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Lateglacial vegetation development in Northeast Germany

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Abstract

This paper describes Lateglacial vegetation development in Northeast Germany, linked to the climate changes and compared to the climate changes that are recorded in the Greenland ice cores. This was done by analyzing the organic content, carbonate content, oxygen isotope record, vegetation development and tephro stratigraphy. In the organic content, carbonate content and vegetation development 4 zones could be distinguished. These zones show that there was a sequence of a cold period that is followed by a warm period, then a cold period again and at last a warm period. The tephro stratigraphy points out that the first warm period correlates to the Allerød warm period and the last cold period correlates to the Younger Dryas (GS - 1). The last warm period correlates to the Holocene. The first cold period is difficult to correlate to a certain cold phase in the Lateglacial. If there was a hiatus this period is most likely to be the end of the Last Glacial Maximum. However, it could also be the Older Dryas. Dating this zone should be conclusive.

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1 Introduction

Climate changes are of all times and of the utmost importance for the environment of human inhabitants. With in depth knowledge of the past climate changes, current changes in the environment could be better understood and predicted. For this reason the vegetation development linked to temperature in northwestern Germany are being correlated with the climate development in Greenland, which is regarded as the chronological framework of the past climate changes for our part of the world.

As part of the investigation of past developments and further correlation of different proxy data to the chronological climate sequence, the Lateglacial vegetation development of Northeast Germany was researched in depth by De Klerk (2004; 2008). However, the reconstructed vegetation development was not correlated to temperature changes. Thus it is still unclear how temperature changes affect vegetation changes. The present study has tried to correlate the vegetation development in Northeast Germany to the Greenland ice-cores. The correlation to the Greenland ice-core is important, since these are used as a chronological framework for the Lateglacial climate changes in Northwest Europe.

The correlation between the vegetation and a temperature proxy will give a better understanding of the impact of climate change on the vegetation. Various researches were conducted on this topic in the past, many pollen diagrams were made and the vegetation development is pretty well known in Germany. However, the correlation to the Greenland ice-core has always proven to be difficult. This study is a step closer to correlating the vegetation development in Northeast Germany to the Greenland ice-core and was one of the objectives of this research. This research is part of the research, which describes vegetation development and climate change in the Lateglacial in a transect between Ireland and East Germany, by Nelleke van Asch.

To understand the relation between vegetation changes and climate changes, three different subtopics will be addressed in this paper. First the known climate changes in the Quaternary and especially the Lateglacial, 14,700 to 11,700 years b2k (= before 2000) (chapter 2.1 and 2.2), will be discussed, then the general vegetation development in Germany (chapter 2.3). The last topic that will be addressed concerns the vegetation and temperature changes that are reconstructed from the investigation of a core, which was taken from the Friedländer Große Wiesen (FGW) in Northeast Germany (chapter 5).

2 Literature review

The climate of the Quaternary was the subject of many studies. In this chapter a synthesis of the research findings will be given, with the focus on the Late Glacial period and in particular the vegetation changes in Northeast Germany. The first part of this section discusses the climate changes in the Quaternary (the last 2.6 million years), focusing on the last 15,000 years. The last part of this section is on the vegetation changes in West-Europe, focusing on Germany.

The last 2.6 million years, the so-called Quaternary period, is characterized by a rapidly changing climate. During this period more than 30 glaciations and interglaciations occurred (De Mulder et al., 2003). The shifts from the cold glacial periods to the warm interglacial periods were relatively quick (Berendsen, 2004). These are called glacial terminations. However, shifts from interglaciations to glacial periods occurred gradually and with oscillations. Also in the glacial periods themselves climate oscillations occurred. The colder periods are called stadials and the warmer periods are called interstadials. During the interglaciations, however, climate is relatively stable and no major oscillations occur.

2.1 Climate changes during the last 130,000 years

The most important climate changes for this research are the most recent ones. This section will describe the climate of the last 130,000 years, from the last interglaciation up to the present interglaciation. The last interglaciation was from ±126,000 to 115,000 years b2k (Lowe & Walker, 1997; Novenko et al., 2008). This interglacial is called the Eemian. The exact age of the Eemian is hard to determine, because ^{14}C dating cannot go that far back. Therefore the age determination of the Eemian is based on different proxies, such as stable isotope data from different layers in the ice core (NGRIP members, 2004) and annual layer counting of lake sediments (Müller, 1974; Hahne et al., 1994; Brauer et al., 2007). The climate during this interglacial was comparable to the climate of the present interglacial, the Holocene.

