not been radiocarbon dated. With this in mind, sand drift is first recorded at the end of the Boreal in southwestern Norway, although the premises for sand drift had been present ever since the deglaciation.

In the Younger Dryas and early Preboreal, the sea-level in the study area ranged from 25 metres above present sea-level in the north to 2 metres in the south. Hence, large areas which now include sandy beaches were submerged at that time. There is a potential for early aeolian activity in the southern part of the area, the Ogna district, but it has not yet been recorded. One explanation may be that this study has been confined to excavated archaeological sites and has not included localities specifically chosen with sand drift in mind.

## Sea-level changes

The oldest aeolian deposit recorded in this study is obviously the result of a change in sea-level (Figs. 5 and 61). The sea-level displacement curves drawn for sites along this coast are complicated and show three (sometimes four) transgressions, one (or two) in the Late Weichselian and two in the Holocene: 6500 yrs BP (7430 cal yrs BP) and 4800 yrs BP (5540 cal yrs BP) (Section 2).

The earliest sand drift is recorded in a sediment sequence deposited during the early Tapes transgression in Alvevatn near the mouth of the River Figgjo. Here the lower gyttja samples contain sand particles probably blown in from the seashore and nearby sandy beaches. This event is older than 8145±65 yrs BP (9236-9007 cal yrs BP, TUa-1599A). The sand drift probably started after the Preboreal regression minimum (younger than 9000-8900 yrs BP, 10,200-10,050 cal yrs BP) that reached minus 5 metres below present sea-level in that area (Fig. 40). This is earlier than any records by Selsing (1984) and Selsing & Mejdahl (1994) from southwestern Norway.

Another observation from the first Holocene sea-level transgression is from Sunde, where pockets of aeolian sand below the occupation layer gave radiocarbon dates between 8200 and 6900 yrs BP (9170 and 7700 cal yrs BP). This indicates limited aeolian activity. People probably settled on these aeolian deposits some 6900 yrs BP (7700 cal yrs BP) during a period characterised by a slowly transgressing sea (culminating about 6500 yrs BP, 7430 cal yrs BP, i.e. 400 yrs after the start of the occupation phase). The sandy occupation layer indicates that aeolian activity continued during the period of human settlement and that people accelerated the sand drift. A new phase of aeolian activity postdates the younger occupation elements dated to about 4900 yrs BP (5620 cal yrs BP). This corresponds to the second Tapes maximum and the following regression, when the aeolian activity was more intensive. The aeolian activity at Sunde occurred more or less continuously from 8200 yrs BP (9170 cal yrs BP) until after 4900 yrs BP (5620 cal yrs BP). The reason for aeolian activity is probably that the site is situated on a gentle slope with unconsolidated sandy marine sediments at the outlet of Hafrsfjord, exposed directly to waves and strong onshore winds from the nearby sandy seashore.

At 7400 yrs BP (8200 cal yrs BP), abrupt cooling associated with a southward extension of sea ice in the North Atlantic (Bond *et al.* 2001, Clarke & Rendell 2006, 2009) caused some limited sand accretion in Denmark (Dalsgaard & Odgaard 2001), Scotland (Wilson 2002), Portugal (Clarke & Rendell 2009). The earliest sand drift at Sunde occurred at this time.

A comparable situation where sandy occupation layers are separated by sand layers is observed at the two southernmost sites, Salthelleren and Slettabø. Two Mesolithic occupation layers were recorded at Salthelleren. The lowermost one rests directly on a gravely beach deposit. Its age is between 6500 and 5460 yrs BP (7430 and 6280 cal yrs BP). It is separated from the youngest one by sand deposits; in the southern downslope part by marine sand and in the northwestern part by aeolian sand. The youngest occupation layer is dated to 5470 yrs BP (6290 cal yrs BP) and is covered by a thick layer of aeolian sand. Two radiocarbon dates give the age of the Tapes regression minimum between the two maxima, 5810±160 yrs BP (6790-6414 cal yrs BP, T-1286) from Eigerøy to the south of Ogna, and 5600±80 yrs BP (6447-6302 cal yrs BP, β-171188) from Hålandsvatnet on the Stavanger peninsula (Prøsch-Danielsen 2006a:46-47, 80-81). They suggest that the Tapes regression minimum on the southwest coast of Norway occurred about 5700 yrs BP (6470 cal yrs BP). The oldest aeolian activity at Salthelleren is thus observed at about 6500 BP (7430 cal yrs BP) and continued after 5400 yrs BP (6240 cal yrs BP), showing that it lasted throughout the period from the first Tapes maximum until the transgression after the Tapes regression minimum.

