

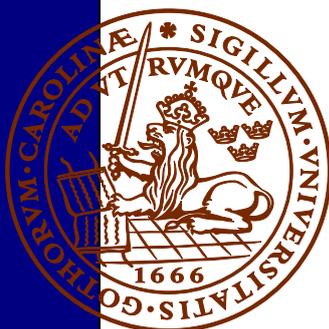
Vegetation responses to Late Glacial climate shifts as reflected in a high-resolution pollen record from Blekinge, south-eastern Sweden, compared with responses of other climate proxies

Artemis Karlatou-Charalampoulou

Dissertations in Geology at Lund University,

Master's thesis, no 464

(45 hp/ECTS credits)



Department of Geology
Lund University
2016

**Vegetation responses to Late Glacial
climate shifts as reflected in a high-
resolution pollen record from Blekinge,
south-eastern Sweden, compared with
responses of
other climate proxies**

Master's Thesis
Artemis Karlatou-Charalampopoulou

Department of Geology
Lund University
2016

Table of Contents

1 Introduction	7
2 Background	7
2.1 Previous studies of the Hässeldala Port sedimentary sequence	7
3 Aim of Study	9
4 Site Description	11
4.1 General Description	11
4.2 Current climate and vegetation	11
4.3 Bedrock	11
4.4 Quaternary Deposits	14
5 Methods	14
5.1 Field Methods	14
5.2 Laboratory Methods	14
5.2.1 Core preparation, lithostratigraphic description and subsampling	14
5.2.2 Analysis of loss on ignition (LOI)	15
5.2.3 Pollen sample preparation	15
5.2.4 Microscopy and data handling	16
5.2.5 Age model	17
6 Results	17
6.1 Lithostratigraphy, loss-on-ignition (LOI) and chronology	17
6.2 Pollen stratigraphy	19
7 Discussion	21
7.1 Correlation of the local pollen zones to the regional pollen zones for Blekinge	21
7.2 Interpretation of pollen zones in references to the vegetation changes and comparison with other proxies	24
7.3 Comparison with previous studies from Blekinge region	29
8 Conclusions	31
9 Acknowledgements	33
10 References	34

Vegetation responses to Late Glacial climate shifts as reflected in a high-resolution pollen record from Blekinge, south-eastern Sweden, compared with responses of other climate proxies

ARTEMIS KARLATOU-CHARALAMPOPOULOU

Karlatou-Charalampopoulou, A., 2016: Vegetation responses to Late Glacial climate shifts as reflected in a high-resolution pollen record from Blekinge, south-eastern Sweden, compared with responses of other climate proxies. *Dissertations in Geology at Lund University*, No. 464, 36pp. 45 hp (45 ECTS credits) .

Abstract:

This study focuses on an almost 1700 year long lake sediment sequence from Hässeldala Port in central Blekinge, SE Sweden. It covers the transition period between the Pleistocene and Holocene, or more precisely the GI-1a and GS-1 events and into the Holocene Epoch in the ice cores, corresponding to the Late Allerød to the early Preboreal south Swedish pollen zones. In order to study the late glacial climate development and time lags between different proxies several studies have been conducted before at the same site. In this study detailed loss on ignition analyses were carried out to correlate with a detailed total organic carbon sequence. Since the latter was extremely well-dated with 49 ¹⁴C measurements of terrestrial macro-fossils it was possible to obtain a detailed chronology for the new sequence. A very dense pollen analysis was performed to compare the vegetation response to the other proxies from previous works. Such an analysis is especially crucial for critical transitions between warm and cold periods. The pollen based reconstruction shows that the gradual onset of the Younger Dryas cold period began at 12770 cal yr BP characterized e.g. by declining *Empetrum* pollen values. However, the main cold period of the Younger Dryas cold event, characterized mainly by increased frequencies of *Artemisia*, *Dryas octopetala* and *Juniperus* pollen grains, occurred between 12540 and 11850 cal yr BP, lasting less than 700 years. The transition from Younger Dryas to the Early Holocene pollen zones appears to be smoother than the transition from the Late Allerød to Younger Dryas pollen zones, lasting 200-300 years, with rising values of *Empetrum* and declining frequencies of *Artemisia* pollen grains as the main diagnostic feature. The correlation to the other studies reveals a consistent response of the different proxies to the main climate changes seen in the pollen record, although there are certain time lags between them.

Keywords: : lake sediments, Blekinge, SE Sweden, Pleistocene-Holocene boundary, loss on ignition, pollen analysis, high time-resolution, time lags.

Supervisor(s): Svante Björck, Professor emeritus, Department of Geology, Lund University, Sölvegatan 12, SE-223 62 Lund, Sweden. E-mail: svante.bjorck@geol.lu.se, +46462227882

Barbara Wohlfarth, Professor, Institute of Geological Sciences, Stockholm University, Svante Arrheniusväg 8 C, Geohuset, Stockholm, Sweden, E-mail: Barbara@geo.su.se, +468164883

Mats Rundgren, Senior lecturer, Department of Geology, Lund University, Sölvegatan 12, SE-223 62 Lund, Sweden. E-mail: mats.rundgren@geol.lu.se, +46462227856

Subject: Quaternary Geology

Artemis Karlatou-Charalampopoulou, Department of Geology, Lund University, Sölvegatan 12, SE-223 62 Lund, Sweden. E-mail: artemis.kc@gmail.com

Vegetationsresponser på senglaciala klimatförändringar indikerade av pollendata med hög upplösning från Blekinge, sydöstra Sverige, samt en jämförelse med responser hos andra klimatindikatorer

ARTEMIS KARLATOU-CHARALAMPOPOULOU

Karlatou-Charalampopoulou, A., 2016: Vegetationsresponser på senglaciala klimatförändringar indikerade av pollendata med hög upplösning från Blekinge, sydöstra Sverige, samt en jämförelse med responser hos andra klimatindikatorer. *Examensarbeten i geologi vid Lunds universitet*, Nr. 464, 36sid. 45 hp.

Sammanfattning:

Denna studie fokuserar på en nästan 1700 år lång sjösedimentsekvens från Hässeldala Port i centrala Blekinge, sydöstra Sverige. Den omfattar övergångsperioden mellan pleistocen och holocen, eller mer precist eventen GI-1a och GS-1 samt början av den holocena epoken i iskärnorna, vilket motsvarar de sydsvenska pollenzonerna sen allerød till tidig preboreal. För att studera den senglaciala klimatutvecklingen, och tidsförskjutningar mellan olika klimatindikatorer, har det tidigare utförts flera undersökningar på samma lokal. I denna studie utfördes detaljerade glödförlustanalyser för att möjliggöra korrelation med tidigare utförda och detaljerade analyser av organisk halt. Eftersom den tidigare dataserien var extremt väldaterad med 49 st ^{14}C -analyser av terrestra makrofossil, var det möjligt att upprätta en detaljerad kronologi för den nya sedimentsekvensen. En mycket tät pollenanalys genomfördes för att jämföra vegetationsresponsen med data för andra klimatindikatorer från tidigare undersökningar. Sådan analys är särskilt viktig i anslutning till kritiska övergångar mellan varma och kalla perioder. Den pollenbaserade rekonstruktionen visar att den gradvisa inledningen av kallperioden yngre dryas började för 12770 cal sedan och karakteriserades bl.a. av minskande pollenvärden för *Empetrum*. Dock inträffade den kallaste delen av kallperioden yngre dryas, vilken främst karakteriserades av ökade pollenfrekvenser för *Artemisia*, *Dryas octopetala* och *Juniperus*, mellan 12540 och 11850 år före nutid, och varade alltså mindre än 700 år. Övergången mellan pollenzonen yngre dryas och pollenzonen tidig-holocen förefaller att vara mer gradvis än övergången mellan pollenzonerna sen allerød och yngre dryas och varar 200-300 år, samt kännetecknas främst av stigande värden för *Empetrum*-pollen och avtagande frekvenser av *Artemisia*-pollen. Korrelation med de andra undersökningarna visar på en samstämmig respons hos de olika klimatindikatorerna på de större klimatförändringar som ses i pollenstratigrafin, även om det finns vissa tidsförskjutningar dem emellan

Nyckelord: sjösediment, Blekinge, sydöstra Sverige, gränsen pleistocen/holocen, glödförlust, pollenanalys, hög tidsupplösning, tidsförskjutningar

Handledare:

Svante Björck, Professor emeritus, Geologiska institutionen, Lunds Universitet, Sölvegatan 12, 223 62 Lund, Sverige. E-post: svante.bjorck@geol.lu.se, +46462227882

Barbara Wohlfarth, Professor, Institutionen för geologiska vetenskaper, Stockholms universitet, Svante Arrheniusväg 8 C, Geohuset, 106 91 Stockholm, Sweden, E-post: Barbara@geo.su.se, +468164883

Mats Rundgren, Senior lecturer, Geologiska institutionen, Lunds Universitet, Sölvegatan 12, 223 62 Lund, Sverige. E-post: mats.rundgren@geol.lu.se, +46462227856

Ämnesinriktning: Kvartergeologi

Artemis Karlatou-Charalampopoulou, Geologiska institutionen, Lunds Universitet, Sölvegatan 12, 223 62 Lund, Sverige. E-post: : artemis.kc@gmail.com

1 Introduction

Many studies have addressed the dramatic climatic and environmental changes that took place at the last glacial/interglacial transition. Of these, the Younger Dryas period, is probably the best known, but also the most debated (Broecker et al., 2010), as it represents a marked climatic cooling during a period with high summer insolation (Berger, 1990; Björck, 2007; Muscheler et al., 2008). Evidence from Northern Hemisphere climate archives shows that abrupt climate changes during the last glacial/interglacial transition occurred even in a matter of decades (Rasmussen et al., 2006). Since these changes had a huge impact on terrestrial and marine ecosystems, their imprints are ideal to gain a better understanding of the biotic responses (Birks & Ammann, 2000), which in turn can be used to reconstruct past environmental and climate conditions.

Efforts have been made; not only to map the spatial distribution of past climatic shifts, but also to identify the origin of and mechanisms that triggered natural climatic changes (Berger, 1990; Björck et al., 1996). Hypotheses that were brought forward to explain the rapid climate shifts during the last glacial/interglacial transition included changes in North Atlantic Thermohaline Circulation (Broecker, 2003), which affected North Atlantic deep water formation and as a consequence the formation of sea ice cover (Björck et al., 1996; Hughen et al., 1998; Pinter et al., 2011; de Vernal et al., 2013), and/or changes in solar activity (Renssen et al., 2000; Bond et al., 2001; Björck et al., 2001; van der Plicht et al., 2004).

Researchers have, however, stressed the need of a good chronology, in order to place these changes on a common time frame and to enable regional correlations. To accomplish this, the Greenland Ice Core records were chosen as a template, against which other well-dated regional records can be compared (Svensson et al., 2008). The Greenland Ice Core Chronology (GICC05) now represents a standard for the climatic events of the Last Glacial period (Table 2) and allows comparisons of ^{14}C dated palaeoclimatic archives (Lohne et al., 2013). This comparison will lead to a better discernment of the causes behind last glacial/interglacial transition climate changes and possible time lags between different archives and different proxies (Lowe and Hoek, 2001).

Some of the most commonly used proxies to reconstruct past environmental and climatic conditions are pollen, plant and animal macrofossils (e.g. chironomids), diatoms and stable isotopes. Some of these proxies are more sensitive to some factors than others and as a result there are some discrepancies among the records (Lotter et al., 2010). Here I present a detailed pollen stratigraphic study for the Hässeldala Port sedi-

mentary sequence in S. Sweden and discuss the vegetation development and response to climate shifts during the last glacial/interglacial transition. The excellent chronology for Hässeldala moreover makes it possible to assign revised age estimates to local and regional pollen zones and thus provides a new chronological framework for the vegetation development during Allerød – Younger Dryas – Early Holocene for southernmost Sweden.

2 Background

2.1 Previous studies of the Hässeldala Port sedimentary sequence

Over the years several studies have been conducted at Hässeldala Port (Table 1) in order to obtain a detailed and complete story concerning Late Glacial climate changes in the area. Davies et al. (2003, 2004) have, ever since one of the first cores were retrieved from the site, used tephrochronology to correlate the Late Glacial and Early Holocene sedimentary sequence to the regional pollen stratigraphy and identified three tephra layers: the Borrobol Tephra, the Askja Tephra (10000 ^{14}C yr B.P.), and one tephra of Icelandic origin, which until recently had not been known and which was termed the Hässeldala Tephra (Fig. 1). Moreover, two other tephra layers were discovered, but these could not be attributed to a known volcanic eruption. The Borrobol Tephra in the lowest part of the sequence was estimated at ca 12300 ^{14}C yr B.P. in comparison with an equivalent tephra layer found at a site in Scotland. The Hässeldala Tephra is geochemically similar to the Borrobol Tephra and likewise originates from an Icelandic eruption. It occurs in the Hässeldala sequence at the transition between the Younger Dryas and Preboreal pollen zones and before the Preboreal Oscillation which lasted from 11300 to 11200 cal yr B.P. in southern Sweden (Björck et al., 2002).

Davies et al. (2004), in a further paper, introduce an updated age-depth model for Hässeldala suggesting that the Borrobol Tephra dates to the late Older Dryas and correlates with event GI-1d or GI-1c in the Greenland ice core stratigraphy. This assignment was supported by a pollen stratigraphic study of the Hässeldala sequence (Andersson, 2004).

Wohlfarth et al. (2006) attempted to better constrain the ages of these five tephra layers in Hässeldala: the Borrobol Tephra (BT), the Hässeldalen Tephra (HDT) and the 10-ka Askja Tephra (AsT) and the two unidentified ash layers (Davies et al. 2003). This work was based on three parallel cores, which were correlated to each other using loss-on-ignition and total carbon values. This correlation showed differences in the sedimentation rates of the different layers, a feature that is

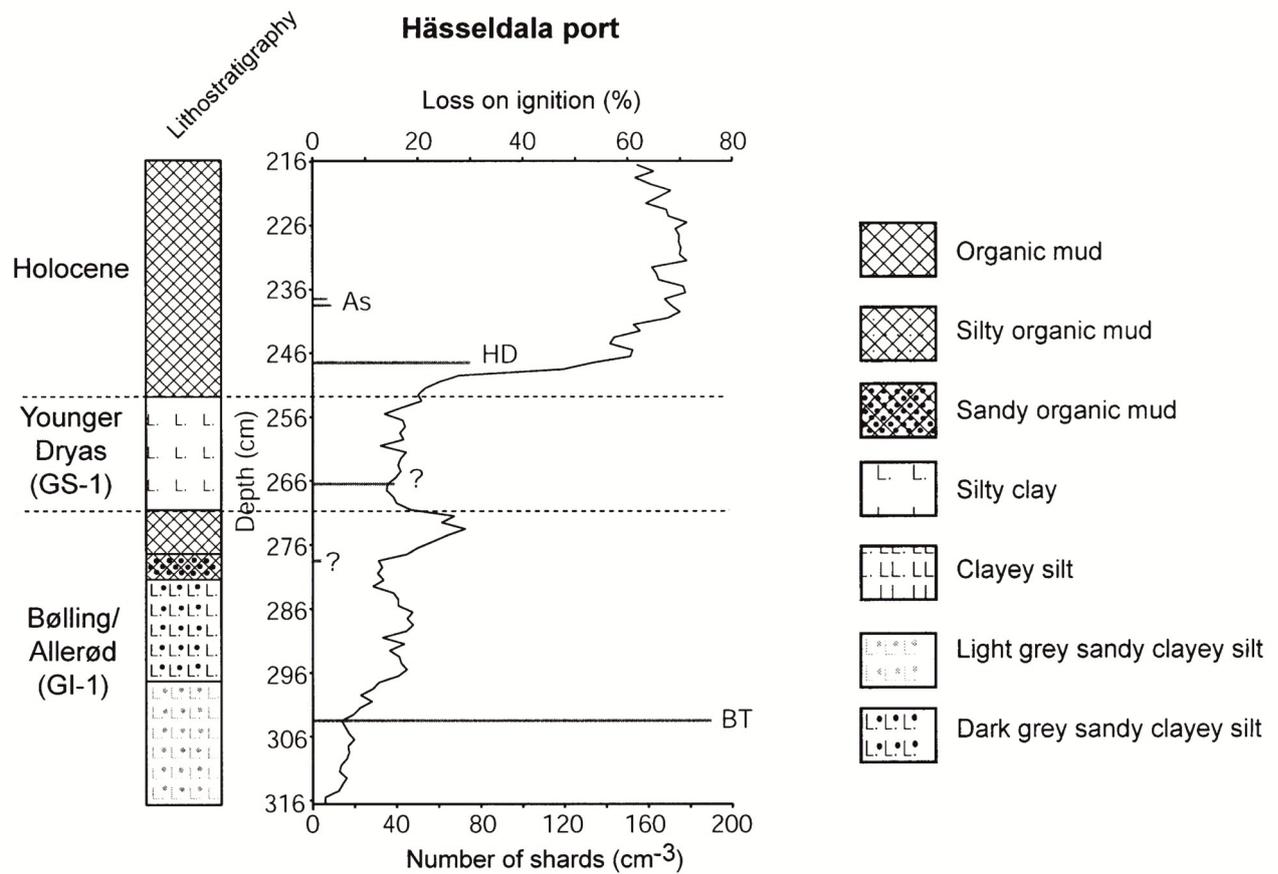


Figure 1, Lithostratigraphy, loss on ignition, and tephra counts for Hässeldala port (Davies et al., 2003; Fig. 2), where BT: Borrobol Tephra, HD: Hässeldalen Tephra, AS: Askja Tephra

quite common for Late Glacial lake sediments. The Borrobol Tephra was for example found in Core #1 at 303 cm depth, in Core #2 at 302 cm depth and in Core #3 at 394 cm depth. The two unidentified tephra layers were only found in core #1 at 278 and 266 cm depth, respectively. The Hässeldalen Tephra was found at 247 cm depth in Core #1, but at 321-322 cm depth in Core #3. The Askja tephra, which is the youngest, was found in Core #1 at 238 cm depth and in Core #3 at 308-310 cm depth. Pollen analysis was only made on Core #3 and seven local pollen zones were defined (Wohlfarth et al., 2006; Andersson, 2003) and correlated with the regional pollen zones for Blekinge (Björck et al., 1998). This correlation showed that this analysed sequence covers the Chronozone interval from the Older Dryas to the Preboreal Chronozone. Related to the pollen stratigraphy of Wohlfarth et al. (2006), the Borrobol Tephra coincides with the end of their regional OD pollen zone; the older of the two unidentified tephtras corresponds to the local HÄP3 pollen zone, corresponding to the upper part of the AL pollen zone, and the younger to the early stage of their regional YD pollen zone (HÄP4); and finally the Hässeldalen and Askja Tephra to the HÄP6 and HÄP7 local pollen zones, respectively, corresponding to the regional Preboreal pollen zone. Although Wohlfarth et al. (2006) used 28 ^{14}C measurements and three diffe-

rent age models (Wohlfarth et al. 2006, Fig.3); it was pointed out that an exact age for the tephtras and the different pollen zones cannot be determined and that a robust chronostratigraphy of the site still needs to be constructed.