Novenko et al. (2008) did a pollen analysis on several small lake basins near Klinge in Eastern Germany, which contain Eemian sediments. The results showed that sediments exposed in the Klinge section accumulated during a long time, which started from the Saalian termination and reached well into the Early Weichselian glaciations. During the Eemian interglacial a full succession of forest communities - with a short break in sedimentation in the first half of the optimum - is recorded. The climate reconstruction, based on the vegetation change, of this study shows that warming occurred until the middle part of the Eemian, when temperatures reached its maximum. After this maximum there was a cooling trend which ended in the next glacial.

The cold phase that started after the Eemian is called the Weichselian. This glacial period is characterized by different stadials and interstadials (figure 1) (Lowe & Walker, 1997). The interstadials were recorded all over the world, as can be seen in figure 1. In this figure from Lowe & Walker (1997), it can be seen that the general sequence of climatic changes as recorded in the deep sea, on Antarctica and in France correlate. The Vostok ice-core is one of the ice-cores which were taken from Antarctica. Also indicated in the figure are the interstadials in the Weichselian: the Denekamp, Hengelo, Moershoofd and the St. Germain 1 and 2 interstadials.

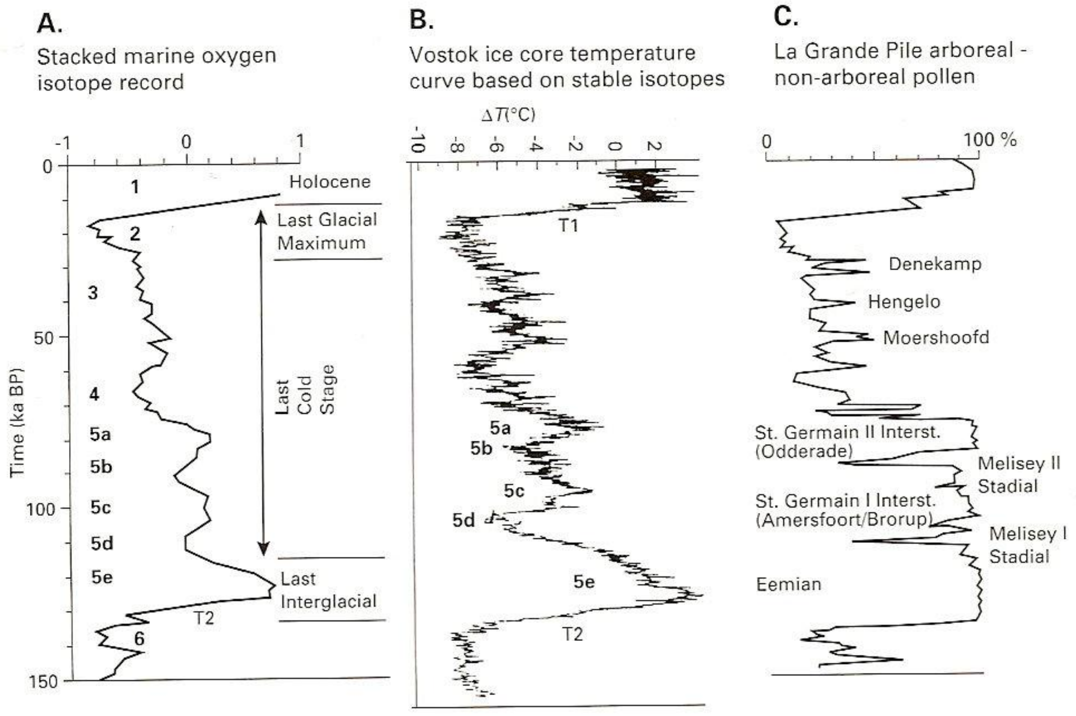


Figure 1: A The stacked marine oxygen isotope record of the last 130 ka (after Martinson et al., 1987) **B** The Vostok ice core temperature curve for the same period (after Jouzel et al., 1987) **C** The arboreal/non-arboreal pollen record from La Grande Pile, Vosges, France (after De Beaulieu & Reille, 1992) (from: Lowe & Walker, 1997).