At Slettabø, no fewer than three occupation layers are separated by aeolian sand layers. These occupation layers range in age from 5300 to 2400 yrs BP (6090 to 2400 cal yrs BP). The oldest one rests on aeolian sand. The earliest aeolian activity is thus from the first Tapes regression phase. Sand drift was active in the area until after 2400 yrs BP (2400 cal yrs BP).

On the coast of Stad in central Norway, the base of a peat layer below aeolian sand was dated to 6090±80 yrs BP (7155-6803 cal yrs BP, T-2536A), and was thus formed during the Tapes maximum (Longva *et al.* 1983, Svendsen & Mangerud 1987). Only one Tapes transgression is observed in this area. The sand drift thus started during the regression, thus supporting our observation that sand drift was intensified during the Tapes regression.

Chronologically, the next two observations of sand drift are from Hølen and Bybergsletten, on the present-day marine foreland in the low-lying, flat part of Jæren. At these sites, the oldest recorded aeolian activity is connected with the second Tapes regression phase starting about the time of the second Tapes maximum around 5200-4800 yrs BP (5930-5540 cal yrs BP) and continuing up to the present, only interrupted by a stable period at Bybergsletten (where a peat layer is dated to 4860±50 yrs BP, 5651-5490 cal yrs BP). The reason for the aeolian activity was that large areas with unconsolidated sandy sediment close to sea-level were exposed to wind and waves from the North Sea. This is also the situation at Solavika (P7) where thick aeolian sand originates from sand drift from 4720 yrs BP (5400 cal yrs BP).

As the Tapes transgression had two maxima, which is unique for this part of Norway, the period of high sea-level lasted more than 2000 calendar years. Sand drift escalated and topsoil accumulation was prevented. The regression phase after the second Tapes maximum lasted until the present day, but with a decreasing rate. When the sea withdrew, large areas with marine sand deposits were exposed and became prone to wind erosion. The effect of the long, slow, final regression connected to sand drift was strengthened by the impact of people on the natural environment. Anthropogenic factors have been important as the trigger for aeolian activity at least since Neolitisation started about 5200-4800 yrs BP (5950-5550 cal yrs BP, 4000-3600 BC) with forest clearance, pasturing, cultivation and ultimately heathland management.

## Human impact

The deforestation changed the local climate, both the temperature and the wind (Wishman 1987, Nitter 2008). The climatic challenges to people are primarily the climate space on the local level (100 m to 20 km) (Nitter 2008:11). The topography and the surface qualities of the landscape are important and the challenges are primarily temperature and wind. As the forest disappeared during the Neolitisation process, the local beach zone climate space increased inland and the coastal climate changed. The wind was stronger and the temperature lower. In the terminology of Nitter (2008), the beach zone is a climate space comparable to the open landscape (Nitter 2008:13). This space is deforested with a prevailing strong westerly wind. The unwooded landscape with few obstacles means that the wind speed is only slightly reduced when it blows in across the land.

A forest presses the wind above the treetops and gives a nearly calm situation in the lower trunk layer. The wind also influences the temperature and humidity. The cooling effect of the wind is strong and a combination of temperature (measured as a standard protected from the wind) and the wind is therefore called the "wind chill", which is the "real" temperature as people and other living organisms feel it (http://retro.met.no/met/met_lex/v_a/vindavkjoling.html). The chill temperature is therefore more important for people than the ordinary measured temperature. The cooling effect of the wind depends upon the wind speed and may be very high when the wind speed is high, reducing the effect of temperature.