Kylander et al. (2013) studied the geochemical responses to palaeoclimatic changes from the sediment record of Hässeldala, with the use of XRF core scanning, total organic carbon (TOC), the C/N ratio, and bulk sediment ^{14}C analyses. These authors suggested that sediment accumulation reached a peak during the Bølling/Older Dryas pollen zones. During the Allerød pollen zone sediment accumulation was constant, with only a minor increase, which was indicated by changes in lake organic productivity and silicate sources. Around 12,000 cal yr BP lake organic productivity and hydrological activity began to change progressively. Steinthorsdottir et al. (2013; 2014) investigated leaf stomata and reconstructed past atmospheric CO_2 levels. This proxy revealed a sudden increase in atmospheric CO_2 concentration (pCO_2) at the onset of the Younger Dryas pollen zone and then a decrease in atmospheric CO_2 concentration (pCO_2) during the Younger Dryas pollen zone (Steinthorsdottir et al. 2013(Fig.3)).

Table 1, Number of cores that were studied in Hässeladala site, along with each study and its reference respectively. Cores #1 and #2 were retrieved in 2001, while Core #3 and Core #4 were retrieved in 2002. Core #5 is the most recent, core that was retrieved in 2011. Core #6, is one of the first cores retrieved along with core #3, but it is named #6, for the needs of the present study.

Core No.	Study performed	References
Core #1	TOC, Tephra analysis, ¹⁴ C dating	Davies et al. (2013,2014)
Core #2	TOC, ¹⁴ C dating, Cryptotephra positions	Wohlfarth et al. (2006)
Core #3	TOC, pollen analysis, Cryptotephra positions	Wohlfarth et al. (2006)
Core #4	Geochemistry	Kylander et al. (2011)
Core #5	LOI, fossil leaf stomata, diatoms, biomarker and stable isotope analysis	Steinhorsdottir et al. (2013,2014), Ampel (2015), Muschitiello et al. 2015a
Core #6	LOI, pollen analysis	Pollen analysis (present study)

Finally Ampel et al. (2015) used the fossil diatom record to analyse the response of diatom assemblages to abrupt climate change and lake status changes. The record covers a period from 13,900 up to 11,200 cal yr BP, i.e. from the Older Dryas to the Preboreal pollen zones. An acidification event occurred between 13,900 and 12,500 cal yr BP. During the early Younger Dryas pollen zone the amount of opportunistic taxa increased, due to a change in aquatic conditions. The cooling at the onset of the Younger Dryas pollen zone coincides with the disruption of this acidification trend and an increase in lake pH. The observed climatic changes affected the hydrological cycle and through this the terrestrial and aquatic system of the site.

Further studies are currently taking place (Muschitiello et al., 2015) and focus on biomarkers and hydrogen isotopes.

3 Aim of Study

The last Late Glacial period of NW Europe that took place 14,700 -11,700 years ago was characterised by multiple large-scale climate shifts as shown by Greenland ice core records (Table 2), and marine and lacustrine sedimentary archives (Lowe et al., 2008). Thus crucial questions have arisen concerning these rapid climate shifts: did they occur suddenly and

Table 2, Depths and preliminary ages (based on the recognition of interstadial events) events and episodes in the GRIP ice-core respectively. Note that the ages denote the onset of the events and episodes. The Holocene epoch is also included. There are some uncertainties, ±30yr, due to unclear boundaries or differences with the isotopic profiles of records, for the older part of the chronology (2σ-uncertainty). Modified from Björck et al. (1998) and Blockley et al. (2012). *b2k: before 2000 AD; ** feature not consistent between records (Blockley et al., 2012); however in the original publication by Björck et al. (1998) the ages and depth for GS-2a are the aforementioned: 1823.7 m for the NGRIP and 16.900 years b2K for the GICC05.

Events	Episodes	Ice-Core depth (m) in NGRIP	GICC05 age (years b2K)*
Holocene Epoch		1492.45	11703
Start of GS-1		1523.52	12896
GI-1	GI-1a	1534.5	13099
	GI-1b	1542.1	13311
	GI-1c	1570.5	13954
	GI-1d	1574.8	14075
	GI-1e	1604.64	14692
GS-2	GS-2a**	1823.7	16900
	GS-2b	1745.31	20900
	GS-2c	1783.62	22900
GI-2		1793.19	23340

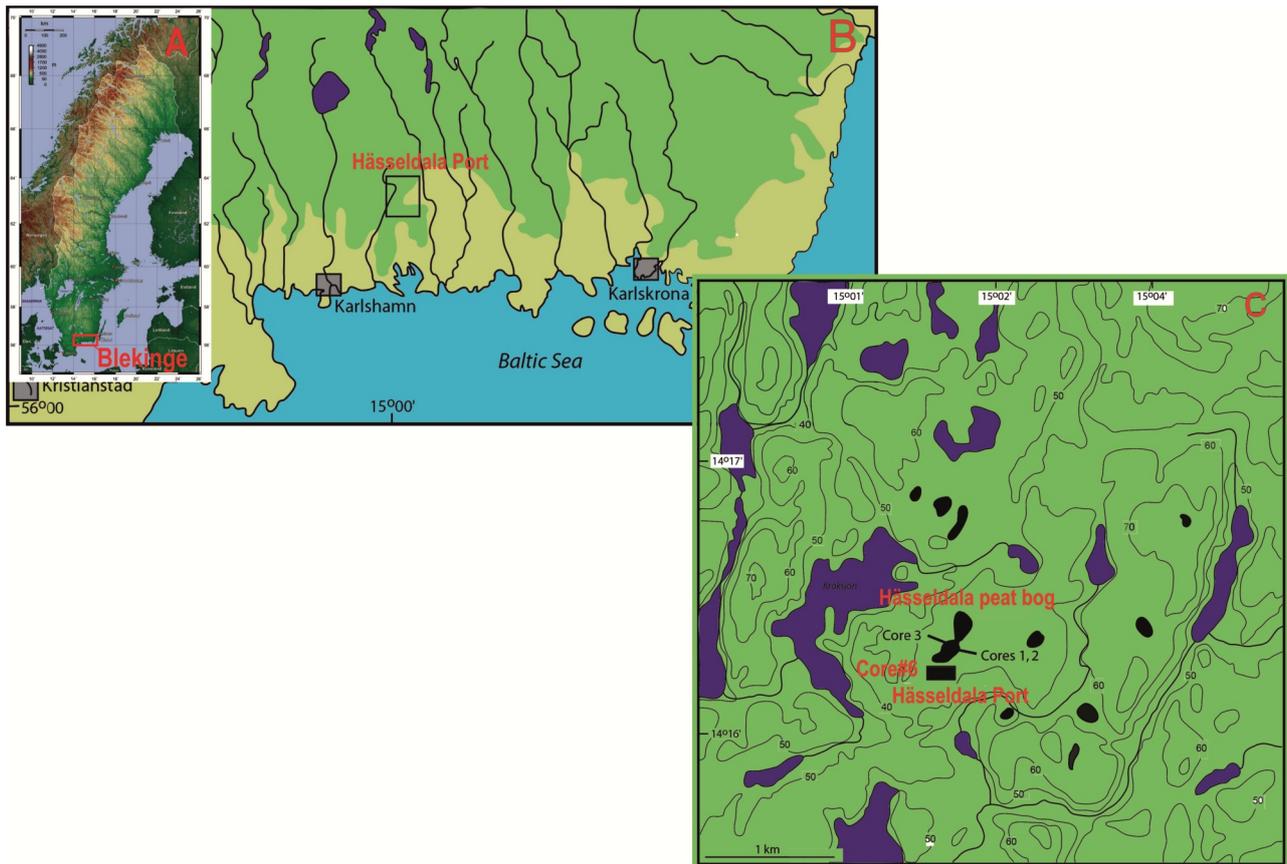


Figure 2, (A) Topographic Map of Sweden (Figure by GNU project ; location of Blekinge (S. Sweden) is marked on the map (B) Topographic map of Blekinge; location of Hässeldala Port, where green: contours above 50 m, brown: contours below 50m (C) Topographic map of Hässeldala Port and its surrounding area. The location of the sediment sequence [Core 3.1(#6)] studied here is indicated. (Figure modified from Kylander et al., 2013). Hässeldala Port Cores #1, 2 and 3 were used in previous studies in the area (Davies et al., 2003, 2004; Wohlfarth et al., 2006).

synchronously over continental regions, or were they gradual and stepwise? If so, the question is to what degree? Can the response to these climatic changes be mapped in time and space? To investigate these questions it is vital to have a number of extremely well-dated records with a variety of climatic and environmental proxies. According to Cohen (2003) lake sediments are excellent natural archives that play a pivotal role in obtaining knowledge about temporal and spatial changes in the environment on shorter and longer time scales.

This thesis is part of a larger multi-proxy project studying the Late Glacial palaeoclimatic and palaeoenvironmental record preserved in the sediments of the former lake of Hässeldala Port in Blekinge, southern Sweden (Fig. 2), ((modified from Kylander et al., 2013(Fig.1)). This site has previously been studied in great detail regarding Late Glacial lithology, chronology, tephra, pollen stratigraphy (Andersson, 2004, Davies et al., 2003, Wohlfarth et al., 2006), chironomids and coleoptera (Watson, 2010), leaf stomata (Steinthorsdottir et al., 2013, 2014) and biomarkers

(Muschitiello et al., 2015). However, an updated and high-resolution pollen stratigraphic study covering the late Allerød, Younger Dryas and early Preboreal regional pollen zones is still missing. Such a study is important to compare the response of the vegetation to that of the other proxies at rapid climate transitions from warm to cold and cold to warm climate states.

The main aim of my Master thesis project has therefore been to produce a detailed pollen stratigraphic record of the Allerød – Younger Dryas - Preboreal sediments from the Hässeldala Port site and to compare the response of the vegetation to already established climate proxies from this site. Moreover, the new pollen stratigraphy for Hässeldala Port is compared to regional pollen stratigraphies to find out whether the changes observed at Hässeldala represent local or regional vegetation changes. Together with other proxies studied at Hässeldala (Andersson, 2004; Davies et al., 2003; Wohlfarth et al., 2006; Steinthorsdottir et al., 2013, 2014; Ampel et al., 2015) the new pollen stratigraphy will help understanding of how past climate change impacted on the ancient lake and on its catchment and if the response was sudden or gradual.

Specific research questions are:

I) What do the vegetation changes tell us about shifts in local environmental conditions and how do they relate to larger scale climate shifts?

II) Did changes in vegetation co-occur with the changes seen in other proxies (e. g. lithology, chironomids, diatoms) or are there time lags between the different responses?

III) Are the pollen stratigraphic responses gradual or sudden in response to a changing climate?

4 Site Description

4.1 General Description

The significance of this site is that it provides a vast amount of information about the climatic and environmental changes during the last Glacial-Interglacial transition (Wohlfarth et al., 2006; Kylander et al., 2013; Ampel et al., 2015).

Hässeldala Port (56°16'N, 15°03'E) is located in the province of Blekinge in the southernmost part of Sweden at 65 m above sea level (Fig. 2). The site is known to contain a detailed stratigraphic record covering parts of the Late Glacial and Holocene. Today Hässeldala is a small peat bog, located within a mixed forest. Below the peat are lake sediments dating to the late Bölling until the Early Holocene pollen zones (Anderson, 2003).

4.2 Current climate and vegetation

Blekinge is classified as having a humid continental climate and is characterised as Dfb in the Köppen and Geiger classification system (Köppen, 1936; Peel, 2007). Mean annual temperature is 7.0° C and mean maximum and minimum temperatures are 11.2° C and 3.0° C respectively (Meteorologisk institutt, www.met.no/). Mean annual precipitation is approximately 780 mm and clear seasonal variations exist (SMHI, www.smhi.se). Westerly to south-westerly winds are dominant in the region (SMHI, www.smhi.se). Most of the present vegetation of Blekinge is influenced by human activity (Yu et al., 2005) and has been modified by forestry.

The area is located in a transition of various forest zones: it mostly consists of broad-leaved forests, of which some have a very long continuity in the southern part, while mixed forests with broad-leaved and coniferous trees are present in the northern part (Berglund, 1966; Yu et al., 2005). Broad-leaved forests most commonly consist of oak and beech, in combination with other tree species, such as ash, lime and elm. Along the east coast of Blekinge, there is a significant area of coniferous forest of pine and planted spruce, which was planted during the previous two centuries (Biosfärområde Blekinge Arkipelag, [http://](http://www.blekingearkipelag.se)

www.blekingearkipelag.se). Another type of land cover is the natural grazing land, varying from dry lean grass to tall herb meadows; juniper wood is here usually dominant in the shrub layer (Berglund, 1966).

4.3 Bedrock

Blekinge forms part of the south-eastern fringe of the Fennoscandian Shield. The bedrock consists mainly of crystalline rocks of Precambrian age and is mostly dominated by granites and gneisses. In more detail, it is composed of granites, quartzmonzodiorites and according to Čečys and Benn (2007) the plutonic rocks form meter sized dykes and pockets. The area to the north is dominated by granitoids, which are gneissic to various degrees but in the western part doleritic and diabasic dykes are also present. Tectonism is indicated by N-S faults lines and although Blekinge is a low land area open to shallow sea water, the relief remains peculiar due to the N-S oriented bedrock ridges. The bedrock in the study area of Hässeldala (Fig. 3, a/b) mostly consists of isotropic and partly gneissic, acidic intrusive rocks, whereas the surrounding area is characterized by porphyritic or augen-bearing acidic intrusive rocks with some appearances of ultrabasic up to intermediate intrusive rocks.

In particular, according to the SGU's bedrock description of Blekinge (Af series, No 179)(Fig. 3a), the northern part of the region consists of fine-grained, grey gneiss with hornblende, which is of limited extent. This gneiss is a metamorphosed volcanic rock with dacitic composition. The bedrock in the S-SE parts, which is in proximity with and includes our study site (Fig. 3a/b.) is a fine-grained up to finely medium grained, red grey- to grey coloured gneiss, which is dated to 1690±39 m yr. (Johansson and Larsen, 1989).