The Vostok ice-core oxygen record shows a correlation to the GRIP oxygen isotope recored. Most of the major events during the Weichselian can be correlated to each other. However, major event of the Younger Dryas is only seen in the North-Atlantic rergion. The Younger Dryas is not recorded in the Vostok ice-core like most of the Dansgaard/Oeschger events. Dansgaard/Oeschger events are rapid climate oscillations that were observed in the oxygen isotope records of the Greenland ice-cores (Johnsen et al., 1992; Dansgaard et al., 1993). The various Dansgaard/Oeschger events that were found in the GRIP oxygen isotope record can be seen in figure 2. This figure also shows: the different terrestrial interstadials and stadials, the oxygen isotope stages and the chronostratigraphy from the Saalian to the Holocene. In Germany at least some of the interstadials (Dansgaard/Oeschger events) were recorded in the sediment sequence. For example Bohncke et al. (2008) have a record of the Dansgaard/Oeschger events 14, 15 and 16 in a gyttja deposit. The coldest stage of the Weichselian glaciations is called the Last Glacial Maximum (LGM) which ended around ± 15,000 years B2K. After this there were major climatic oscillations at the end of which the Holocene started figure 3. These different climate oscillations are studied in this paper.

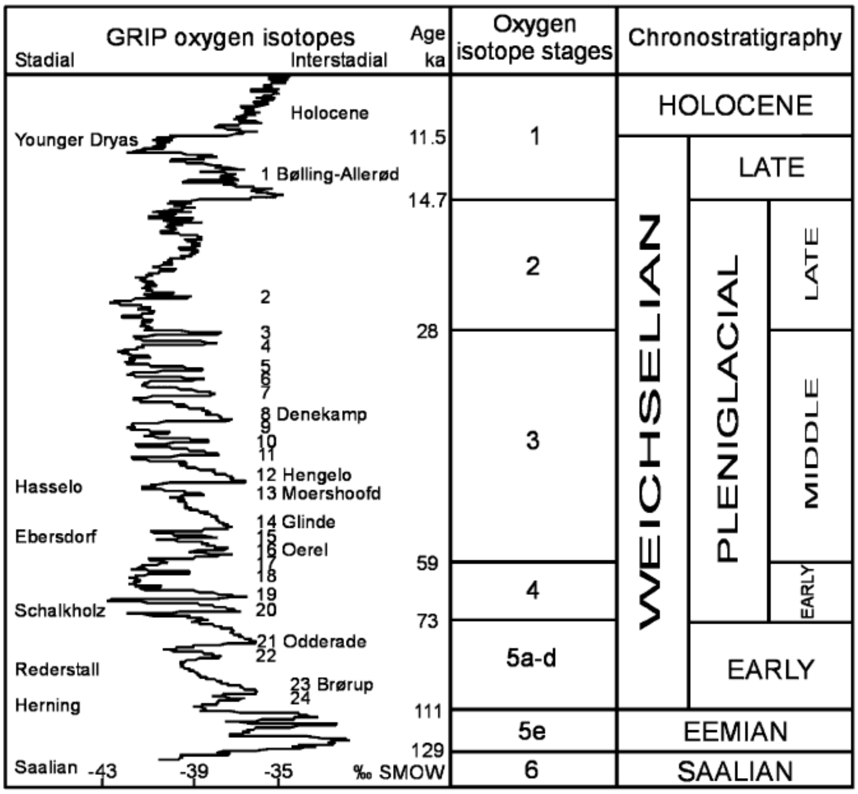


Figure 2: Chronostratigraphy of the Weichselian and comparison with the $\delta^{18}O$ records of the GRIP ice-core (Johnsen et al., 1992), the Oxygen Isotope stages (Martinson et al., 1987) and the terrestrial Interstadials and Stadials (e.g. Ran and van Huissteden, 1990; Behre and van der Plicht, 1992; Dansgaard et al., 1993). Ages follow Martinson et al. (1987) and Walker et al. (1999) (from: Bohncke et al., 2008), this figure also depicts the Dansgaard/Oeschger events in the GRIP ice-core during the Weichselian.

2.2 Climate change from 14,700 – 11,700 years b2k

This section will discuss the transition from the Last Glacial Maximum (LGM) to the Holocene; this period is called the Lateglacial, 14,700 – 11,700 years b2k. The chronological framework of the major climate oscillations of the last 30,000 years are depicted in figure 3. This framework is based on the oxygen isotope records of the Greenland ice-cores (GRIP and NGRIP) (Lowe et al., 2008).

As can be seen in figure 3, at the end of the LGM there is a warming, which marks the start of the Greenland Interstadial-1 (GI-1) period (± 14,700 years b2k). This is the last interstadial of the Weichselian. In this interstadial there are some smaller fluctuations (GI-1a – GI-1e). After the GI-1 interstadial there was a cold period: the Greenland Stadial-1 (GS-1). This was the last stadial before the Holocene. After this cold period the Holocene starts, this is shown by relatively stable high oxygen isotope values in the records.