The wind force required to keep aeolian sand moving is 5 m/sec 10 cm above the surface (Bagnold 1973). Because of a logarithmic increase in the wind force with height, this value will correspond to a wind force of strong breeze to near gale (12-15 m/sec) 10 m above the ground. A wind force of 12-15 m/sec gives a wind chill of -1 °C with a temperature of 5 °C, and temperatures of 0 and -5 °C give wind chills of -7 to -8 °C and -14 to -15 °C, respectively. These examples indicate much lower temperatures (6-11 °C) with wind forces strong enough to cause aeolian drift than the traditional measured temperatures in unforested areas, in contrast to areas where there is a complete woodland cover where the wind is greatly reduced. The deforestation of the area investigated here therefore caused major changes to the wind and temperature climate close to the coast. This may be a reason for the so-called "fimbulvinter", which is supposed to have changed the climate from dry and warm to wet and cool at the transition from the Subboreal to the Subatlantic pollen-defined zones, based mainly on the interpretation of palynological analyses from southern Scandinavia (e.g. Fægri 1940, Hafsten 1960, Selsing 1996a:152).

When the landscape was totally deforested, wood for fuel became extremely scarce and tree stumps were uprooted to counter this (Smart & Hoffman 1988). Peat and earth were also cut and dried for burning (see e.g. Fine 1987 [1745] and Løwold in Lye 1978:33-34, 46 for historical times in Jæren), thus lowering the surface. As a result, the unprotected, unconsolidated sediments below were exposed to wind erosion.

Until the Neolithic, this area was densely forested by mixed oak vegetation grading into more pine dominance in the southern part of Jæren. During the Late Mesolithic, land use had limited impact on the vegetation and is difficult to distinguish from natural processes. However, some areas close to the coast, like the Ogna area, had more open vegetation than areas further from the sea. The lower occupation layer 2 at Salthelleren has an age between 6470 and 5460 yrs BP (7380 and 6280 cal yrs BP). The palynomorph composition gives information about an environment with a seashore meadow and a sporadic tree cover. Human impact causing aeolian drift was recorded from about 6470 yrs BP (7380 cal yrs BP) in the Late Mesolithic, before agriculture was introduced here. People probably influenced the natural environment, in part by burning and otherwise managing the vegetation. A more open forest may have resulted in richer ground vegetation with herbs and shrubs, which made the vegetation more attractive to grazing animals, especially big ungulates, a principal quarry of the Mesolithic hunters. Improving the grazing increased the quantity of game.

When habitation sites were located in an area prone to aeolian activity, for example close to a sandy seashore, soil erosion and sand drift were often triggered by the human activity. This did not happen in areas where till dominated, exemplified by organic sediments from the Obrestad Harbour located on a wave-erosion cliff. Early deliberate burning was recorded here (Prøsch-Danielsen & Simonsen 2000a:32, 50, 2000b). The rise in the charcoal and grass curves is earlier than 7000 yrs BP (7860 cal yrs BP). The spread of heathery vegetation is especially early, too, dated to 6835±90 yrs BP (7751-7588 cal yrs BP, T-13084). These results confirm that pre-Neolithic vegetation management took place. Another locality, Stavnheimsmyra, close to the North Sea coast, was also deforested early and heathery vegetation spread 5025±55 yrs BP (5889-5663 cal yrs BP, T-13497) due to early pasturing (Prøsch-Danielsen & Simonsen 2000a:33, 2000b). An increase in charcoal dust was recorded shortly before deforestation, confirming that deliberate burning was used to remove the forest and prepare for pasturing of domestic animals and the spread of heather. The location close to the sea is comparable to many of the sites in this investigation, but bouldery till prevented sand drift.

At Alvevatn, dense forest dominated the vegetation at the same time as the charcoal dust curve rose in the pollen diagram in the period 6500-5400 yrs BP (7430-6240 cal yrs BP) with little soil erosion. This indicates anthropogenic activity during the first Tapes regression, resulting in soil drift, but not yet sand drift (Prøsch-Danielsen & Sandgren 2003).