This rock type was formed from the transformation of initially volcanic rocks into gneisses, which is also called the coastal gneiss of Blekinge. The main characteristic of this rock type that it has neither better preserved volcanic or sedimentary rocks fragment residues, nor clear gneissic granites. The coastal gneiss is locally migmatized, which could be related to the intrusion of the Karlshamn granite. In the northern and south eastern part of the area are present foliated granites, granodiorites and tonalites. Furthermore in the northern part there is a strongly foliated, finely medium-grained, greyish red to reddish grey granite. While the gneissic granite in the eastern part is a dark grey medium grained granodiorite to tonalite, with

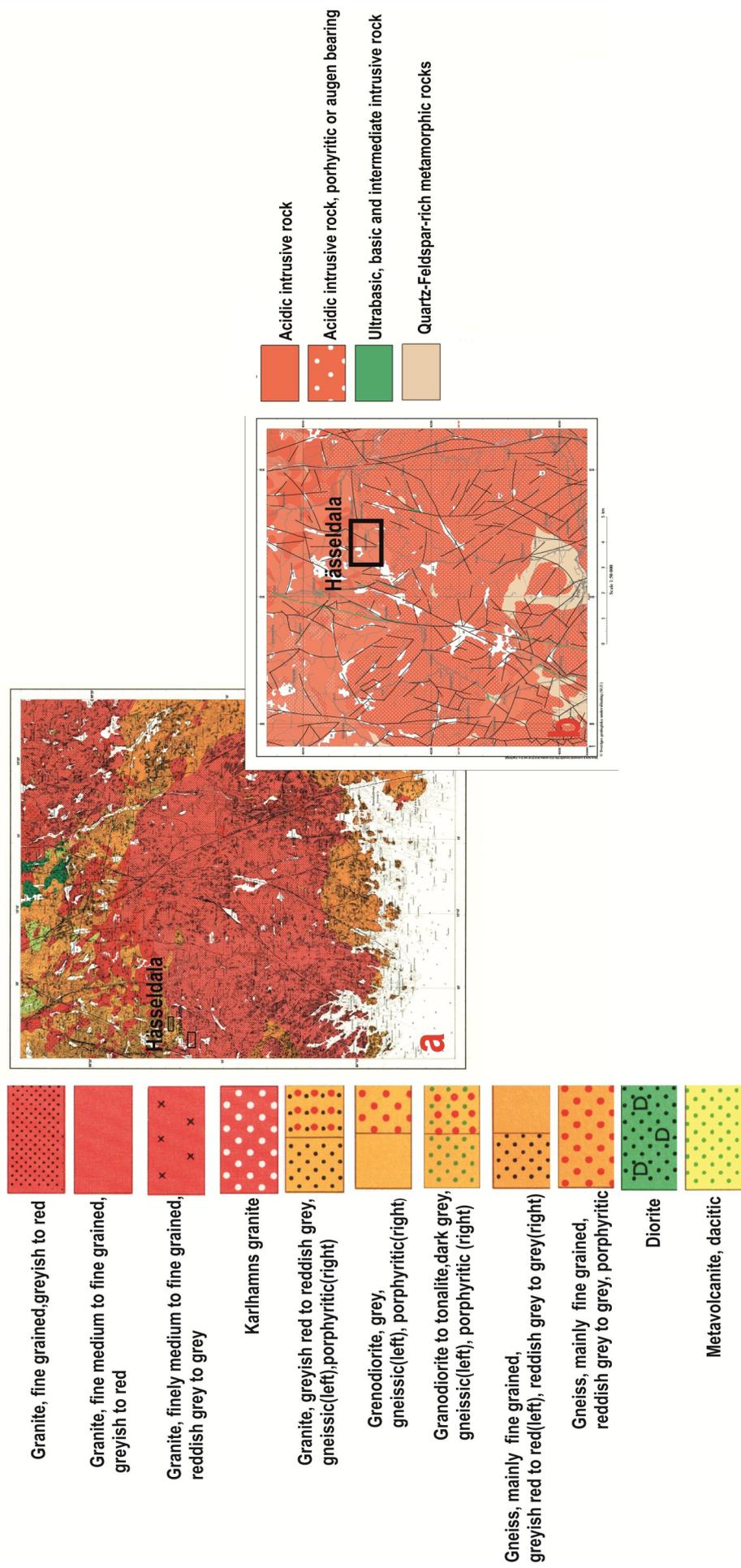


Figure 3 (a and b), Bedrock map of the study area and its surroundings. The site of Hässeldala Port is indicated by a square (green and black). The map was constructed online using SGU's map generator (http://apps.sgu.se/kartgenerator/maporder_sv.html) and Geolagret application (<http://www.sgu.geolagret.se/GeoLagret/>)

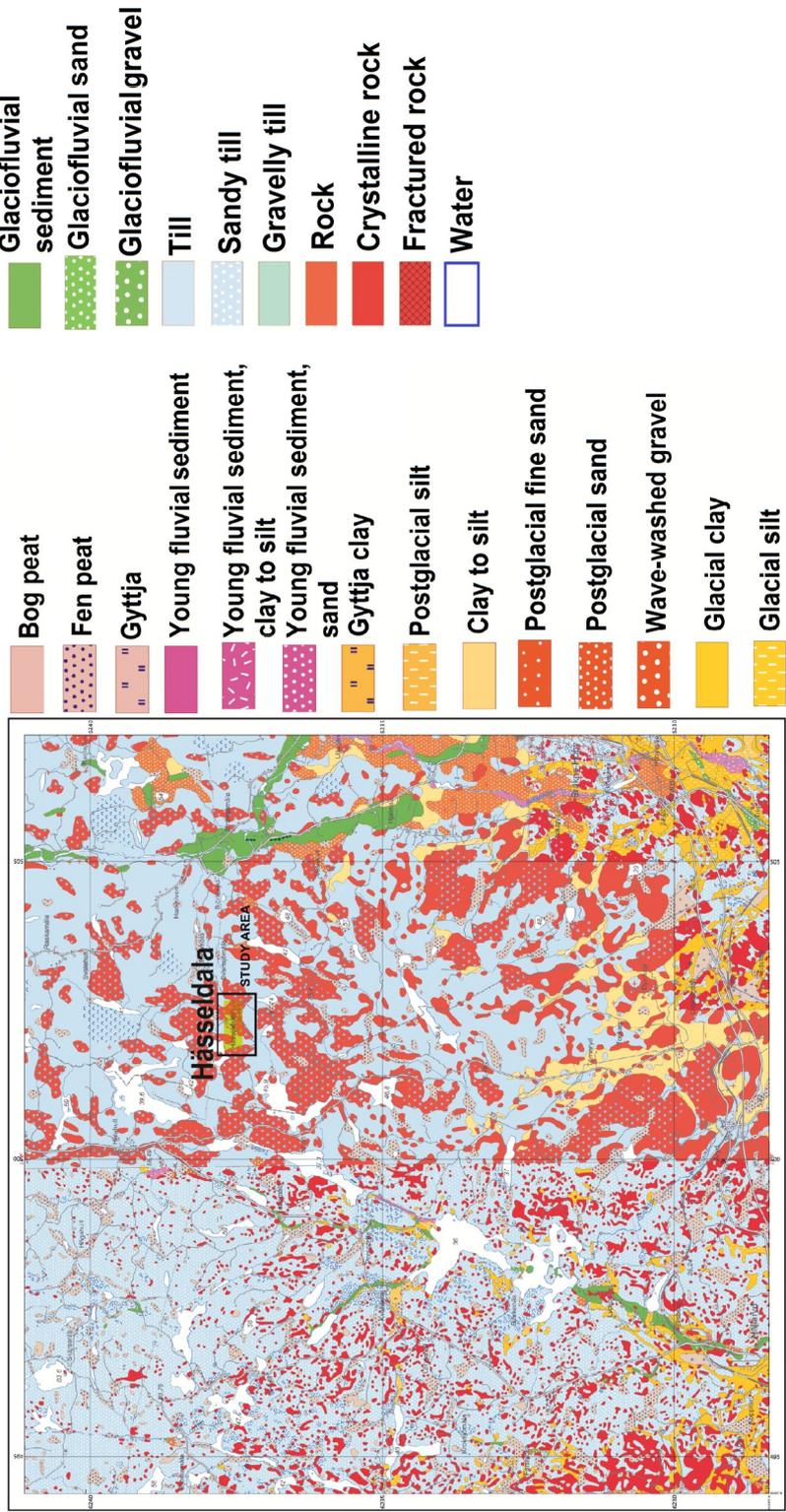


Figure 4, Map of the Quaternary deposits in the study area. The site of Håsseldala Port is indicated by a square. The map was generated using SGU's map generator (http://apps.sgu.se/kartgenerator/maporder_sv.html).

occasionally microcline megacrysts (Tving granite). The Karlshamn granite is mostly met in the youngest granites of the site and is a reddish, medium to coarse grained porphyritic granite. North of the Karlshamn granite are found finely medium to fine grained granites, both porphyritic and non porphyritic. Narrow dykes and limited massifs of pegmatite run through the overall area. Dolerite dikes cut through the area and occur from Bornholm in the south up to Dalarna in the north and are the youngest rocks in the area, called Blekinge-Dalarna dolerite.

4.4 Quaternary deposits

For Sweden and Blekinge the Quaternary period is marked by repeated glaciations and ice free stages. The last ice age has left the most visible marks in the area and most of the Quaternary deposits were formed during the last glaciation and deglaciation. The area is thus dominated by Late Weichselian glaciofluvial and till deposits of varying thickness that overly the granite bedrock. Because granites are dominant in the region the glaciofluvial deposits and the moraine are mainly composed of Archaean bedrock, gneiss and granites (SGU, Ae series). In most cases the till follow the underlying bedrock, which affects their shape.

Any exposed rocks were smoothed by the ice sheet. Some rock fields without soil cover are present in the area (Berglund et al., 2005). Exposed rock surfaces have been weathered, so that striations are barely visible anymore. Existing glacial striations on bedrock suggest different glacial movements from Northwest to Southeast and from East to West. The unique formations of trenching valleys of Blekinge's coast are attributed to the S-N deglaciation and the W-E oriented ice front (Björck and Möller, 1987; Lagerlund & Björck, 1979).

The highest shoreline of the Baltic Ice Lake in Blekinge, 65-67 m a.s.l., was formed when the ice retreated about 14,400 years ago (Berglund et al., 2005). The underlying landscape forced the melting ice to create deeper and narrow river valleys and glaciofluvial material was deposited along the coast of the Baltic Ice Lake. The grain size decreased as the (glaciofluvial) rivers' discharge decreased, leading to grain size sorting and rounding of particles. The boulder frequency increases northwards. In most of the valleys eskers are present and follow the N-S morphology of the landscape (Berglund, 1966).

By the time the coast had become ice free, the bedrock remained depressed. Silt and clay sediments were deposited in the Baltic Ice Lake that existed in the southern Baltic. Characteristic sediments for this time are varved clays with their distinct clay/silt layers. During the winter months, when the suspended load was reduced, fine clay sediments formed darker laminations, while during summer when energy conditions were higher due to increased ice melt and higher sedimentation, coarser laminae of silt and fine sand were deposited (Zolitschka, 2007). In-between the bedrock ridges fine grained sediments can be found. These were deposited below the highest shoreline Ringberg (1976), which here is at approximately 65 m above sea level.

5. Methods

5.1 Field methods

The field work was performed by colleagues from Stockholm University. From this site three cores were retrieved (Core 1, 2, 3) in 2003 (Fig. 2). Coring was performed in autumn 2003 by using a strengthened Russian peat sampler (10 cm Ø and 1 m length). Until 2011 another two cores (4 and 5) were collected from the site. The goal was to obtain long and undisturbed sediment sequences from the site. The core of the present study (now named #6) was one of the first cores retrieved from this site. Core depth for core#6, was 4.14-3.14 m below ground (peat) surface.

5.2 Laboratory methods

5.2.1 Core preparation, lithostratigraphic description and subsampling

The 1 m long core #6 was accessed in the Department of Geological Sciences at Stockholm University in April 2014, where it had been kept intact in a cold storage since retrieval at Hässeldala Port in the autumn of 2003. Subsampling was done at once, to avoid any contamination, without leaving the core exposed to pollen from the air in the lab longer than necessary.

The sediment core was cleaned with a knife parallel to its strata and described in detail. Pins were placed to mark each lithostratigraphic boundary. The lithostratigraphic description was based on the physical appear-

ance of the sediment (colour, lithology, water content, types of contact). Subsamples were taken contiguously at every 1 cm, and at critical levels, every 0.5 cm. The sediments were placed in plastic boxes with lids and marked. After transportation to Lund University, the samples were placed in a cold storage until further subsampling was made for pollen and LOI (Loss on Ignition) analysis. Small plastic syringes were used to take 56 subsamples of 1 cm³ for LOI analysis and 45 subsamples for pollen analysis. At every step, the syringes were carefully cleaned with deionized water, and wiped to avoid any contamination between the samples. The pollen samples were placed in plastic tubes with lids and marked.

5.2.2 Analysis of loss on ignition (LOI)

The LOI analysis was performed in order to estimate the lake productivity that could be an indication of climatic conditions (temperature) and complement interpretations based on pollen data and further more to enable correlation of the sequence to the previously dated sequence from the same site to get a chronology for the sequence of the present study. For LOI analysis, 56 cleaned, marked and empty crucibles were first weighed. Then subsamples of 1 cm³ were added to each crucible and the crucibles with wet sediments were weighed once again to calculate the wet weight. Subsequently the samples were dried in their crucibles for 12 hours at 105°C to enable calculation of the dry weight. Before weighing, the samples were allowed to cool in a desiccator. The water content was calculated as percentage of the wet weight. As a third step the samples were burned in a muffle furnace for 3 hours at 550°C. Again, the crucibles were allowed to cool first in desiccators and then the loss of organic matter was calculated as percentage of the dry weight (Heiri et al., 2001; Dean, 1974). One sample (from 389-388 cm depth) was analysed twice, as the first initial LOI value for that sample was suspicious.

The percentage of the dry weight was calculated using the following equations:

Step 1, LOI1 = [(Wet Weight – Dry Weight, 105 ° C)/ Wet Weight ° C]*100]

The first formula represents the weight % water. The sediment water content is calculated as the difference in weight between the wet and dry values.

Step 2, LOI2 = [(Dry Weight, 105 °C – Dry Weight, 550 °C)/ Dry Weight 105 °C]*100]

The second formula represents the loss of organic matter in the sediment, which is calculated as the difference in weight between the sediment dried in 105 °C and the sediment heated at 550° C (Heiri et al., 2001).

5.2.3 Pollen sample preparation

Pollen sample preparation followed standard procedures (Faegri, 1989). The plastic tubes with sediment were placed in a hot water bath, and two Lycopodium spore tablets were added, which were dissolved with 10% HCL. Each tablet contained 9666 Lycopodium spores ($s = \pm 2123$ $V = \pm 2.2$ %, where s = STD deviation and V = STD deviation %) and the purpose of adding a known number of Lycopodium spores to a known sediment volume is to estimate absolute concentration and pollen influx values (Stockmarr, 1971 1973). Ideally, the amount of Lycopodium spores should equal the amount of pollen in a sample, or not less than 20% of the total of fossil pollen (Faegri, 1989).

In a next step, humus particles were dissolved by adding 10% NaOH, followed by treatment with hot 40% HF in order to dissolve fine mineral material. Any formed salts and liberated carbonate were removed by adding 10% HCl. Organic material was removed during the acetolysis process, by adding 9 parts of anhydride acetic acid and 1 part of concentrated sulphuric acid. The samples were heated gently and then centrifuged. Later on, the samples were washed with glacial acetic acid, then washed with water until neutral and filled with glycerine water and finally let stand and dry overnight. Between each of these steps, the samples were repeatedly rinsed with deionised water, centrifuged, and decanted. Finally, the tubes were filled with deionised water, centrifuged and refilled with glycerine water (50/50). As a final step, they were left upside down overnight to dry. The following day, the content was mixed with 4-5 drops of glycerine to attain a consistency suitable for microscope slide preparation.

A drop of the prepared sample was placed on a glass slide and spread gently, and then a cover glass was placed on top. The slides were left to dry for one day and then sealed along the edges with Permout™ Mounting Medium and labelled. In total 90 slides (two from each level) were made.

5.2.4 Microscopy and pollen data handling

A light microscope was used for the pollen counting, which was usually made at x400 (x10 in oculars and x40 in objective) magnification. In some cases, higher magnification was used to verify the identity of the pollen grains. The reference pollen collection at the Department of Geology, Lund University was studied in advance of counting the samples to get accustomed to the pollen taxa that were expected to be encountered. During the pollen counting, reference literature (Erdman et al., 1961; Moore et al., 1994 and Faegri et al., 1989, Shivanna & Rangaswamy, 1992, Hesse, 2009) and the PalDat website database (www.paldat.org) was used to aid identification. Because the pollen material used for the slides was abundant and dense and in some slides aggregated in many places of the slide, the whole slide was counted. Statistical errors were reduced, by counting more grains than the typical 500 in order to avoid having a non-representative pollen sample, which would be having many similar pollen grains gathered at one place and omitting others that could affect the results. *Betula* pollen grains were separated into *Betula pubescens* and *Betula nana* mainly based on their size. As the mean pollen grain diameter for *B. pubescens* should be

approximately 24 µm and for *B. nana* approximately 20 µm, uncertainties in the identification of *Betula* pollen grains might occur (Karlsdóttir, 2008.). This means that the current differentiation between the two *Betula* species may suffer from uncertainties, and this is one of the reasons that in the pollen diagrams (Fig. 8, 9) *Betula* pollen have been put as undifferentiated, to avoid losing resolution because of uncertainties among species, and the other reason is that in many other studies, the same pattern had been kept (undifferentiated: refer all as *Betula* pollen grains), so it was easier to do comparisons.

The pollen counts were transferred to Microsoft Excel to calculate pollen percentages, concentrations and the total pollen sum.

To calculate the pollen sum, trees, shrubs, dwarf shrubs and herbs were included. The percentages for the pollen taxa were calculated using the equation:

$$(\text{Pollen taxa counted}/\text{Total Sum}) * 100\% = \text{Pollen \%}$$

The percentages for the other taxa (Pteridophyta, *Sphagnum*, Algae, Unidentified and Coal) were calculated using the equation:

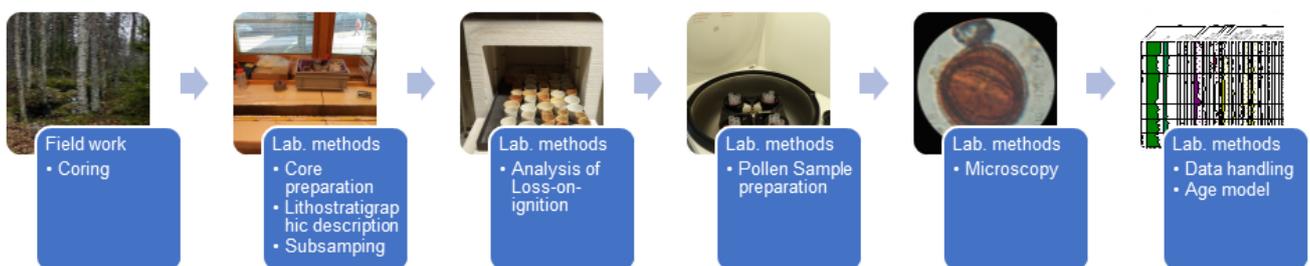


Figure 5, Schematic illustration of the methods used in this project. (From Left): Field; coring,, Lab; core subsampling, LOI, pollen preparation stage (centrifuge), microscope analysis, plotting of data.

Other taxa counted/ (Other taxa counted+Total Sum)
*100% = Other taxa % percentages

The concentrations for the pollen taxa were calculated using the equation:

$(\text{Lycopodium added} / \text{Lycopodium counted}) * (\text{Pollen grains counted} / \text{Volume cm}^3) = \text{Pollen Concentration (grains/cm}^3)$

The data were then imported into the Tilia program v.1.5.12 (Grimm, 2007) to construct the pollen diagrams. The local pollen assemblage zones (LPAZs), were named after the most abundant pollen taxa, the criteria for the selected pollen taxa were the calculated mean percentages above 5% in each taxon. The LPAZs were defined based on results from a stratigraphically constrained cluster analysis performed with the CONISS program implemented in Tilia. The local pollen assemblage zones were then compared to the regional pollen stratigraphy of Björck and Möller (1987).