According to Dansgaard et al. (1993), Taylor et al. (1997) and Rasmussen et al. (2006) the climatic shifts during the last termination (transition from glacial period to interglacial) occurred very quickly, in a matter of decades. Some records show that the transition from the GS-1 to the Holocene was established in less than 20 years. The shifts during the last 14,700 years are well researched and the transitions are well established, though dating uncertainties are still a problem.

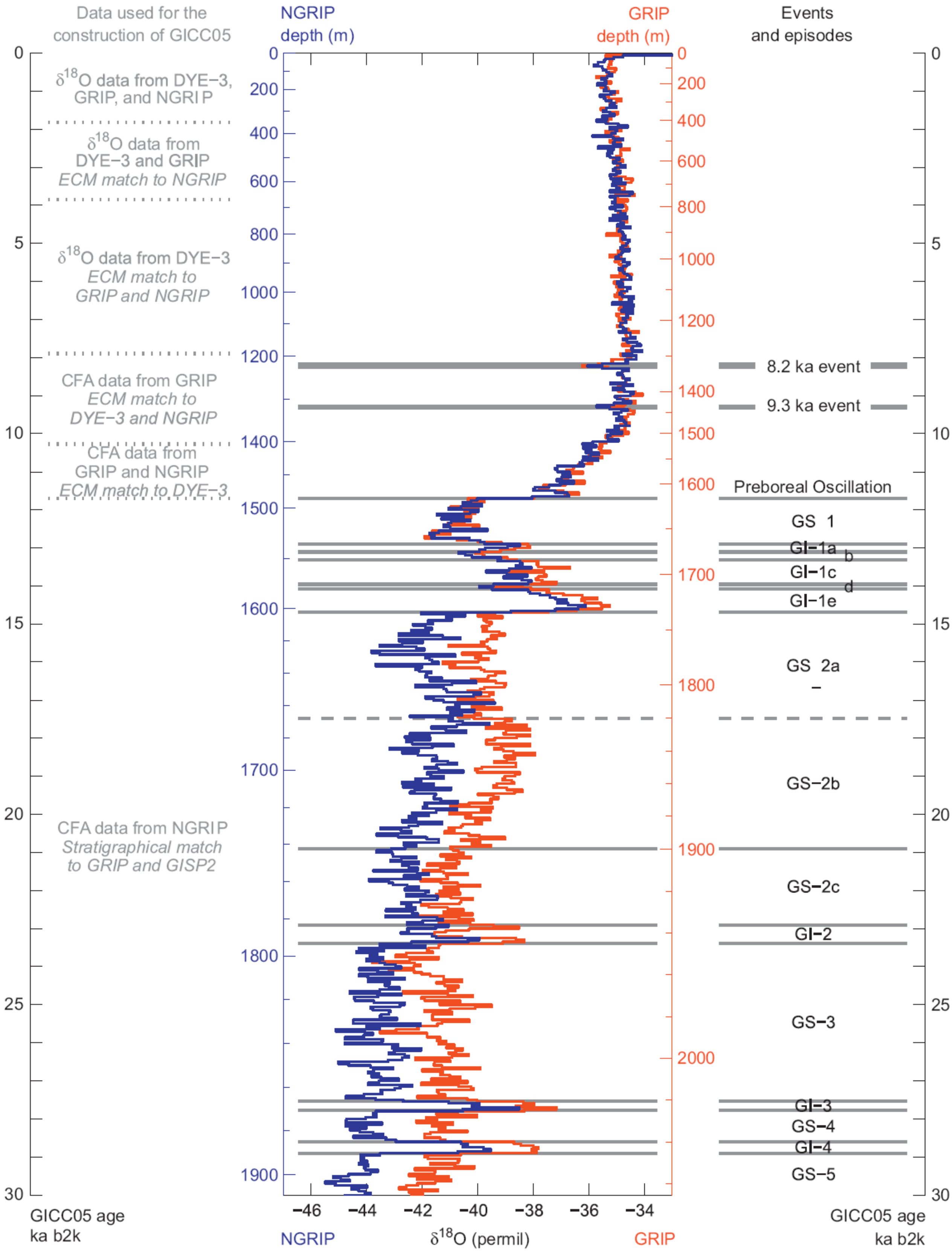


Figure 3: comparison of the δ^{18}O records for the NGRIP and GRIP ice-core records for the last 30,000 years at a 50-year resolution (Lowe et al., 2008).