The second erosional event at Alvevatn is due to anthropogenic erosion starting with slight forest clearance in the Late Mesolithic, c. 5400 yrs BP (6340 cal yrs BP), resulting in sand drift c. 4300 yrs BP (4850 cal yrs BP). This marked the first husbandry at the site. Sand drift escalated about 3800 yrs BP (4190 cal yrs BP) due to deforestation (forest clearance step 2) with subsequent heathland establishment. Subsoil erosion is recorded in the upper layers dated to 3030±30 yrs BP (3325-3209 cal yrs BP, TUa-7254A). Aeolian activity is closely linked to the first grazing by domesticated animals in the area. Subsoil erosion connected with cereal cultivation is recorded further up the sediment sequence at Alvevatn. A simple interpolation indicates that cereal cultivation began about 2000 yrs BP (1960 cal yrs BP). One reason for increased aeolian activity caused by cultivation could be a higher frequency of strong winds locally because fields were enlarged and wind-breaking vegetation was removed from the agrarian landscape (Jönsson 1992). A particularly sensitive period is spring, when the soil is vulnerable to wind erosion.

At Slettabø, the whole sediment sequence is composed of aeolian sand with three separate occupation layers. Pottery and cattle bones indicate that a culture with husbandry probably started in the Early or early Middle Neolithic. The bones are only recorded in occupation layer 2. The oldest date recording habitation at the site is about 5300 yrs BP (6090 cal yrs BP) (Glørstad 1996) or 4800 yrs BP (5540 cal yrs BP) (Skjølsvold 1977), and the second is 4200 yrs BP (4780 cal yrs BP) (Glørstad 1996) or 3700 yrs BP (4040 cal yrs BP) (Skjølsvold 1977). This indicates that the site became inhabited at the onset of forest clearance step 1. Sand drift continued after the site was abandoned, and the people may have left the site because of sand drift. It cannot be determined whether the presence of people and husbandry intensified the aeolian drift or not. Aeolian drift also continued throughout and after the last (third) occupation phase (2900-2400 yrs BP, 3030-2400 cal yrs BP).

In northern Jutland in Denmark, the start of aeolian activity combined with human impact was also recorded in the Early to Middle Neolithic and continued into the Early Iron Age (Liversage & Robinson 1988, 1992-93) (about 200 BC, 2150 BP, 2140 cal BP).

At Bybergsletten, husbandry was introduced about 4800 yrs BP (5540 cal yrs BP) (forest clearance step 1) at the same time as the second Tapes maximum occurred. Sand drift set in immediately afterwards, probably caused by a combination of pasturing animals and the regression giving large areas of exposed sand particles. This caused a double stress on the vegetation and soil. Sand drift, dated to 3930 yrs BP (4410 cal yrs BP) (forest clearance step 2), escalated when the heathland expanded. Cereal cultivation started 3380 yrs BP (3620 cal yrs BP). Palaeosols indicate that sand drift was interrupted by short stable periods.

At Ølstervatn, the earliest recorded pasturing is dated to 4500 yrs BP (5280-5050 cal yrs BP). Sand lenses are recorded in the gyttja after deliberate forest clearance with subsequent heathland establishment about 4300-3800 yrs BP (4850-4190 cal yrs BP) (forest clearance step 2). The sand drift was delayed compared to indications of husbandry, probably by 300-500 calendar years. Soil erosion and sand drift set in only when heathland management was introduced, a phenomenon that is well documented in historical times (Fine 1987 [1745], Grude 1914, Kastellet 1996, Kastellet *et al.* 1998, see also Lees 1982).

After a long period of aeolian activity at Salthelleren, palaeosols indicate 1000 calendar years of standstills and stabilisation in the sand drift from about 4100 yrs BP (4660 cal yrs BP) to around 3400 yrs BP (3660 cal yrs BP), when sand drift ceased and allowed peat to form at the site. Sand drift started again after 2300 yrs BP (2340 cal yrs BP) at the same time as coastal heathland was established in area C. Human activity like burning, pasturing and probably cereal growing caused this sand drift that lasted until the present time.

At Tunge, a short period of sand drift is recorded at the same time as deforestation is recorded, dated to 3500 yrs BP (3780 cal yrs BP) (forest clearance step 3) when heathland became established, indicating husbandry. A new sand drift period started 2400 yrs BP (2400 cal yrs BP).