5.2.5 Age model

The chronology of Core#6 was obtained by aligning the LOI record to the Total Organic Carbon (TOC) record from Core#5 (Steinthorsdottir et al., 2013), for which a chronological framework had been previously established (Muschitiello et al., 2015), as the data are likely comparable, because of the lack in carbonates in this site. The correlation was achieved using a Monte Carlo alignment method (Muschitiello et al., 2015a,b). At Hässeldala Port, the correlation of the cores was facilitated by the small size of the basin, which covers an area of approximately 20 m², resulting in TOC records from adjacent cores to reveal the same high-resolution and identifiable lithostratigraphic patterns (e.g. Muschitiello et al., 2015).

The chronology of Core#5 is based on a Bayesian age model based on 49 AMS ¹⁴C measurements based exclusively on terrestrial plant macro remains (Muschitiello et al., 2015b) (Fig. 6a). The model was produced using Bacon2.2 (Blaauw et al., 2011) after calibration with the IntCal13 calibration curve (Reimer et al., 2013). The parameters selected for the model are the following: thickness thick=0.5; accumulation rates acc.mean=50 years; gamma distribution of the accumulation rate acc.shape=2.5; sample size of the MCMC iterations size=10,000; related age error t-distribution t.a=33, t.b=34.

It has been demonstrated that the age-depth model (Fig. 6b) is robust and reliable throughout the regional Late Allerød, Younger Dryas and Early Holocene pollen zones, i.e. the study period discussed in this thesis. For further details see Muschitiello et al. (2015b).

6. Results

6.1 Lithostratigraphy, loss-on-ignition (LOI) and chronology

The sediment sequence of the 1 m long core of Hässeldala is described in Table 3. It was divided into 16 lithological units, which were differentiated from each other based on changes in lithology and colour (Fig. 6b and 7). This study is focused mostly on the section between 380-330 cm depth. As seen in Table 3 the sediments mostly consist of clayey gyttja, which contains silty clay layers. The transition from one unit to the other (Fig. 7) (Table 3) is gradual in most of the cases. A bioturbated zone was observed at 371.5-371.0 cm depth. LOI values of the whole sequence are 18-31% with some deviations in the upper- and lowermost parts, where LOI reaches 75% and 8% respectively. More specifically the first LOI peak was noticed at 386 cm. The next peak occurs at 372 cm (23%), where the sediment is a brown algal gyttja, followed by a LOI decrease at 368 cm (16%), where the sediment is described as brown silty clay with organics and reaching its lowest levels at 345 cm, in Unit XII, the dark brown clayey gyttja. This minimum in LOI is followed by a constant increase in LOI, with a peak over 64% in the last/upper Unit XV, consisting of dark brown gyttja. Below Unit IV there are no ages available, but an estimated age, based on the sedimentation rate is > 13,004 yr BP. A simple plot of the age-depth model used is shown in Fig. 6, together with the lithostratigraphy.

- Unit XVI (319.0-314.0) is a very dark to black gyttja with gradual lower boundary. This part was not used in the analysis, so there are not any ages and %Org. Matter available data, solely the sediment description.
- Unit XV (325-319 cm depth) is a dark brown gyttja with the highest % of organic matter reaching 64-75% and an age of 11,930-11,660 cal yr BP. The uppermost part of the core was not used for LOI, as it was considered unnecessary. These sediments consist of a very dark brown to black gyttja that corresponds to an age <11322 yr BP.
- Unit XIV (341-325 cm depth) is a very dark brown, almost black gyttja, which shows a rapid increase in organic matter content (from 27% to 75%) and corresponds to an age of ap-

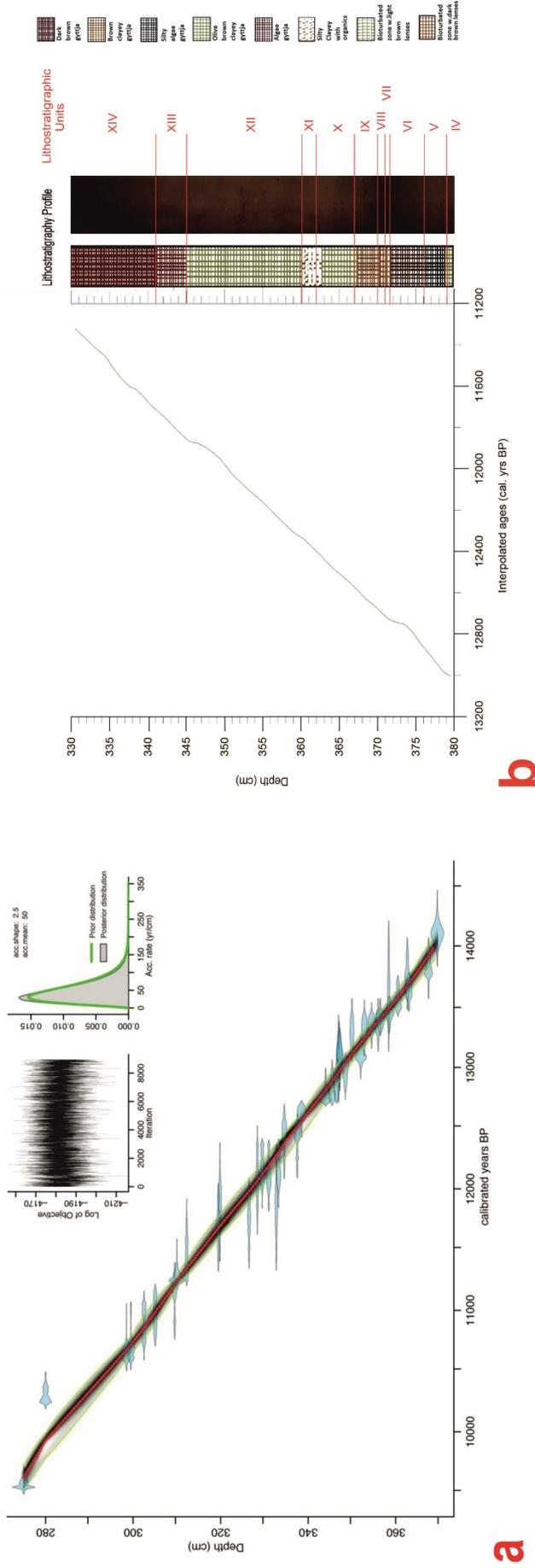


Figure 6, a) Bayesian age-depth model. Age model of Håsselådal's composite radiocarbon-dated sequence based on the Bayesian analysis procedure of Bacon2.2 with the use of IntCal13 calibration curve. In blue colour, it is shown the ^{14}C calibrated dates, as well as the modelled age-depth relationship. The darker shades depict more likely calendar years. In green colour, it is indicated the 95% confidence envelopes, and in the red colour it is shown the weighted mean age for each depth. The panels on the right of figure (a) depict the MCMC iterations and prior-posterior distribution for the accumulation rate (modified by Muschitello et al. 2015b (Fi.7), complementary data).

b) A simple plot of age model (age-depth) used is shown in together with the lithostratigraphic units of Core #6. The age-depth model, along with the lithostratigraphic units, are for the depth that pollen analyses was performed (330-380 cm)

- proximately 11320-11710 yr BP.
- Unit XIII (345-341 cm depth) is a dark brown gyttja with higher organic matter values (19-27%) and an age of 11710 - 11850 cal yr BP.
 - Unit XII (360-345 cm depth) is the longest unit of the sequence and consists of a dark brown clayey gyttja, with a gradual lower boundary; it has LOI values of 15-19% and an age of 11850-12360 yr BP.
 - Unit XI (362-360 cm depth) is a dark olive brown clayey gyttja with higher water content, LOI values of 17-18% and an age of 12360 - 12400 yr BP.
 - Unit X (367-362 cm depth) is a brown silty clayey gyttja with organics, LOI values of 16-19% and has an age of 12400 -12570 yr BP.
 - Unit IX (370-367 cm depth) is an olive brown clayey gyttja, with LOI values of 19-24% and corresponds to an age of 12570-12680 yr BP.
 - Unit VIII (371-370 cm depth) is a brown clayey gyttja with some algae and has similar LOI values as Unit VII. This Unit corresponds to an age of approximately 12680 -12700 yr B.P.
 - Unit VII (371.5-371 cm depth) comprises a bioturbated zone with light and dark brown lenses and minor variations in the organic matter content (31-34%). This Unit corresponds to an age of approximately 12700-12730 yr B.P.
 - Unit VI (376-371.5 cm depth) is a dark brown algal gyttja, with a gradual lower boundary and an organic matter content of 31-41%. This Unit corresponds to an age of 12730 -12880 yr B.P.
 - Unit V (379-376 cm depth) is a silty algal gyttja, slightly lighter brown than Unit IV and an organic matter content of 31%. This Unit corresponds to an age of 12880 -13000 yr B.P.
 - Unit IV (390-379 cm depth) is a brown algal gyttja with LOI of 18-23%. This Unit corresponds to an age of >13000 yr B.P.
 - Unit III (392-390 cm depth) is a lighter brown-greenish clayey silty gyttja, slightly sandy with LOI values of 14-19%.
 - Unit II (398-392 cm depth) is a brown clayey algal gyttja, with a gradual lower boundary and LOI values of 7-19%.
 - Unit I (413-398 cm depth) consists of a greenish brown clayey silt or gyttja silt, with visible organics; LOI is low at 5-8%.

6.2 Pollen stratigraphy

This study focuses on the section between 380-330 cm depth, from where pollen samples had been extracted. The pollen diagram shows the different calculated pollen percentages, as well as the pollen sum of each analysed level in reference to depth and age (Fig. 8). An additional figure shows the concentration (grains/cm³) along with the % values for the major

pollen types (Fig. 9). The pollen percentage diagram was subdivided into the following six local pollen assemblage zones (LPAZs) (Fig. 8). They are named based on the percentages of the major taxa, with taxon names given in the order of descending percentages.

Zone Hä1 (379-373 cm depth) - *Betula-Pinus-Empetrum* LPAZ. This zone is the lowermost zone and is characterised by high values for *Betula* (50%). *Pinus* pollen attain values of 30 % with an abrupt increase to 42% at 375 cm. *Empetrum* (10%) percentages are increasing. There are some *Poaceae* peaks (8%) and some minor peaks of *Salix* (2%) and *Cyperaceae* (2%). The zone corresponds to lithostratigraphic unit V and the lower part of unit VI and has an age of 12770-13000 cal yr BP.

Zone Hä2 (373-366cm depth) - *Betula-Pinus-Empetrum-Poaceae-Artemisia* LPAZ. This zone is characterised by high *Betula* values (≈50%), *Pinus* (15%) and a decrease of *Empetrum* values to ≈10%. Present are also *Poaceae* (6%), *Artemisia* (5%) and *Juniperus* (4%). The zone corresponds to the upper half of lithostratigraphic unit VI, lithostratigraphic units IX-VII as well as to a minor part of lithostratigraphic unit X and has an age of 12540- 12770 cal yr BP.

Zone Hä3 (366-359 depth) - *Betula-Juniperus-Pinus-Ericaceae-Cyperaceae-Poaceae* LPAZ. This zone is characterised by *Betula* (48%) and *Juniperus* (13%), *Pinus* (9%) is present, but its values have decreased compared to zone Hä2. *Ericaceae* (7%), *Poaceae* (6%) and *Cyperaceae* (6%) are present with a small deviation of values. The zone corresponds to lithostratigraphic unit X, XI and lower part of XII and has an age of 12340-12540 cal yr BP.

Zone Hä4 (359-345 cm depth) - *Betula-Juniperus-Pinus-Artemisia-Poaceae-Cyperaceae* LPAZ. This zone is the widest pollen zone. *Betula* starts to decrease, but is still present up to 50%. This zone is characterised by high values of *Juniperus* (≈13%) and *Artemisia* (8%) pollen. The first starts to increase gradually. *Pediastrum* and algae are rather high (1-2%). The presence of *Dryas octopetala* pollen is at 6%. The zone corresponds to the larger part of lithostratigraphic unit XII and has an age of 11850-12340 cal yr BP.

Zone Hä5 (345-337 cm depth) - *Betula-Pinus-Empetrum-Cyperaceae-Poaceae-Juniperus* LPAZ. This zone is characterised by *Betula* (48%) and *Pinus* (16 %), *Empetrum* (16%) and lower values of *Cyperaceae* (7%). *Poaceae* pollen are present (6%) and *Juniperus* at 6%. *Artemisia* pollen values have decreased (4%). This zone corresponds to lithostratigraphic unit XIII and part of lithostratigraphic unit XIV and has an age of 11580-11850 cal yr BP.

Zone Hä6 (337-330 cm depth) - *Betula-Pinus-*

Table 3, Lithostratigraphy, chronology and organic matter content (%) as estimated by LOI of the Hässeldala Port sediment sequence Core #6. The sequence was sub-divided into 16 lithological units. The age of each unit was determined using a Bayesian age model (Muschitiello personal communication). LB = lower boundary; g = gradual.

Hässeldala Core 6, 1m, 4.14-3.14m				
Units	Depth (cm)	Sediment description	Age (cal yr BP)	% Org. matter (LOI)
XVI	319.0-314.0	Very dark brown to black gyttja; gLB	N/A	N/A
XV	325.0-319.0	Dark brown gyttja; gLB	<11320	64-75%
XIV	341.0-325.0	Very dark brown, almost black gyttja; gLB	11320 -11710	27-75%
XIII	345.0-341.0	Dark brown gyttja; gLB	11710 -11850	19-27%
XII	360.0-345.0	Dark brown clayey gyttja; gLB	11850 -12360	15-19%
XI	362.0-360.0	Dark olive brown clayey gyttja, higher water content; gLB	12360 -12400	17-18%
X	367.0-362.0	Brown silty clay with organics; gLB	12400 -12570	16-19%
IX	370.0-367.0	Olive brown clayey gyttja; gLB	12570 -12680	19-24%
VIII	371.0-370.0	Brown clayey gyttja with some algae; gLB	12680 -12700	31-34%
VII	371.5-371.0	Bioturbated zone with lighter and dark brown lenses; gLB	12700 -12730	31-34%
VI	376.0-371.5	Dark brown algal gyttja; gLB	12730 -12880	31-41%
V	379.0-376.0	Lighter brown than below, slightly silty algal gyttja; gLB	12880 -13000	19-31%
IV	390.0-379.0	Brown algae gyttja; gLB	>13000	18-23%
III	392.0-390.0	Lighter brown-greenish clayey silty gyttja, slightly sandy; gLB	For this part of the core (Units IV-I) there are no ages available.	14-19%
II	398.0-392.0	Brown clayey algae gyttja; gLB	Only through extrapolation of the current age model	7-19%
I	413.0-398.0	Greenish brown clayey silt or gyttja silt, with visible organics.	could approximate ages be determined	5-8%

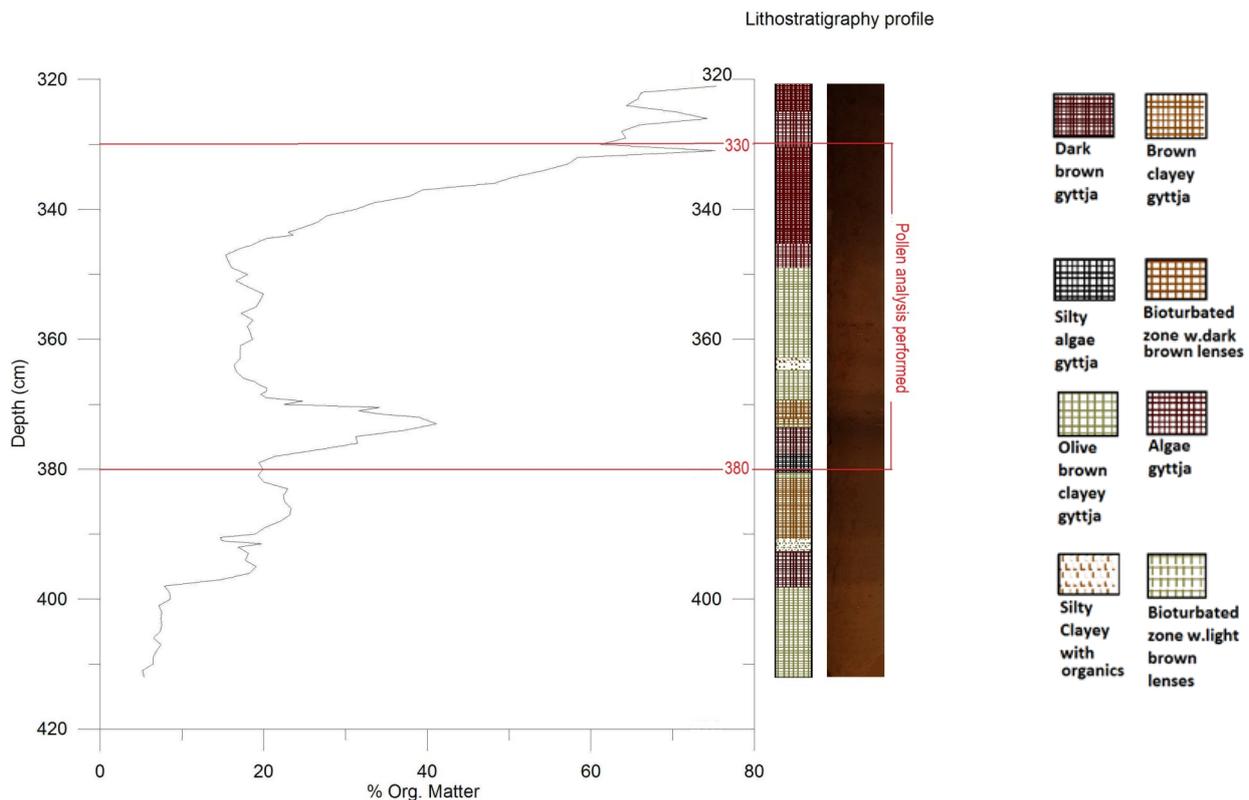


Figure 7, Lithostratigraphy profile (shown also as picture of the core) and organic matter content (%) as estimated by LOI of Core #6 shown against depth (cm) for the whole 1m core.