2.3 The Vegetation development of the Lateglacial in Germany

The vegetation development of the Lateglacial was reconstructed in various areas in Northwest Europe. The vegetation development in the Lateglacial in the Netherlands was thoroughly researched and documented by several authors (e.g. Van der Hammen, 1951; Van Geel et al., 1989; Bohncke, 1993; Hoek, 1997). With 239 ^{14}C-dates derived from 102 pollen diagrams from the Netherlands, northern Belgium and western Germany a general vegetation development has become clear in that area. In figure 4 this general vegetation development is shown. The development was divided into different biozones. In this figure the biozones are 1 Early Dryas, 2 Allerød, 3 Late Dryas and 4 Preboreal. The vegetation changes from an open landscape in beginning of the Early Dryas to a more closed landscape. In zone 1b there is still a domination of herbs and shrubs but there are more trees, mainly birch trees. In zone 1c there is again a more open landscape. After this there is a closed forest landscape with first a domination of birch trees (zone 2a), which then goes to a domination of pine trees (zone 2b). After zone 2b the last cold stage before the Holocene occurs with again a more open landscape and a decrease of all trees. The Holocene is marked by a transition to a closed woodland with a domination of birch trees.

Biozones 1 and 2 (the Early Dryas and the Allerød) can be correlated to GI-1 (figure 4), which had different warm periods and cold periods (GI-1a – GI-1e figure 3). Biozone 3 correlates to GS-1, the last cold period before the Holocene. Last biozone 4 correlates to the beginning of the Holocene. The first warm period (in figure 4 zone 1b) is commonly called the Bølling. This period correlates to the first warm period in figure 3 GI-1e. The Allerød (zone 2) correlates to GI-1a to GI-1c. This zone has some oscillations; these are shows in the pollen zone by oscillations in the tree percentages. Zone 3 commonly called the Younger Dryas correlates to GS-1.

The study in the Netherlands is very extensive and many pollen diagrams have been used. Though not as extensive, studies were also done in other areas. David (1993) did a study of eight neighboring sites to determine the vegetation development of the northern French Alps. In this region, the vegetation development was similar. Here again the Bølling-Allerød biozone can be correlated to the GI-1, the Younger Dryas to the GS-1 and the Preboreal to the beginning of the Holocene. These zones also correlate very nicely to the regional vegetation development of the Netherlands as determined by Hoek (1997).

Because this research focuses on northeast Germany the next two sections will discuss the Lateglacial vegetation development of Germany. Because there are very good varve dated profiles in West Germany, the first section will focus on West Germany. The next section will focus on the vegetation development of East Germany.

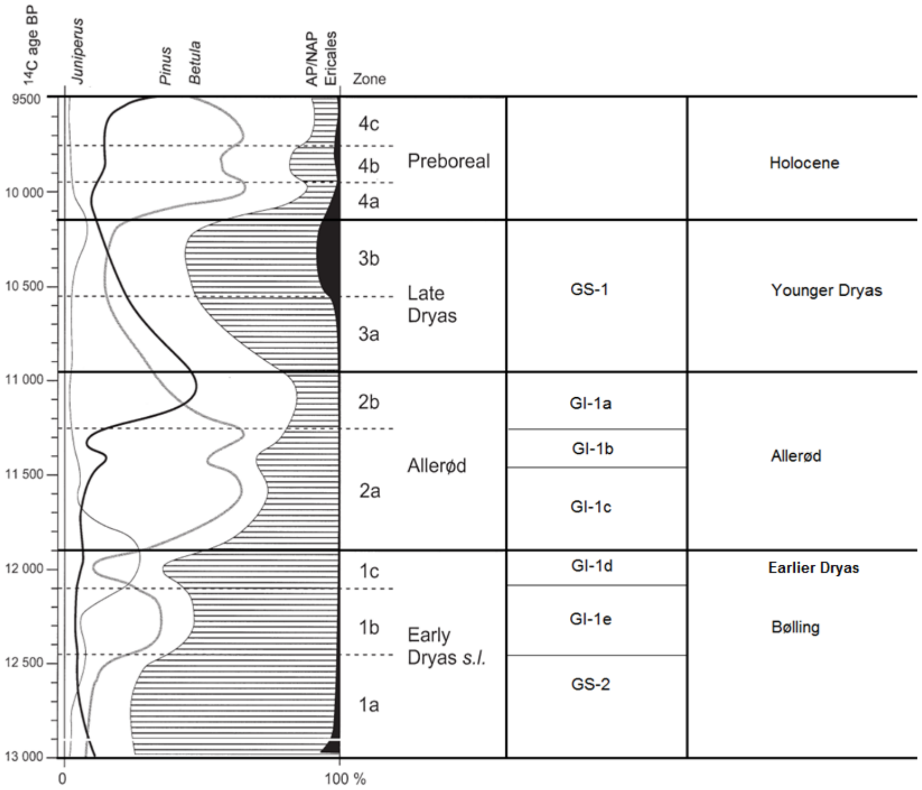


Figure 4: General vegetation development presented in a schematic percentage pollen diagram against uncalibrated ^{14}C timescale (from Hoek, 1997).