At Sele Channel, aeolian activity started about 2700 yrs BP (2800 cal yrs BP), after the coastal heathland had become established in the area. This is 400 calendar years younger than forest clearance step 3 and also younger than the start of aeolian activity at the other sites near the mouth of the River Figgjo. The onset of the aeolian drift seems to be closely related to where people chose to use the land.

At Stavanger Airport, soil and sand drift started in the period 2800-2200 yrs BP (2900-2230 cal yrs BP). The landscape was treeless from about 3500 yrs BP (3780 cal yrs BP) (forest clearance step 3). A combination of cereal cultivation and husbandry in the sensitive phase of deforestation, combined with large areas of uncovered marine sand, may have caused the aeolian activity. It lasted until the present time, interrupted by standstills indicated by palaeosols and a peat layer. The palaeosols indicate pauses in the aeolian drift recorded at least about 2800 yrs BP (2900 cal yrs BP), 2700 yrs BP (2800 cal yrs BP) and 2200 yrs BP (2230 cal yrs BP). The peat layer dated to 1800-1500 yrs BP (1720-1380 cal yrs BP), parts of the Roman Iron Age and Migration Period, reflects a stable phase of 200-500 calendar years that allowed humic vegetation cover to develop.

After the Stavanger Airport site was abandoned and cereal cultivation ceased (c. 2200 yrs BP, 2230 cal yrs BP), the settlement and infield were moved to the hillslope to the west (Eilertsen 2007, Aasbø & Eilertsen 2009) as the sandy areas with thick sand sheets were useless for cultivation. Heathland expanded and husbandry was practised in the low-lying areas. At the same time, the heathery vegetation developed into the coastal heaths as an independent landscape element and an important part of the outfield system all over western Norway (Kaland 1979, 1984, Prøsch-Danielsen & Simonsen 2000a, 2000b). The management of this coastal heathland included grazing, burning and scything that increased soil erosion and sand drift. New agricultural technology was introduced and the land use also involved cereal growing which further accelerated sand drift. This change was completed in the Roman Iron Age and the Migration Period, and the well-established farm (known as the "Jærske" Farm) with its well-defined infields and outfields was in place (Myhre 2002, Soltvedt *et al.* 2007).

Standstill was also recorded at Slettabø about 1700 yrs BP (1590 cal yrs BP). Here, the reasons for sand drift were regular burning of the heathland and increased grazing, combined with strong onshore winds in the dune area, the same triggering factors as at the Stavanger Airport site.

Aeolian activity increased in Denmark (Djursland) from the Late Bronze Age to the Roman Age in the form of dust (soil) storms and sand drift triggered by landscape changes caused by human impact (Bahnson 1973, Mikkelsen *et al.* 2007). Aeolian activity in the Iron Age is also recorded elsewhere in northwestern Denmark (Vesthimmerland and the Aalborg area, Jørgensen 1994, Johansen 1994). In western Ireland (Co. Galway), McCormick *et al.* (1993) recorded sites in the coastal dunes dating from the Bronze Age to the Middle Ages.

At Hebnes, aeolian activity started before 1400 yrs BP (1300 cal yrs BP), in the Merovingian Period, and has continued until today. The triggering factors were natural processes (high wind speed and unprotected sand close to the beach) and erosion of the vegetation and soil cover by people, their livestock and cultivation.

The aeolian drift at Solavika (P7, at the foot of the slope) ceased before 1170 BP (1110 cal yrs BP) due to more humid conditions downslope. At around 1020±60 yrs BP (1048-801 cal yrs BP), the anthropogenic impact at P9, higher on the slope, had increased considerably due to husbandry and cereal cultivation. Incipient sand drift that has continued until the present day was the result, only interrupted by short standstills. As the population increased and aeolian drift intensified again, people moved their dwellings and infields to the hilltops from the Pre-Roman Iron Age (Høgestøl & Bakkevig 1986, Hommedal 1994, Mari Høgestøl, pers. comm.). At Solavika Bay (P9) this is confirmed by depositing of sand in the peat from 1020±60 yrs BP (1048-801 cal yrs BP).

Another site where aeolian drift started in the Viking Period is Stad (Longva *et al.* 1983:41, 43). In the upper sediment sequence, a radiocarbon date from the top of a peat layer is dated to 1090±70 yrs BP (1065-930 cal yrs BP, T-2535) giving a maximum age of the last sand drift in the area.