Cyperaceae LPAZ. This zone is the uppermost pollen zone and is characterised by high values of *Betula* (60%) and *Pinus* (15%), and *Cyperaceae* pollen values have increased (10%). *Poaceae*, *Empetrum* and *Juniperus* pollen values are around 4%. The zone corresponds to a part of lithostratigraphic unit XIV and has an age of approximately 11320-11580 cal yr BP.

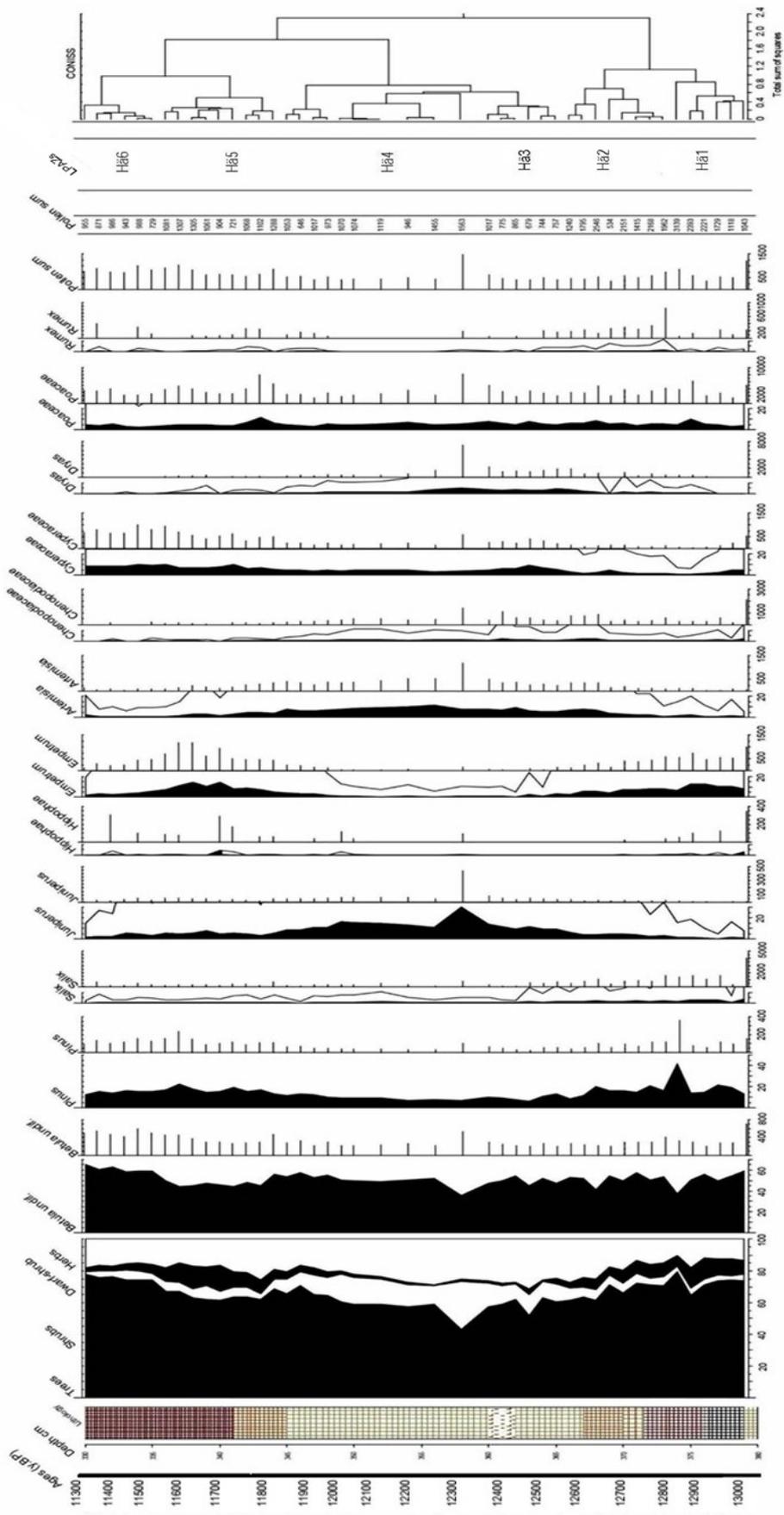
7. Discussion

7.1 Correlation of the local pollen zones to the regional pollen zones for Blekinge.

The local pollen assemblage zones established for Hässeldala can be compared to the regional pollen zones for Blekinge, which were proposed by Björck and Möller (1987) (Table 7). In this scheme, each pollen zone for S. Sweden, proposed by Björck & Möller (1987), can be divided into RPAZs for the Blekinge area. By that, the pollen zone for the Bølling(BÖ) (BL1) is characterised by a *Betula* – *Artemisia* – *Betula nana* – Gramineae assemblage and the pollen zone for the Older Dryas (OD) (BL2) by *Salix* – *Artemisia* – *Rumex* – *Chenopodiaceae* assemblages (Björck and Möller, 1987). The Allerød Chronozone pollen assem-

blages were divided into two regional zones, an older one with a *Pinus* – *Betula* assemblage (AL/BL3) and a younger zone(AL II), characterised by *Pinus* – *Empetrum* pollen (BL4). The Younger Dryas (YD I-III) was subdivided into three regional pollen zones, an older *Artemisia* – *Juniperus* – Gramineae – *Chenopodiaceae* zone (BL5), a middle zone with *Betula nana* – *Cyperaceae* – *Pinus* – *Artemisia* assemblages (BL6) and a younger zone with *Juniperus* - *Empetrum* – *Pinus* – *Betula* assemblages (BL7) (Björck and Möller, 1987). The first Preboreal pollen zone is characterized by *Betula* – *Pinus* (BL8).

The new pollen stratigraphy for Hässeldala covers the late Allerød (AL II), Younger Dryas and early Holocene pollen zones of Björck and Möller (1987) (Table 7, Table 4). Local pollen zone Hä1 correlates with the regional late Allerød pollen zone and Hä2 with the transition between the regional AL and YD pollen zones. Correlated with the Björck and Möller (1987), Hä1 is BL4 pollen zone, while the transition zone Hä2 is characterised by the first increase of *Artemisia* and a decrease in pollen concentrations and is possibly the onset of the BL5 Regional Pollen Assemblage Zone (RPAZ), and accordingly, Hä3 marks the continuation



Hässelblad, Analyst: Artemis Kariabou

Figure 9, Combined diagram of percentages and concentrations of the main pollen types.

of this regional YD pollen zone (BL6). Local pollen zone Hä4, where the highest values of *Artemisia* are noted, corresponds to the major event of YD. Hence, Hä2, Hä3 and Hä4 are correlated to the BL5 and BL6 regional pollen zone complex, but without detailed correlations. Hä5 most likely corresponds to BL7 pollen zone, which is the YD/PB transition (Berglund, 1966), which Björck et al. (1996) showed belongs to the very earliest part of the Holocene Series. This interval is characterised by a decline of *Artemisia*, *Dryas* and *Juniperus* pollen values, and an increase in *Pinus*, *Betula* and *Empetrum* pollen values, as well as other plants that mark the transition into the Holocene. Hä6 correlates with the early Holocene and BL8, where the presence of *Pinus* and *Betula* increases markedly.

The above correlation enables to assign ages to the regional pollen zones as seen in Table 4. The Late Allerød (Hä2) has an assigned age of older than 12770 cal yr BP, which is the lower boundary of the YD. The Younger Dryas cold event covers the time interval of Hä3 and Hä4, between 12540 and 11850 cal yr BP. The transition from YD into the earliest Holocene, that comprises Hä5 LPAZ, lasts less than 300 yr and its upper boundary is at 11580 cal yr BP. If the transitions at the beginning (AL/YD) and at the end (YD/PB) of Younger Dryas are included, then the overall duration of the cold period would be 920 cal yr (LPAZs Hä2/3/4). The uppermost part of our sequence is the Early Holocene and has an assigned age of 11320 cal yr BP.

7.2 Interpretation of pollen zones in references to the vegetation changes and comparison with other proxies

The late Allerød pollen zone (Hä1) is marked by the presence of arboreal, shrub, and dwarf shrub pollen; higher values of *Betula* pollen have been interpreted as presence of a sparse forest of *Betula* (Berglund, 1966). The peaks in *Pinus* pollen percentages could be due to redeposited pollen grains and/or wind transport, as according to Björse (1996) *Pinus* pollen grains can be transported far, because of their air-sacks. Other taxa that are present are *Sorbus aucuparia* and *Populus*, which belong to the subarctic tree flora; *Juniperus* is present but not yet abundant and *Hippophaë* has only some occasional peaks (Berglund, 1966).

The transition between the AL and YD pollen zones is characterised by a change in the dominance of arboreal pollen (AP), with some non-arboreal taxa (NAP) of herbs becoming present. These indicate some open habitats (Brauer et al. 1999), but still of limited extent. *Empetrum* has started to decrease and becomes less common and Saxifragaceae values have risen up to 2%. Also *Pediastrum* is increasing, which could indicate more eutrophic conditions. Brauer (1999) has interpreted that as “a result of a severe increase in nutrient supply”. The change in the vegetation type implies reduced abundance of trees and is an index that temperatures have decreased. The sedimentological processes also change. The Late Allerød is marked by increased algal content of the sediments, which in turn indicates an increase in the aquatic productivity. This

Table 4, Correlation of Hässeldala local pollen assemblage zones to the regional pollen assemblage zones of Björck & Möller (1987) and assigned ages based on the new chronology for Hässeldala. The ages (cal yr BP) are rounded to integer number .

Age (cal yr B.P)	Local Pollen Assemblage Zones	Regional Pollen Assemblage Zones for S.Sweden	RPAZs (Björck and Möller, 1987) for Blekinge
11580-11320	Hä 6	EH	BL8
11850-11580	Hä 5	YD/EH	BL7
12340-11850	Hä 4	YD	
12540-12340	Hä 3	YD	BL6 & BL5
12770-12540	Hä 2	LA/YD	
13000-12770	Hä 1	LA	BL4

increase could be because of soil erosion that led to a higher nutrient supply. A bioturbated zone at 370–371.5 cm, in the upper part of this transition, implies a change in the oxygen supply, which is visible in the core (Fig. 6, 7, 8). However, the disturbances that are noticed in the upper part of Hä1, are probably not related to large scale disturbances, but are rather of local origin (Wohlfarth et al., 1994). Above this depth the sediment composition alters and the algal gyttja of the lower layers is replaced by a more clayey gyttja. The LOI values are now approximately 20%, suggesting a better preservation of the organic material and/or increased accumulation of organic matter. Berglund (1966) described this increase, as typical for lacustrine sediment sequences in Blekinge. Towards the end of the Allerød pollen zone, an increase in the acidophilus *Empetrum* is noticed, leading to more acidic environmental conditions and light demanding plants become dominant (Berglund, 1966).

Sediment and vegetation changes at the start of the Younger Dryas pollen zone are almost synchronous, and therefore suggest an interaction between the vegetation cover and the sediment supply. The onset of YD is marked by a change in the sediments. The Younger Dryas sediments mainly consist of clayey gyttja, followed by fine detritus gyttja, which is marked in the sediments in the area of Blekinge (Ising, 1998). The cooling in the beginning of this stage is typified by the increase of *Dryas octopetala*, grasses and *Artemisia*, which is the most common pollen grain evidence of this period with >15%. Ericaceae pollen start to decline in the beginning of the stage, *Empetrum* almost disappears and *Pinus* pollen become scarce. The increase of herbs and dwarf shrubs during this period could be a result of less competition with other plants. *Juniperus* was very common during Hä3 with >15%. *Salix* is also present with <5%. The vegetation during this period resembles that of a tundra landscape, but with more arctic – alpine elements, such as *Dryas octopetala* (Berglund, 1966). The general pattern is treeless vegetation, with more dominant NAP of cold temperate herbs and grasses. The climatic changes, causing the vegetation and environmental conditions around Hässeldala Port, can be related to the reduction in the North Atlantic meridional overturning circulation (Broecker, 1998; McManus et al, 2004), which was a result of a meltwater pulse into this region (Duplessy et al., 1992; Bard et al., 2002; Bradley and England, 2008; Muschitiello and Wohlfarth, 2015). The transition from Younger Dryas to the Early Holocene is smoother than the AL/YD transition; this transition is not only depicted in the pollen diagram, where

pollen of tree birch and dwarf shrubs become more dominant, but also in the lithology where organic matter content increases rapidly (Fig. 7) and the sediments change to a much darker colour. This change coincides with the start of Hä5, and with the end of Younger Dryas cold event.

The transition to the early Holocene is shown by the gradual immigration of *Pinus* and tree sized *Betula* forming open mixed forests of *Pinus* and *Betula*. That the landscape remained fairly open is seen by high values of *Hippophaë* and *Empetrum* pollen. As an effect of competition, the richness in grasses and *Artemisia* vegetation start to decline and is replaced by other vegetation types. Saxifragaceae and Cyperaceae also rise again; the latter could be a result of a meadow expansion (Berglund, 1966). The early Holocene, which is the uppermost part of the sequence (Hä5 and above), is characterised by increased forest cover. *Betula*, as pioneer plant, has expanded as well as *Hippophaë*. *Empetrum* and *Artemisia* have both declined and are being replaced by other species of Ericaceae and Asteraceae respectively. Green algae e.g. *Pediastrum* have slightly increased but have not reached the same high values as before. This increase could be either due to changes in the nutrient supply, competition with other species, or due to change in climatic conditions, which were becoming warmer. However, this expansion has also been noticed before in the present study, so we can assume that the response of green algae to climate change has started earlier. There is an abrupt increase in the organic content to >60% and the sediments now consist of a dark brown almost black gyttja, indicating the development of high productivity. All evidence shows that a warming of the climate occurred. However this shift has some smaller fluctuations of smaller scale, as it is shown from the LOI curve (Fig. 7). The transition to the Early Holocene, as depicted from the changes in vegetation, coincides with the climate shift in the North Atlantic region and around Greenland, where at that time a post-glacial atmospheric and oceanic circulation pattern was established (Funder and Hansen, 1996; Björck et al. 1996).

By comparing the vegetation changes with those changes seen in other proxies that have been studied in Hässeldala (diatoms: Ampel, 2015; chironomids: N.J.Whitehouse (unpublished data); leaf stomata: Steinthorsdottir, 2013; 2014, pollen: Andersson, 2004), it is possible to obtain a more complete reconstruction of the different climate responses. Although diatoms (Fig.10) appear to have a consistent pattern

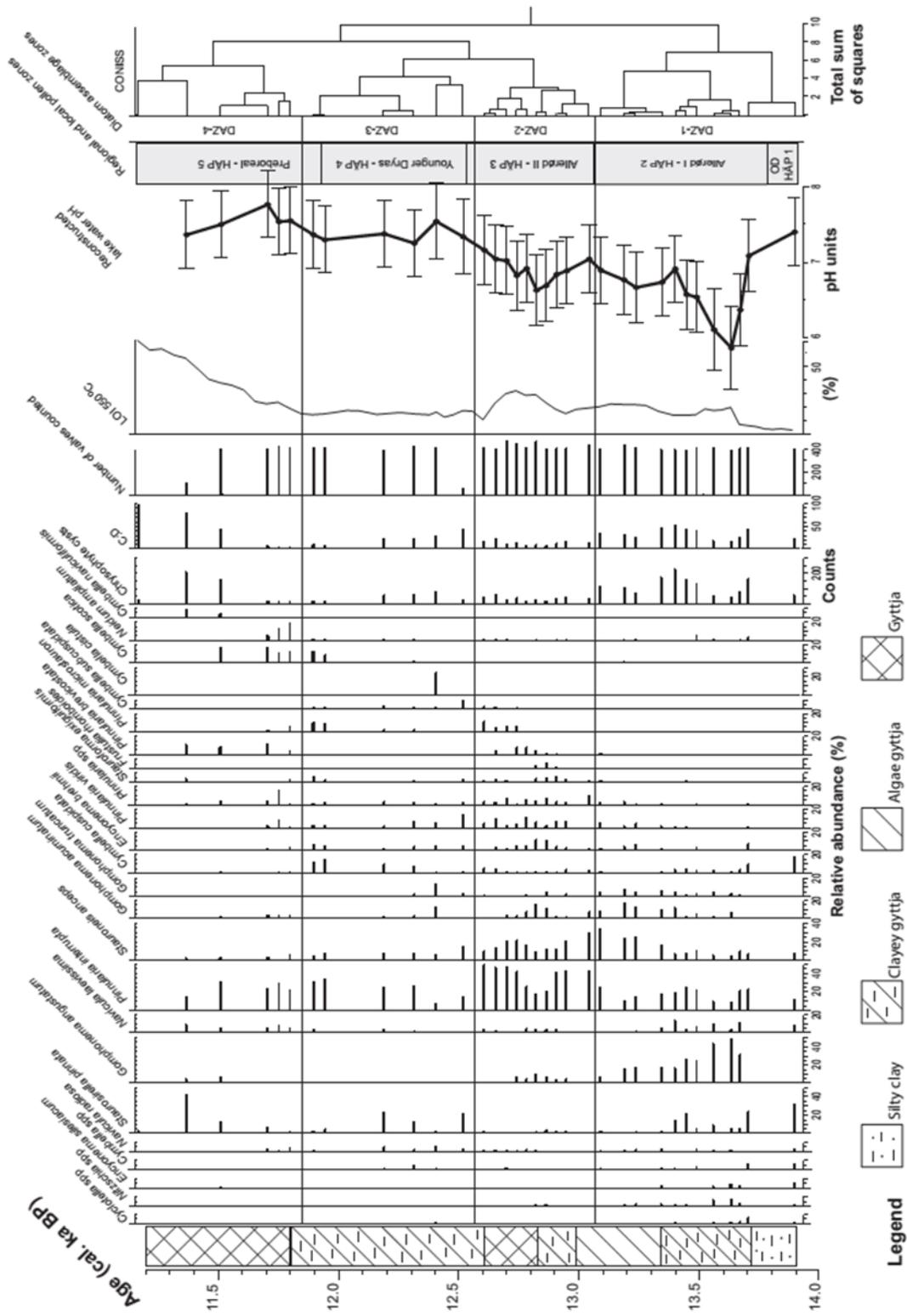


Figure 10, Lithology and stratigraphy of fossil diatoms, with reconstructed pH values by Ampel (2015).