Grazing, deforestation of the birch forest and soil erosion about 1100 years ago, in the Viking Period, has been reported from Iceland (Thorarinsson 1961, 1970:21-23, Guðmundsson & Kjartansson 1984:66-68). The result was a loss of about half the soil of the country. At Frøslev Plantage in southern Jutland in Denmark peat covered by aeolian sediments were recorded (Castel *et al.* 1989, Kolstrup 1997:99). A charcoal horizon was radiocarbon dated to 1100±100 yrs BP (1168-928 cal yrs BP). It was located in aeolian sand above a peat layer (Sørensen 1972:8-9) and indicates aeolian drift in the Viking Period. Kolstrup (1997:99) excluded climate as a reason for the devastating environmental change as no major climatic changes are known from that time. Aeolian drift was also recorded from the inland dunes at Ulfborg in western Jutland in this period (Jonassen 1954) and pre-AD 1800 at Kristianstadsletten in northeastern Skåne, Sweden (Agrell 1979).

Sand drift was intensified during the "Little Ice Age" (AD 1350-1850) due to a higher frequency of storms. At Slettabø, the early part of this event was radiocarbon dated to 665±25 and 435±25 yrs BP (666-567 and 514-492 cal yrs BP, AD 1284-1383 and 1436-1458). In Denmark, Hansen (1957:82-83) summed up information from Thy about aeolian drift in the Late Middle Ages, from AD 1550 to after 1750, but peaking in AD 1680-1715 (see also Andersen 1994, Bech 2006 and Skarregaard 2006). Hansen (1957:84) also pointed out the coincidence with the "Little Ice Age". In northern Jutland in Denmark, many place names indicate that farms were abandoned after AD 1500 (Liversage & Robinson 1988:269). This was correlated with similar catastrophic aeolian drift in England and sand invasion which caused problems for human settlement, including abandonment of villages, driven by an increased frequency of severe storms along the Atlantic coast of southwest France. Wilson *et al.* (2001) pointed out that most of the dunes in northeast England (Northumberland) were formed during the "Little Ice Age", probably in association with specific climatic and morphosedimentary conditions in this period (e.g. periods of easterly circulation and a greater frequency of severe North Sea storms). Aeolian sand movement at Ho Bugt, western Denmark, was dated to the early part of the "Little Ice Age", a period with increased storminess, coastal dune formation, salt marsh formation and increased relative sea-level rise (Szkornik *et al.* 2008). The authors pointed to transgressive conditions and relative sea-level rise, rather than a low sea-level, as the important contributing factors to coastal sand movement and dune formation. The heathland and dune vegetation on a coastal plain in Portugal was degraded by destabilisation and immigration of dunes and a subsequent desertification (Danielsen 2009). It was possibly a consequence of intensive grazing and connected to the deterioration of climate during the "Little Ice Age". A higher frequency of storms during the late Holocene, peaking during the "Little Ice Age", was also demonstrated by Jelgersma *et al.* (1995) in the coastal dunes of the western Netherlands, and they suggested that the causes of increasing storm surge levels in this area were climatic variations and the foreshore bathymetry. Indeed, they actually coincided with the Maunder Minimum, AD 1645-1715, the coldest phase of the "Little Ice Age" in northwestern Europe (Pedersen 1996). This is also the case of the sand drift on the Danish island of Læsø in the Kattegat, which culminated in AD 1667-77 when the northern part of the island developed into desert. Deforestation (to obtain fuel to extract salt by boiling seawater) and the use of soil and peat to improve the soil, combined with more stormy weather during the "Little Ice Age", caused this desertification (Hansen 1995:58, 67). In Jæren, a combination of strong wind and anthropogenic activity was probably the reason for aeolian activity when excessive pasturing triggered erosion. Many authors (se section 1) confirmed aeolian drift in the area investigated during historical times.

Conclusions about climate as a cause of aeolian activity often underrate or do not consider prehistoric people as agents of environmental changes such as aeolian activity (e.g. Filion 1984, Wishman 1990, Filion *et al.* 1991, Clemmensen *et al.* 2001). Our study confirms that people played an important role in triggering sand drift both in prehistoric and historical times.