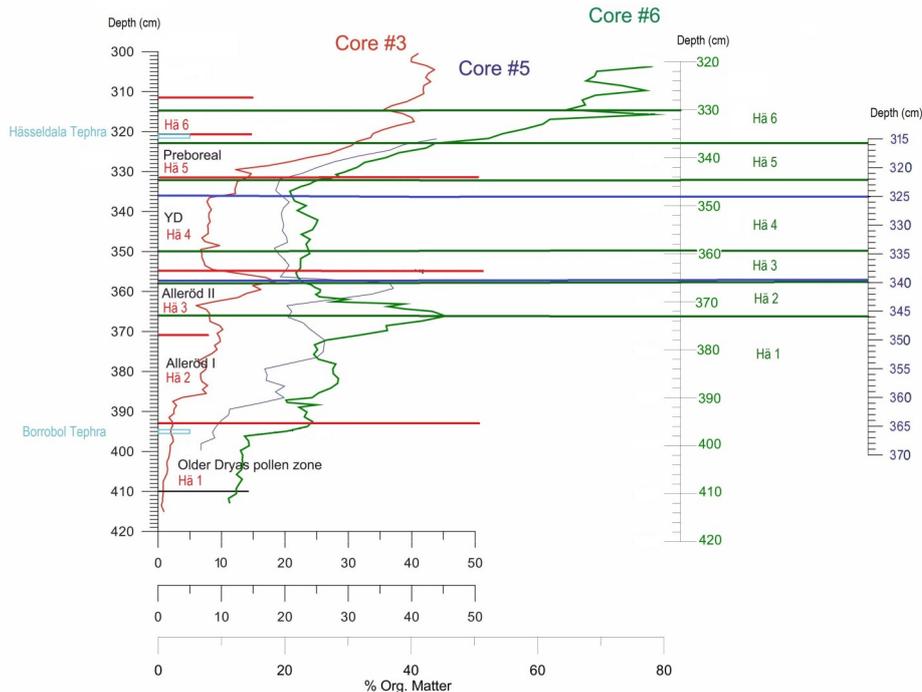


Figure 11, Correlation between core #3, #5, and #6, based on Loss-on-ignition, in relation to the LPAZs (Modified from Steinthorsdottir et al., 2013 (Fig. 2)). Red: Core #3, Blue: Core #5, Green: Core #6.

with the different climate periods, that were previously been established by pollen analysis, it is suggested that there are minor time lags between the different proxies. Ampel (2015) has divided the diatom stratigraphy in four LDAZ covering a time frame of 13900-11200 cal yr BP and the pH reconstruction is based on the LDAZ. Hä1 and Hä2 LPAZ are equivalent with the LDAZ2. There is a 20 yr difference between the two zones, in the upper boundary, with the diatom response being the later one. DAZ3 coincides with Hä3 and Hä4 LPAZs, where both mark the YD cooling event. The upper boundary is 11850 cal yr BP for diatoms and 11853 cal yr BP for pollen, so the climate response is almost synchronous. It is worth noticing that in the present study the YD has been divided into two clear zones (Hä3 and Hä4), however Ampel (2015) suggests a single LDAZ (3), although it is noticed that there is a change in the diatom abundance and species dominance after 12300 cal yr BP. During this period, with approximately 200 cal yr time lag in the two studies (for the present pollen study is after 12570 cal yr BP), is noticed a big difference in the sediment composition. The previous clayey gyttja is followed by silty clayey with organics until 12400 cal yr BP and clayey gyttja with higher water content until 12360 cal yr BP, where the environmental conditions change again and the material is dark brown clayey

gyttja. LDAZ 4 marks the Preboreal and coincides with Hä5 and Hä6. The LOI results (Fig. 10 and Fig. 7) agree in both studies, at the onset of the LDAZ4 and LPAZ 5, the %Org. matter is around 20% and a vast increase is noticed in the uppermost part with LOI values to reach more than 60%.

In reference to the stomata index [CO_2] record, Steinthorsdottir et al. (2013) provide a very robust high resolution record. The dynamic behaviour of CO_2 and its concentration changes, verifies the fluctuations that have been noticed in the LOI curve of core #5 (Fig. 11) (Steinthorsdottir et al., 2013) and these results show significant correspondence with those of the present study, where fluctuations are also depicted in the LOI curve of core #6 (Fig. 7) in the Late Allerød/Younger Dryas Transition. Furthermore the results are in coherence with the fact that there are lower amplitude fluctuations during the YD period in both studies and I would like to point out that the high values of [CO_2] that Steinthorsdottir et al. (2013) have noted during the GS-1(YD) and assumed it might be due to overestimation, and should be really taken into consideration. In both studies, it is clearly shown that the transition from YD to the Preboreal is less severe than the AL/YD.

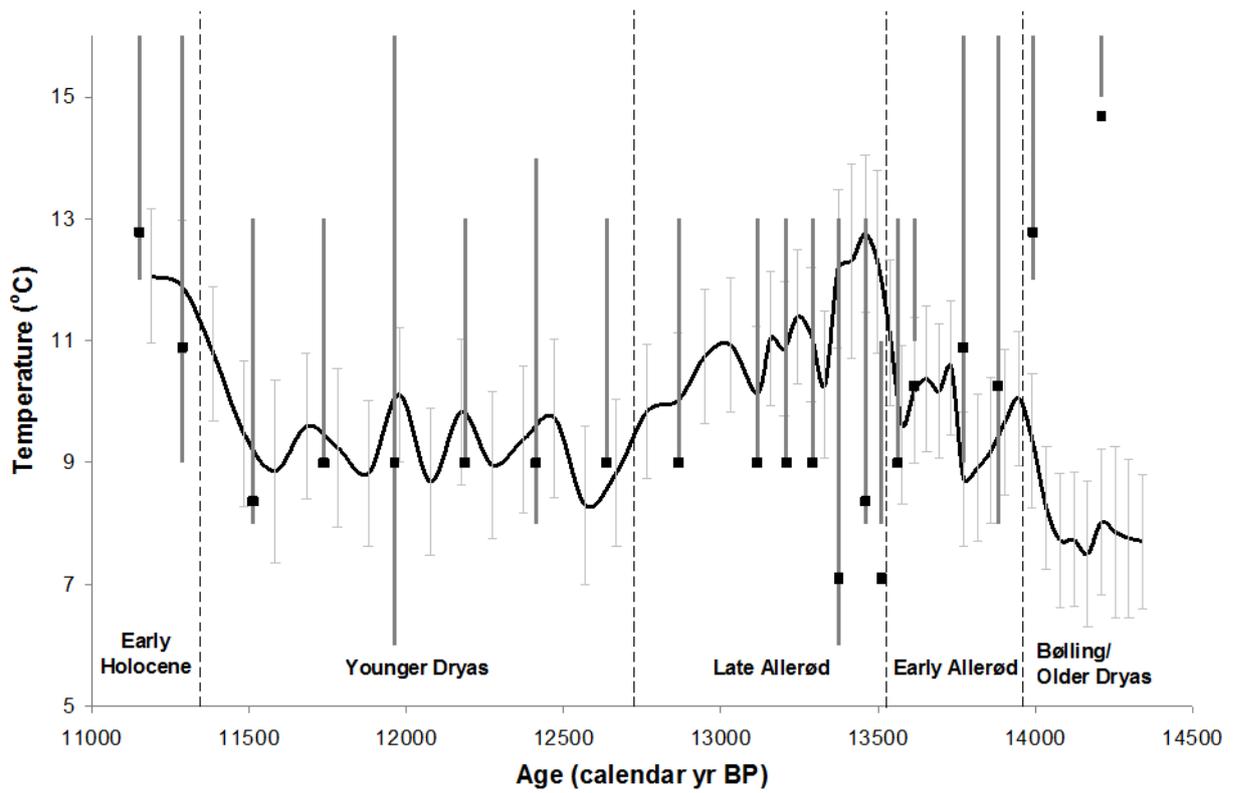


Figure 12, Chironomids(black line)/coleopteran (squares) comparison of the most dominant taxa from Hässeldala Port and assigned ages for each species respectively (in cal. yr BP) (N.J.Whitehouse, unpublished data).

Table 5, Average temperatures estimated for the late glacial period format the Hässeldala Port site. G = Glacial ice was covering the site(s) during these periods (N.J.Whitehouse, unpublished data).

Site	Stratigraphic Subdivisions						
	GS-2	GI-1e	GI-1d	GI-1c	GI-1b &a	GS-1	Holocene
Hässeldala Port Coleoptera	G	14.5	10.5	8.5	9	9	12.5
Hässeldala Port Chironomids	G	8	9	12	10.5	9	12

The chironomids enable quantitative temperature reconstruction of high resolution (Brooks, 2006; Walker and Cwynar, 2006; Watson et al., 2010). The results of N.J.Whitehouse (unpublished data) show that the climatic changes noted in the pollen record are in accordance with those in the chironomids and coleoptera record. Coleoptera temperature distribution show more consistencies with the local pollen zones, than the chironomids. This is when one examines the average temperature reconstructions for both species (Fig. 12, Table 5) for Hässeldala site, the coleoptera record does show an abrupt temperature decline at the AL/YD transition from 14.5 °C to 8.5-9°C, as well as warmer temperatures and climate amelioration at the YD/PB (GS-1/Holocene) boundary, from 9°C to 12 °C. Chironomids do not show that severe temperature fluctuations in all cases, where the range is ± 2 °C. However it should be taken into consideration that perhaps the higher values in Coleoptera inferred temperatures could be because of the difference in ecosystems or methodology. This is evident also from Fig. 13 that shows the Chironomids temperature distribution based on different numbers of species used. It is self-evident that the higher the number of species the more robust the temperature reconstructions and it is more coherent the results with the ones established by pollen analysis (LPAZ). Yet, N.J.Whitehouse's % LOI curve implies the exact same pattern as the one in the present pollen study, i.e. the organic matter content decreases rapidly in both records at the onset of YD; however in my LOI curve this change is not as steep (as the one noted by N.J.Whitehouse) with only some minor oscillations during the YD and an abrupt increase towards its end, while in N.J.Whitehouse's data both boundaries (AL/YD and YD/PB) are sudden. The % Org. matter has lower values during the YD (5-15%) and the total percentage of the Org. Matter is lower in the PB (maximum 57%), while in our study the % Org. matter has values 15-19% during YD and it exceeds 60% in the Early Holocene.

In another comparison of the current data with those from a previous pollen study on the site with lower resolution in core # 3 (Andersson, 2004; Wohlfarth et al., 2006), it is noted that there is much coherence between these two studies, although they do not cover the exact same age interval. Andersson has suggested 7 Local Pollen Assemblage Zones (LPAZ) over a 1m long core. The detailed description of each pollen zone with the equivalent depths is shown in Table 6. As shown in Fig. 14, these LPAZs cover a period from Older Dryas (OD) until Preboreal (PB) regional pollen zones. HÄP1 LPAZ coincides with Older Dryas with

the upper limit at 392 cm depth. The Allerød period consists of HÄP 2 and HÄP 3 LPAZ at [393-371] cm and [371-355] cm depth respectively. HÄP 4 LPAZ at [355-334] cm depth coincides with the Younger Dryas period, whereas LPAZs HÄP5, HÄP6 and HÄP7 from 334 until 300 cm depth indicate the Preboreal. By this, it is evident that both studies have shown similar results, with the present study to set the boundaries of the pollen zones with 1-2 cm deviation, between the two studies. The total organic carbon curve of core #3 verifies the results, and has a similar pattern with the one of the present study (core #6), again with some cm deviation among the zones (Fig.11). However, the most important difference is the duration of Younger Dryas; where here is the AL/YD transition (Hä3/Hä4) has an age of 13020-12840 cal yr BP and the YD/PB transition an age of 11870-11290 cal yr BP, so total 1730 cal yr, while in the present study the overall duration of YD along with the transitions has an age of 12770-11580 cal yr BP, so total 1190 cal yr, which is 540 yr difference.

7.3 Comparison with previous studies from Blekinge

I have correlated my results with previous studies by Björck and Möller (1987) and Berglund (1966) to find similarities and differences and I suggest that the vegetation and climatic pattern are in general similar. In this study however a shorter duration in YD is noticed, in comparison with the Greenland Ice Cores. This was verified both from the pollen diagram and the LOI curve. The major pollen taxa that represent each period are the same; however there are minor changes in the percentages and the presence/absence of some TAXA. Specifically, in Björck and Möller (1987) during the Late Allerød there were mostly *Pinus* and *Empetrum*, while in this study *Betula* is more abundant and Cyperaceae are also present. As proceeding into the YD Cyperaceae are still present, while in Björck and Möller (1987) Chenopodiaceae are found instead and Cyperaceae are first noticed in the YDII zone. In my study Cyperaceae are again abundant towards the YD/PB transition. Perhaps this is because of the differences in the extension of YD in the present study and the other study areas. It is worth noticing that there is some resemblance with the pollen percentages found in the Lake Åsnen region (Björck and Möller, 1987). The percentages of pollen in the upper part of the se-

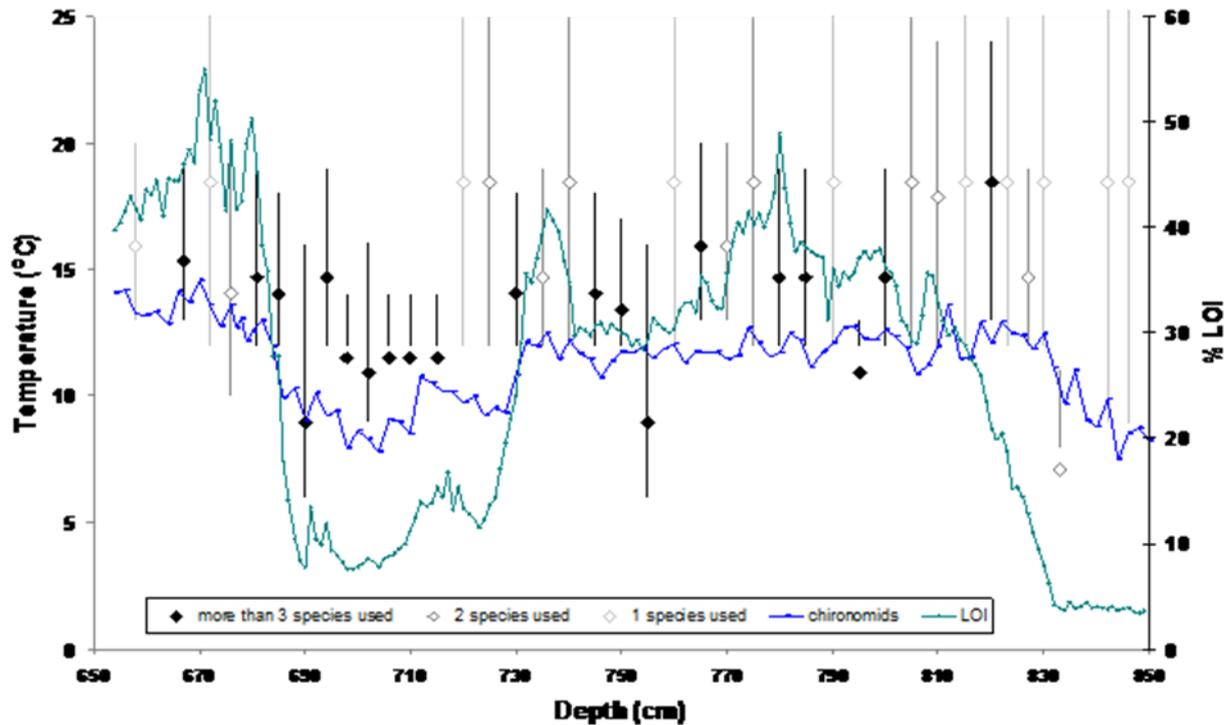


Figure 13, General diagram: Temperature estimates based on chironomids (blue line) and Coleoptera (square/rombus), with % LOI curve and equivalent depths (N.J.Whitehouse, unpublished data).

Table 6, Description of Local Pollen Assemblage Zones, based on Andersson's pollen analysis, and their correlation with the regional pollen stratigraphy for Blekinge, for southernmost Sweden (Björck and Möller, 1984) (table modified from Wohlfarth et al., 2006).

LPAZ	Depth (cm)	Description	Regional Pollen Stratigraphy
HÄP 7	312-300	<i>Pinus-Juniperus</i>	Preboreal(PB)
HÄP 6	322-312	<i>Betula</i>	Preboreal incl Preboreal Oscillation
HÄP 5	334-322	<i>Empetrum-Juniperus - Poaceae</i>	YD/PB
HÄP 4	334-355	<i>Artemisia-Betula - Juniperus</i>	Younger Dryas (YD)
HÄP 3	371-355	<i>Empetrum-Pinus-Betula</i>	Allerød II
HÄP 2	393-371	<i>Betula-Rumex</i>	Allerød I
HÄP 1	400-393	<i>Rumex-Salix-Artemisia - Poaceae</i>	Older Dryas (OD)

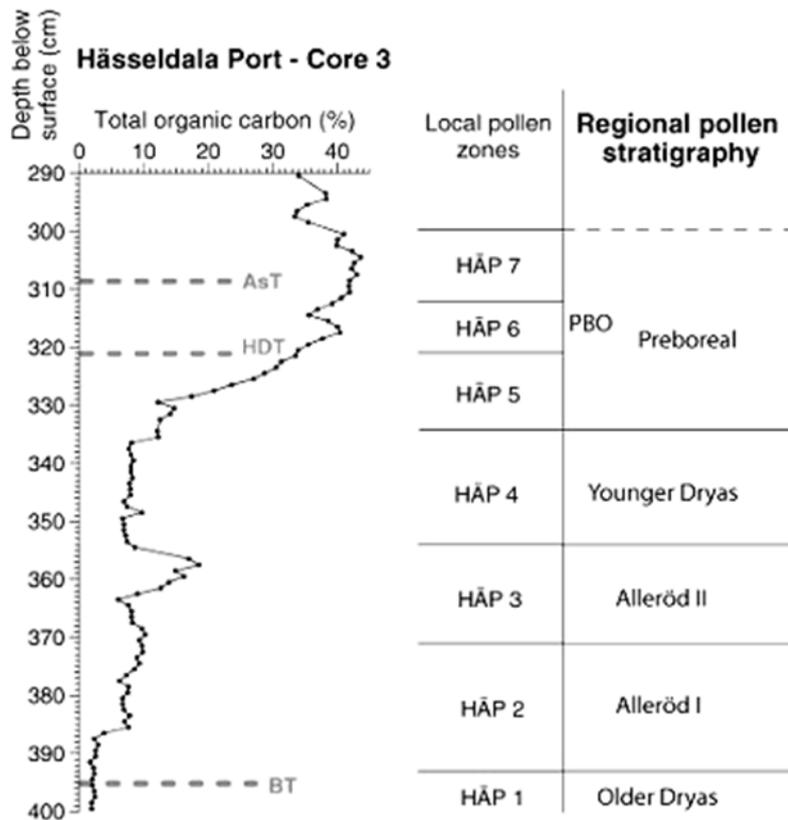


Figure 14, Correlation of the LPAZ with the regional pollen assemblage zones HÄ1-HÄ7, according to Andersson (2004) and the % Total organic carbon curve (Wohlfarth et al., 2006)

quence in this study differ from that of Björck and Möller (1987). *Salix* was more abundant at the YD/PB Holocene transition, while in my study the most abundant pollen were those referred in the HÄ5 and 6 pollen zones. On the other hand, comparing the results with those from Berglund's study (1966), I found the following: the pollen zones as described by Berglund have similarities with the ones described here in reference to the pollen species. Cyperaceae pollen which in Björck and Möller (1987) were not as common in BL5, but were identified in HÄ3 and also present in Berglund (1966) during the Late Alleröd. Furthermore during Younger Dryas, the high values of *Juniperus* are evident in both these studies, while in Björck and Möller (1987) they are not. However, the green algae expansion appears later in Berglund (1966) in the upper part of YD, but in our study they are present also in the lower part of YD/AL. This implies that the temperatures in these intervals are high enough to allow such growth conditions. The similarities continue regarding the pollen species found in the transition AL/PB and beginning of PB (Table 7). Also in both studies a distinct maximum is found in *Pediastrum* at the YD/EH transition with, that recognised by Berglund (1966) showing higher values.

Overall, the current pollen diagram has more similarities with the vegetation patterns found in Berglund (1966), than in Björck and Möller (1987).

8. Conclusions

The pollen record from Hässeldala in Blekinge, S. Sweden was studied to provide a detailed vegetation profile over the Last Deglaciation period and the ecosystem's response to the climate change. The pollen record, which covers a time period of 1680 yr (13000-11320 cal yr BP), ranges from Late Alleröd to Early Holocene. The LPAZs is a clear indicator of the climate changes that took place during this time. We conclude that the vegetation response to these climatic changes can be mapped in time and space over several different records and proxies, which all show the same climatic pattern, however the changes in the vegetation did not co-occur with the changes in some of the other proxies e.g. algae, but there is a notable time lag, of a few decades, between vegetation and climate. Furthermore the duration of these shifts differs depending on the environmental conditions and the proxies examined. The pollen strati-

Ages (cal.yr B.P.)	Local pollen assemblages zones in Hässeldåla	Some vegetation patterns in Hässeldåla	Ages (¹⁴ C.yr B.P.)	Regional pollen assemblage zones in Blekinge	Some major vegetation changes in Blekinge
		This work		According to Björck and Möller (1987)	
11320	H86 <i>Betula-Pinus-Cyperaceae-Poaceae</i>	Sedges, Birch, Pine, Grasses Increase of perennial grasses of different plants and Warm temperate grasslike plants, found in wet conditions or poor soils, Higher values of pioneer plants; Deciduous thinleaved trees of boreal or temperate climate, light demanding, preier acidic soils	10.000	<i>Pinus-Betula</i> BL8	Birch and pine
11580	H85 <i>Betula-Pinus-Empetrum-Cyperaceae-Poaceae-Juniperus</i>	Increase of pioneer plants Coniferous trees: Evergreen trees of fresh dry soil; open landscape. Evergreen dwarf shrubs in recently lean soils or tundra		<i>Juniperus-Empetrum-Pinus-Betula</i> BL7	<i>Juniperus</i> <i>Pinus</i> <i>Empetrum</i>
11850	H84 <i>Juniperus-Artemisia-Dryas</i>	Coniferous trees: Evergreen trees of fresh dry soil; open landscape Herbs of open, Nitrogen rich soils Shrubs of dry, exposed calcareous sand-or shale gravel soil; cold temperate	10.500	<i>B.nana-Cyperaceae-Pinus-Artemisia</i> BL6 and part of BL5	
12540	H83 <i>Artemisia-Cyperaceae-Betula-Juniperus</i>	Increase of Herbs and Sedges (cold temperate plants of open landscape) Decrease of Birch Coniferous trees	11.000	<i>Artemisia-Cyperaceae-Gramineae-Chenopodiaceae</i> BL5	Expansion of cold tolerant herbs Stands of tree birch Empetrum almost disappears Pine disappears
12770	H82 <i>Pinus-Betula-Empetrum-Poaceae-Artemisia</i>	Birch Decreased values of Coniferous trees Dwarf shrubs of temperate to subarctic climate, immigration of herbs of open, Nitrogen rich soils	11.500	<i>Pinus-Empetrum-Betula</i> BL4	Birch and pine <i>Empetrum</i>
13000	H81 <i>Betula-Pinus-Empetrum-Cyperaceae</i>	Birch; Pioneer plants; Deciduous thinleaved trees of boreal or temperate climate, light demanding Expansion of Coniferous trees; temperate or warm temperate. Dwarf shrubs of temperate climate, Sedges	12.000	<i>Salix-Artemisia-B.nana-Rumex-Hippophae-Betula-Pinus</i> BL2	Expansion of cold arid demanding and cold tolerant plans
	N/A		12.500	<i>Artemisia-Rumex-Chenop.-Salix</i> BL1b <i>Salix-Rumex-Cyp.-Artemisia</i> BL1a <i>Betula-Gramineae-Salix-Artemisia</i>	(?Tree birch) Immigration of herbs and shrubs

Table 7, Correlation of local pollen assemblage zones from this study with the regional pollen assemblage zones established by Björck & Möller (1987). All the necessary information on the plants' characteristics are derived from Mossberg and Stenberg (2003)(Figure modified by Björck & Möller,1987(Fig.15)).

graphic responses show a mixed behaviour; there is a gradual response to a changing climate during a zone but at its boundaries (AL/YD, YD/EH) there are sudden shifts, until a gradual steady state in the climate is attained again. During the Younger Dryas it seems that there are some lower-magnitude fluctuations. The results mark the importance of detailed proxy analysis in climate reconstruction that sheds light to significant details through the record and reveals important climate patterns over the regions that can be used to reveal the exact cause of the onset of Younger Dryas.

9. Acknowledgements

I would like to thank my supervisors Svante Björck, Mats Rundgren and my external supervisor Barbara Wohlfarth for all the support, time and inspiration they have given me through this thesis. A special thanks to Barbara Wohlfarth for the opportunity she gave me and for keeping me motivated. Thomas Persson for his help and comments in the Tilia program and Gert Petersson for the IT support he provided during my time in the lab. I am also grateful to Francesco Muschitiello for his help and collaboration during my thesis. Finally, yet much importantly, I would like to thank my beloved family and friends for their endless support through my studies and Elisabeth Goldney for facilitating my writing, and offering encouragement and consolation.

10 References

- Alley, R. B., 2000: The Younger Dryas cold interval as viewed from central Greenland. *Quaternary science reviews* 19(1), 213-226.
- Andersson M., 2004: Master's Thesis (No. 4108), Pollenstratigraphic response for tephra horizons during the last glacial=interglacial transition (LGIT) in southernmost Sweden, University of Stockholm.
- Ampel, L., Kylander, M.E., Steinthorsdottir, M. & Wohlfarth, B., 2015: Abrupt climate change and early lake development – the Late glacial diatom flora at Hässeldala Port, south-eastern Sweden. *Boreas* 44, 94–102.
- Bard, E., Rostek, F., Turon, J. L. & Gendreau, S., 2000: Hydrological impact of Heinrich events in the subtropical northeast Atlantic. *Science* 289(5483), 1321-1324.
- Berglund, B.E., 1964: The post-glacial shore displacement in eastern Blekinge, south-eastern Sweden. *Sveriges Geologiska Undersökning C599*, 47.
- Berglund, B. E., 1966: Late-Quaternary vegetation in eastern Blekinge, south-eastern Sweden. A pollen-analytical study. I. Late-Glacial time. *Opera Botanica* 12, 180.
- Berglund, B. E., Björck, S., Lemdahl, G., Bergsten, H., Nordberg, K. & Kolstrup, E., 1994: Late Weichselian environmental change in southern Sweden and Denmark. *Journal of Quaternary Science* 9(2), 127-132.
- Berglund, B.E., 1971: Littorina transgressions in Blekinge, south Sweden – a preliminary survey. *Geologiska Foreningens i Stockholm, Forhandlingar* 93, 625-52
- Berglund, B. E., Björck, S., Lemdahl, G., Bergsten, H., Nordberg, K. & Kolstrup, E., 1994: Late Weichselian environmental change in southern Sweden and Denmark, J. *Quaternary Sciences* 9, 127–132. doi: 10.1002/jqs.3390090206
- Berglund, B. E., Sandgren, P., Barnekow, L., Hannon, G., Jiang, H., Skog, G. & Yu, S. Y., 2005: Early Holocene history of the Baltic Sea, as reflected in coastal sediments in Blekinge, southeastern Sweden. *Quaternary International* 130(1), 111-139.
- Berger, W. H., 1990: The Younger Dryas cold spell—a quest for causes. *Global and Planetary Change* 3(3), 219-237.
- Birks, H.H. & Ammann, B., 2000: Two terrestrial records of rapid climatic change during the glacial–Holocene transition (14,000–9,000 calendar years BP) from Europe. *Proceedings of the National Academy of Sciences* 97(4), 1390-1394.
- BiosfärområdeBlekinge Arkipelag official website, <http://www.blekingearkipelag.se>
- Biosphere Reserve Nomination Form Blekinge Archipelago, 2009: Collaboration between Karlshamn, Karlskrona, and Ronneby municipalities and the Blekinge County Administrative Board
- Björck, S., Kromer, B., Johnsen, S., Bennike, O., Hammarlund, D., Lemdahl, G., Possnert, G., Rasmussen, T., Wohlfarth, B. & Hammer, C., 1996: Synchronized terrestrial-atmospheric deglacial records around the North Atlantic. *Science* 274, 1155-1160.
- Björck, S., 1981: A stratigraphic study of Late Weichselian deglaciation, shore displacement, and vegetation history in south-eastern Sweden (No. 14). *Universitetsforlaget*.
- Björck, S., Rundgren, M., Ingólfsson, Ó. & Funder, S., 1997: The Preboreal oscillation around the Nordic Seas: terrestrial and lacustrine responses. *Journal of Quaternary Science* 12(6), 455-465.
- Björck, S., Bennike, O., Rosén, P., Andresen, C. S., Bohncke, S., Kaas, E. & Conley, D., 2002: Anomalous mild Younger Dryas summer conditions in southern Greenland. *Geology* 30(5), 427-430.
- Björck, S., 2007: Younger Dryas oscillation, global evidence. *Encyclopedia of Quaternary sciences* 3, 1987-1994.
- Björck, S. & Möller, P., 1987: Late Weichselian environmental history in southeastern Sweden during the deglaciation of the Scandinavian ice sheet. *Quaternary research* 28(1), 1-37.
- Björck, S., Walker, M. J., Cwynar, L. C., Johnsen, S., Knudsen, K. L., Lowe, J. J. & Wohlfarth, B. 1998: An event stratigraphy for the Last Termination in the North Atlantic region based on the Greenland ice-core record: a proposal by the INTIMATE group. *Journal of Quaternary Science* 13(4), 283-292.
- Björse, G., Bradshaw, R.H.W. & Michelson, D.B., 1996: Calibration of regional pollen data to construct maps of former forest types in southern Sweden. *Journal of Paleolimnology* 16(1), 67-78.
- Blaauw, M. & Christeny, J.A., 2011: Flexible palaeoclimate age-depth models using an autoregressive gamma process. *Bayesian Analysis* 6, 457-474.
- Blockley, S.P., Lane, C.S., Hardiman, M., Rasmussen, S.O., Seierstad, I.K., Steffensen, J.P., ... & Intimate Members, 2012: Synchronisation of palaeoenvironmental records over the last 60,000 years, and an extended INTIMATE event stratigraphy to 48,000 b2k. *Quaternary Science Reviews* 36, 2-10.
- Bradley, R.S. & England, J.H., 2008: The Younger Dryas and the sea of ancient ice. *Quaternary Research* 70(1), 1-10.
- Brauer, A., Endres, C., Günter, C., Litt, T., Stebich, M. & Negendank, J. F., 1999: High resolution sediment and vegetation responses to Younger Dryas climate change in varved lake sediments from Meerfelder Maar, Germany. *Quaternary Science Reviews* 18(3), 321-329.
- Broecker, W.S., 1998: Paleoocean circulation during the last deglaciation: a bipolar seesaw?. *Paleoceanograph*, 13(2), 119-121.
- Broecker, W.S., 2003. Does the trigger for abrupt climate change reside in the ocean or in the atmosphere?, *Science* 300(5625), 1519-1522.
- Broecker, W. S., Denton, G. H., Edwards, R. L., Cheng, H., Alley, R. B. & Putnam, A. E., 2010: Putting the