Climate as a cause of aeolian activity has not been directly recorded in either the biostratigraphy or the lithostratigraphy in this study. Ever since the deglaciation, periods with wind strong enough to start aeolian activity have characterised the Polar Front oscillation area where northern Europe is located on the macro scale. As the yearly change in the wind direction during the Holocene is connected with a fundamental Scandinavian monsoon, the mean frequency of the strongest winds has probably not changed significantly in this period. As long as the soil and unconsolidated sandy sediments are protected by vegetation, aeolian activity is limited to a narrow coastal zone. On the other hand, when vegetation is sparse or absent for some reason, the substrate will be exposed to the wind. The consequence is that aeolian activity occurs when the wind is strong enough. In this respect, climate, i.e. the wind, plays a role in aeolian activity, but this is an interpretation of available data, not direct proof based on observations.

# Conclusions

- The studied sites with aeolian deposits are all situated below the marine limit (ML).
- There is a close relation between areas with unconsolidated sediments and sandy beaches. Sand drift is not recorded along the bouldery coast from Obrestad to Kvassheim.
- The premises for aeolian activity are the presence of unconsolidated sandy sediments, wind strong enough to transport the sand particles and a sparse or absent vegetation cover. These premises have been present now and then since the deglaciation. However, there are no records of Late Weichselian or Preboreal aeolian activity in the area studied, probably because areas which now have sandy beaches were submerged at that time.
- The main reasons for aeolian activity are sea-level changes and anthropogenic factors. Aeolian activity during the Holocene primarily took place in areas that were submerged by the sea during the Tapes transgression (6800-4800 yrs BP, 7640-5540 cal yrs BP). The coast of the low-lying Jæren was then located more than one kilometre inland from the present outer coastline, and the large, shallow fjords and river mouths were from then on gradually filled by great amounts of sandy sediment. In this area, the Tapes transgression was double-peaked, which meant that large areas of coast were exposed and prone to erosion and later sand drift for a long time. The second and final regression was the most important as regards sand drift. Until Neolitisation, the sand drift was mainly triggered by sea-level changes along the coastal rim. Later, it escalated due to anthropogenic impact, initially deforestation and husbandry, then heathland development and management, and also cereal cultivation. People played an important role in triggering sand drift in prehistoric and historical times.
- The change from a forested to an unforested landscape changed the local climate following the Neolitisation. The wind speed accelerated and sand drift increased at the same time as the temperature dropped considerably.
- The earliest documented sand drift is older than 8100 yrs BP (9200 cal yrs BP) and started after the Preboreal regression minimum.

- At Sunde aeolian activity was recorded about 7400 yrs BP (8200 cal yrs BP), which corresponds to a cooling event recorded in the North Atlantic region.
- At Salthelleren, human impact caused aeolian drift from about 6470 yrs BP (7380 cal yrs BP) in the Late Mesolithic before agriculture was introduced to this area. People probably influenced the natural environment, in part by burning and otherwise managing the vegetation.
- The effect of the Neolithic culture triggered and accelerated sand drift during the regression after the second Tapes maximum from about 4800 yrs BP (5540 cal yrs BP).
- The sand drift is well correlated with the metachrone forest clearance steps 1-3 defined for this area as starting with the Neolitisation.
- The deforestation caused by people during the Neolitisation process resulted in lower temperatures and stronger wind. Thus people were important for altering climate.
- When the Norwegian coastal heaths were established in two steps, sand drift escalated. Heathland management involved pasturing, burning and scything, which led to soil degradation and thus accelerated sand drift.
- Aeolian activity in the Middle Ages and afterwards is documented in this area from the start of the "Little Ice Age" (AD 1350-1850). It is also documented from the Maunder Minimum (AD 1645-1715), the coldest phase of the "Little Ice Age", a period with more severe storms.
- The data do not give direct indication that climate triggers aeolian activity. However, without wind that is strong enough to set sand drift in motion, aeolian activity cannot exist. The Polar Front oscillation in northern Europe is vitally important for the frequency of aeolian activity if unconsolidated sandy sediments with sparse or no vegetation cover are available.

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