- Younger Dryas cold event into context. *Quaternary Science Reviews* 29(9), 1078-1081.
- Čečys, A. & Benn, K., 2007: Emplacement and deformation of the ca. 1.45 Ga Karlshamn granitoid pluton, southeastern Sweden, during ENE-WSW Danopolonian shortening. *International Journal of Earth Sciences* 96(3), 397-414.
- Davies, S.M., Wastegård, S. & Wohlfarth, B., 2003: Extending the limits of the Borrobol Tephra to Scandinavia and detection of new early Holocene tephras. *Quaternary Research* 59(3), 345-352.
- Davies, S.M., Wohlfarth, B., Wastegård, S., Andersson, M., Blockley, S. & Possnert, G., 2004: Were there two Borrobol Tephras during the early Lateglacial period: implications for tephrochronology? *Quaternary Science Reviews* 23, 581-589
- Dean, W.E., 1974: Determination of carbonate and organic matter in calcareous sediments and sedimentary rocks by loss on ignition: comparison with other methods. *Journal of Sedimentary Petrology* 44: 242-248
- de Vernal, A., Hillaire-Marcel, C., Rochon, A., Fréchet, B., Henry, M., Solignac, S. & Bonnet, S., 2013: Din cyst-based reconstructions of sea ice cover concentration during the Holocene in the Arctic Ocean, the northern North Atlantic Ocean and its adjacent seas. *Quaternary Science Reviews* 79, 111-121.
- Duplessy, J. C., Labeyrie, L., Arnold, M., Paterne, M., Duprat, J. & van Weering, T.C.E., 1992: Changes in surface salinity of the North Atlantic Ocean during the last deglaciation. *Nature* 358, 6
- Erdtman, G., Berglund, B. & Praglowski, J., 1961: An introduction to Scandinavian Pollen flora, Almqvist and Wiksells
- Faegri, K., Kaland, P.E. & Krzywinski K., 1989: Textbook of Pollen Analysis, 4thE, The Blackburn press
- Funder, S. & Hansen, L., 1996: The Greenland ice sheet-a model for its culmination and decay during and after the last glacial maximum. Geological Society of Denmark.
- GNU Project., Free Software Foundation , Boston, Massachusetts, USA
- Grimm, E., 2007: Tilia (v.1.5.12), Springfield, IL, Research and Collection Centre Illinois State Museum.
- Gustafsson, B., 1997: Interaction between Baltic Sea and North Sea. *Deutsche Hydrografische Zeitschrift* 49(2-3) , 165-183.
- Heiri, O., Lotter, A. F. & Lemcke, G., 2001: Loss on ignition as a method for estimating organic and carbonate content in sediments: reproducibility and comparability of results. *Journal of paleolimnology* 25(1), 101-110.
- Hesse, M., Halbritter, H., Weber, M., Buchner, R., Frosch-Radivo, A., Ulrich, S. & Zetter, R., 2009: Pollen terminology: an illustrated handbook. Springer Science & Business Media.
- Hughen, K. A., Overpeck, J. T., Lehman, S. J., Kashgarian, M., Southon, J., Peterson, L. C. & Sigman, D. M., 1998: Deglacial changes in ocean circulation from an extended radiocarbon calibration. *Nature* 391(6662), 65-68
- Ising, J., 1998: Late Weichselian pollen stratigraphy, clay-varve chronology, radiocarbon chronology, and palaeomagnetic secular variations at Farslycke, Blekinge, southern Sweden. *GFF* 120(4), 321-332.
- Johansson, L. & Larsen, O., 1986: Radiometric age determinations and Precambrian geochronology of Blekinge, southern Sweden. *GFF* 111,35-50
- Jowsey, P. C. 1966: An improved peat sampler. *New Phytologist* 65:2, 245-248.
- Karlsdóttir, L., Hallsdóttir, M., Thórsson, A. Th. & Anamthawat Jónsson, K., 2008: Characteristics of pollen from natural triploid *Betula* hybrids, *Grana* 47:1, 52-59, DOI: 10.1080/00173130801927498
- Koppen, W., 1936: Das geographische System der Klimate, in W. Koppen und R.Geiger, eds., *Handbuch der Klimatologie*, Gebr. Borntrager, Berlin, Germany
- Kylander, M. E., Klaminder, J., Wohlfarth, B. & Löwemark, L., 2013: Geochemical responses to paleoclimatic changes in southern Sweden since the late glacial: the Hässeldala Port lake sediment record. *Journal of paleolimnology* 50(1), 57-70.
- Lagerlund, E. & Björck, S. 1979: Lithostratigraphy of the Quaternary deposits in Blekinge, Sweden. Lund University, Department of Quaternary Geology, Report 17, 1-65.
- Lohne, Ø. S., Mangerud, J. A. N. & Birks, H. H., 2013: Precise ¹⁴C ages of the Vedde and Saksunarvatn ashes and the Younger Dryas boundaries from western Norway and their comparison with the Greenland Ice Core (GICC05) chronology. *Journal of Quaternary Science* 28(5), 490-500.
- Lowe, J.J., Hoek WZ, INTIMATE-Group., 2001: Inter-regional correlation of palaeoclimatic records for the Last Glacial-Interglacial Transition: a protocol for improved precision recommended by the INTIMATE project group. *Quaternary Science Reviews* 20, 1175-1187.
- Lowe, J.J., Rasmussen, S.O., Björck, S., Hoek, W.Z., Steffensen, J.P., Walker, M.J. & Yu, Z.C., 2008: Synchronisation of palaeoenvironmental events in the North Atlantic region during the Last Termination: a revised protocol recommended by the INTIMATE group. *Quaternary Science Reviews* 27(1), 6-17.
- McManus, J.F., Francois, R., Gherardi, J.M., Keigwin, L.D. & Brown-Leger, S., 2004: Collapse and rapid resumption of Atlantic meridional circulation linked to deglacial climate changes. *Nature* 428(6985), 834-837.
- Meteorologisk institutt
<http://www.met.no/>
<http://www.yr.no/place/Sweden/Blekinge/Karlskrona/statistics.html>
- Moore, P.D., Collinson, M., Webb, J. A., 1994: Pollen Analysis 2ndE, Wiley.
- Mossberg, B. & Stenberg, L., 2003: Den nya nordiska floran (Vol. 556241257). Stockholm: Wahlstrom &

- Widstrand 928p.-illus., col. illus.. ISBN. 9146175849
- Muscheler, R., Kromer, B., Björck, S., Svensson, A., Friedrich, M., Kaiser, K. F. & Southon, J., 2008: Tree rings and ice cores reveal 14C calibration uncertainties during the Younger Dryas. *Nature Geoscience* 1(4), 263-267.
- Muschitiello, F., & Wohlfarth, B., 2015a: Time-transgressive environmental shifts across Northern Europe at the onset of the Younger Dryas. *Quaternary Science Reviews* 109, 49-56.
- Muschitiello, F., Pausata, F.S., Watson, J.E., Smittenberg, R.H., Salih, A.A., Brooks, S.J., N.J.Whitehouse, N.J., Karlatou-Charalampopoulou, A. & Wohlfarth, B., 2015b: Fennoscandian freshwater control on Greenland hydroclimate shifts at the onset of the Younger Dryas. *Nature communications* 6.
- PalDat - Palynological Database, www.paldat.org
- Peel, M.C., Finlayson, B.L. & McMahon, T.A., 2007: Updated world map of the Köppen-Geiger climate classification. *Hydrology and Earth System Sciences Discussions, Copernicus Publications* 4 (2), 439-473.
- Permout™ Mounting Medium, <http://ww2.valdosta.edu/~tauveno/chemicals/Permout.pdf>
- http://www.fishersci.com/ecom/servlet/fsproductdetail_10652_594900_-1_0
- Personal Notes during laboratory work.
- Pollen Analysis leaflet (in Swedish), Pollen Laboratory, University of Lund
- Pinter, N., Scott, A. C., Daulton, T. L., Podoll, A., Koeberl, C., Anderson, R. S. & Ishman, S. E., 2011: The Younger Dryas impact hypothesis: A requiem. *Earth-Science Reviews* 106(3), 247-264.
- Rasmussen, S.O., Andersen, K.K., Svensson, A.M., Steffensen, J.P., Vinther, B.M., Clausen, H.B., Siggaard-Andersen, M.L., Johnsen, S.J., Larsen, L.B., Dahl-Jensen, D. & Bigler, M., 2006: A new Greenland ice core chronology for the last glacial termination. *Journal of Geophysical Research: Atmospheres* 111(D6).
- Reimer, P.J., Bard, E., Bayliss, A., Beck, J.W., Blackwell, P.G., Ramsey, C.B., Buck, C.E., Cheng, H., Edwards, R.L., Friedrich, M. & Grootes, P.M., 2013: IntCal13 and Marine13 radiocarbon age calibration curves 0–50,000 years cal BP. *Radiocarbon* 55(4), 1869-1887.
- Renssen H, van Geel B, van der Plicht J. & Magny M., 2000: Reduced solar activity as a trigger for the start of the Younger Dryas. *Quaternary International* 71, 373–383.
- Ringberg, Bertil. Beskrivning till jordartskartan Malmö NV. 1976.
- Shivanna, K.R. & Rangaswamy, N.S., 1992: Pollen biology: a laboratory manual. Springer, Heidelberg
- Yu, S.Y., Berglund, B.E., Sandgren, P. & Fritz, S.C., 2005: Holocene palaeoecology along the Blekinge coast, SE Sweden, and implications for climate and sea-level changes. *The Holocene* 15(2), 278-292.
- Sigvaldason, G., 2002: Volcanic and tectonic processes coinciding with glaciation and crustal rebound: an Early Holocene rhyolitic eruption in the Dyngjufjöll volcanic centre and the formation of the Askja caldera, north Iceland. *Bulletin of Volcanology* 64, 192–205
- SMHI, Information provided by Hans Bengtsson <http://www.smhi.se/vadret/vadret-i-sverige/arstidskarta> <http://opendata-download-metobs.smhi.se/explore/> <http://www.smhi.se/klimatdata/meteorologi/temperatur/21240>
- Steinthorsdottir, M., Wohlfarth, B., Kylander, M.E., Blaauw, M. & Reimer, P.J., 2013: Stomatal proxy record of CO₂ concentrations from the last termination suggests an important role for CO₂ at climate change transitions. *Quaternary Science Reviews* 68, 43-58.
- Steinthorsdottir, M., de Boer, A.M., Oliver, K.I., Muschitiello, F., Blaauw, M., Reimer, P.J. and Wohlfarth, B., 2014: Synchronous records of pCO₂ and Δ 14 C suggest rapid, ocean-derived pCO₂ fluctuations at the onset of Younger Dryas. *Quaternary Science Reviews* 99, 84-96.
- Svensson, A., Andersen, K. K., Bigler, M., Clausen, H. B., Dahl-Jensen, D., Davies, S. M. ... & Röthlisberger, R., 2008: A 60 000 year Greenland stratigraphic ice core chronology. *Climate of the Past* 4(1), 47-57.
- van der Plicht J, van Geel B, Bohncke SJP, Bos JAA, Blaauw M, Speranza AOM, Muscheler R, & Björck S., 2004: The Preboreal climate reversal and a subsequent solar-forced climate shift. *Journal of Quaternary Science* 19, 263–269.
- Wastegård, S., 2005: Late Quaternary tephrochronology of Sweden - a review. *Quaternary International* 130, 49-62.
- Watson, J.E., Brooks, S.J., N.J.Whitehouse, N.J., Reimer, P.J., Birks, H.J.B. & Turney, C., 2010: Chironomid-inferred late-glacial summer air temperatures from Lough Nadourcan, Co. Donegal, Ireland. *Journal of Quaternary Science* 25(8), 1200-1210.
- Whitehouse, N.J., Unpublished results
- Wohlfarth, B., Björck, S., Holmqvist, B., Lemdahl, G. & Ising, J., 1994: Ice recession and depositional environment in the Blekinge archipelago of the Baltic Ice Lake. *GFF* 116(1), 3-12.
- Wohlfarth, B., Blaauw, M., Davies, S.M., Andersson, M., Wastegard, S., Hormes, A. & Possnert, G., 2006: Constraining the age of Lateglacial and early Holocene pollen zones and tephra horizons in southern Sweden with Bayesian probability methods. *Journal of Quaternary Science* 21(4), 321-334.
- Zolitschka, B., 2007: Varved lake sediments, In: S.A. Elias (ed.), *Encyclopedia of Quaternary Science*. Elsevier, Amsterdam, 3105-3114 pp.

Tidigare skrifter i serien

”Examensarbeten i Geologi vid Lunds universitet”:

415. Fredrich, Birgit, 2014: Metadolerites as quantitative P-T markers for Sveconorwegian metamorphism, SW Sweden. (45 hp)
416. Alebouyeh Semami, Farnaz, 2014: U-Pb geochronology of the Tsineng dyke swarm and paleomagnetism of the Hartley Basalt, South Africa – evidence for two separate magmatic events at 1.93-1.92 and 1.88-1.84 Ga in the Kalahari craton. (45 hp)
417. Reiche, Sophie, 2014: Ascertaining the lithological boundaries of the Yoldia Sea of the Baltic Sea – a geochemical approach. (45 hp)
418. Mroczek, Robert, 2014: Microscopic shock-metamorphic features in crystalline bedrock: A comparison between shocked and unshocked granite from the Siljan impact structure. (15 hp)
419. Balijs, Fismik, 2014: Radon ett samhällsproblem - En litteraturstudie om geologiskt sammanhang, hälsoeffekter och möjliga lösningar. (15 hp)
420. Andersson, Sandra, 2014: Undersökning av kalciumkarbonatförekomsten i infiltrationsområdet i Sydsvensk vattenverk, Vombverket. (15 hp)
421. Martin, Ellinor, 2014: Chrome spinel grains from the Komstad Limestone Formation, Killeröd, southern Sweden: A high-resolution study of an increased meteorite flux in the Middle Ordovician. (45 hp)
422. Gabrielsson, Johan, 2014: A study over Mg/Ca in benthic foraminifera sampled across a large salinity gradient. (45 hp)
423. Ingvaldson, Ola, 2015: Ansvarsutredningar av tre potentiellt förorenade fastigheter i Helsingborgs stad. (15 hp)
424. Robygd, Joakim, 2015: Geochemical and palaeomagnetic characteristics of a Swedish Holocene sediment sequence from Lake Storsjön, Jämtland. (45 hp)
425. Larsson, Måns, 2015: Geofysiska undersökningsmetoder för geoenergisystem. (15 hp)
426. Hertzman, Hanna, 2015: Pharmaceuticals in groundwater - a literature review. (15 hp)
427. Thulin Olander, Henric, 2015: A contribution to the knowledge of Färö's hydrogeology. (45 hp)
428. Peterffy, Olof, 2015: Sedimentology and carbon isotope stratigraphy of Lower-Middle Ordovician successions of Slemmestad (Oslo-Asker, Norway) and Brunflo (Jämtland, Sweden). (45 hp)
429. Sjunnesson, Alexandra, 2015: Spårämnesförsök med nitrat för bedömning av spridning och uppehållstid vid återinfiltration av grundvatten. (15 hp)
430. Henao, Victor, 2015: A palaeoenvironmental study of a peat sequence from Iles Kerguelen (49° S, Indian Ocean) for the Last Deglaciation based on pollen analysis. (45 hp)
431. Landgren, Susanne, 2015: Using calcein-filled osmotic pumps to study the calcification response of benthic foraminifera to induced hypoxia under *in situ* conditions: An experimental approach. (45 hp)
432. von Knorring, Robert, 2015: Undersökning av karstvittring inom Kristianstadsslättens NV randområde och bedömning av dess betydelse för grundvattnets sårbarhet. (30 hp)
433. Rezvani, Azadeh, 2015: Spectral Time Domain Induced Polarization - Factors Affecting Spectral Data Information Content and Applicability to Geological Characterization. (45 hp)
434. Vasilica, Alexander, 2015: Geofysisk karakterisering av de ordoviciska kalkstensenheter på södra Gotland. (15 hp)
435. Olsson, Sofia, 2015: Naturlig nedbrytning av klorerade lösningsmedel: en modellering i Biochlor baserat på en fallstudie. (15 hp)
436. Huitema, Moa, 2015: Inventering av föroreningar vid en brandövningsplats i Linköpings kommun. (15 hp)
437. Nordlander, Lina, 2015: Borrningsteknikens påverkan vid provtagning inför dimensionering av formationsfilter. (15 hp)
438. Fennvik, Erik, 2015: Resistivitet och IP-mätningar vid Äspö Hard Rock Laboratory. (15 hp)
439. Pettersson, Johan, 2015: Paleoeologisk undersökning av Triberga mosse, sydöstra Öland. (15 hp)
440. Larsson, Alfred, 2015: Mantelpolymer - realitet eller *ad hoc*? (15 hp)
441. Holm, Julia, 2015: Markskador inom skogsbruket - jordartens betydelse (15 hp)
442. Åkesson, Sofia, 2015: The application of resistivity and IP-measurements as investigation tools at contaminated sites - A

- case study from Kv Renen 13, Varberg, SW Sweden. (45 hp)
443. Lönsjö, Emma, 2015: Utbredningen av PFOS i Sverige och världen med fokus på grundvattnet – en litteraturstudie. (15 hp)
444. Asani, Besnik, 2015: A geophysical study of a drumlin in the Åsnen area, Småland, south Sweden. (15 hp)
445. Ohlin, Jeanette, 2015: Riskanalys över pesticidförekomst i enskilda brunnar i Sjöbo kommun. (15 hp)
446. Stevic, Marijana, 2015: Identification and environmental interpretation of microtextures on quartz grains from aeolian sediments - Brattförsheden and Vittskövle, Sweden. (15 hp)
447. Johansson, Ida, 2015: Is there an influence of solar activity on the North Atlantic Oscillation? A literature study of the forcing factors behind the North Atlantic Oscillation. (15 hp)
448. Halling, Jenny, 2015: Inventering av sprickmineraliseringar i en del av Sorgenfrei-Tornquistzonen, Dalby stenbrott, Skåne. (15 hp)
449. Nordas, Johan, 2015: A palynological study across the Ordovician Kinnekulle. (15 hp)
450. Åhlén, Alexandra, 2015: Carbonatites at the Alnö complex, Sweden and along the East African Rift: a literature review. (15 hp)
451. Andersson, Klara, 2015: Undersökning av slugtestsmetodik. (15 hp)
452. Ivarsson, Filip, 2015: Hur bildades Bushveldkomplexet? (15 hp)
453. Glommé, Alexandra, 2015: $^{87}\text{Sr}/^{86}\text{Sr}$ in plagioclase, evidence for a crustal origin of the Hakefjorden Complex, SW Sweden. (45 hp)
454. Kullberg, Sara, 2015: Using Fe-Ti oxides and trace element analysis to determine crystallization sequence of an anorthositenorite intrusion, Älgön SW Sweden. (45 hp)
455. Gustafsson, Jon, 2015: När började platttektoniken? Bevis för platttektoniska processer i geologisk tid. (15 hp)
456. Bergqvist, Martina, 2015: Kan Ölands grundvatten öka vid en uppdämning av de utgrävda diken som genom strandvallarna på Ölands östkust? (15 hp)
457. Larsson, Emilie, 2015: U-Pb baddeleyite dating of intrusions in the southeasternmost Kaapvaal Craton (South Africa): revealing multiple events of dyke emplacement. (45 hp)
458. Zaman, Patrik, 2015: LiDAR mapping of presumed rock-cored drumlins in the Lake Åsnen area, Småland, South Sweden. (15 hp)
459. Aguilera Pradenas, Ariam, 2015: The formation mechanisms of Polycrystalline diamonds: diamondites and carbonados. (15 hp)
460. Viehweger, Bernhard, 2015: Sources and effects of short-term environmental changes in Gullmar Fjord, Sweden, inferred from the composition of sedimentary organic matter. (45 hp)
461. Bokhari Friberg, Yasmin, 2015: The paleoceanography of Kattegat during the last deglaciation from benthic foraminiferal stable isotopes. (45 hp)
462. Lundberg, Frans, 2016: Cambrian stratigraphy and depositional dynamics based on the Tomten-1 drill core, Falbygden, Västergötland, Sweden. (45 hp)
463. Flindt, Anne-Cécile, 2016: A pre-LGM sandur deposit at Fiskarheden, NW Dalarna - sedimentology and glaciotectionic deformation. (45 hp)
464. Karlatou-Charalampopoulou, Artemis, 2016: Vegetation responses to Late Glacial climate shifts as reflected in a high resolution pollen record from Blekinge, south-eastern Sweden, compared with responses of other climate proxies. (45 hp)



LUNDS UNIVERSITET

Geologiska institutionen
Lunds universitet
Sölvegatan 12, 223 62 Lund