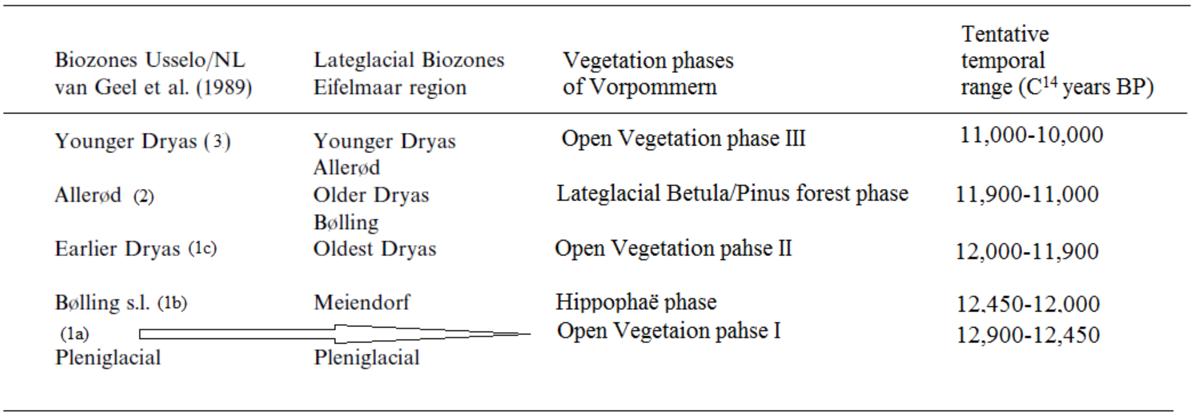
2.3.1 Vegetation in West Germany

There are multiple studies that have reconstructed the vegetation development of west Germany (e.g. Usinger, 1982; Lotter et al., 1995; Merkt & Müller, 1999; Leroy et al., 2000; Brauer et al., 2001; Lücke & Brauer, 2004; Scharf et al., 2005). In this section these studies will be addressed and a general reconstruction of the vegetation development will be given.

Most studies were done on the varved sediments of Lake Holzmaar and Lake Meerfelder Maar (Usinger, 1982; Lotter et al., 1995; Leroy et al., 2000; Brauer et al., 2001; Lücke & Brauer, 2004). These sites are relatively well datable, since the sediments contain annual layers, so called varves. Studies have also been done on other sites, these are: a site near Miesenheim (Scharf et al., 2005) and Lake Hämelsee (Merkt & Müller, 1999). Sites that are discussed in this paper are shown in figure 5.

Giving an intergraded overview of the vegetation development in Germany during the Lateglacial has proven to be difficult. Most German researchers have found an extra warm phase in the Lateglacial, which is not recognized in the surrounding countries. Thus the Bølling was replaced by the Meiendorf and there is an extra warm phase between the Allerød and the Meiendorf, which German researches call Bølling (figure 6). This is all very confusing so to be clear, in this paper we will used the biostratigraphy of Van Geel et al. (1989) (figure 6). In Figure 6 the correlation between the different biostratigraphies is shown in combination with the vegetation zones of Northeast Germany as found by De Klerk (2002), which will be discussed in the following paragraph.

Figure 5: Locations of sites in West Germany.



Biozones Usselo/NL van Geel et al. (1989)	Lateglacial Biozones Eifelmaar region	Vegetation phases of Vorpommern	Tentative temporal range (C^{14} years BP)
Younger Dryas (3)	Younger Dryas	Open Vegetation phase III	11,000-10,000
	Allerød		
Allerød (2)	Older Dryas	Lateglacial Betula/Pinus forest phase	11,900-11,000
	Bølling		
Earlier Dryas (1c)	Oldest Dryas	Open Vegetation pahse II	12,000-11,900
Bølling s.l. (1b)	Meiendorf	Hippophaë phase	12.450-12.000
(1a)		Open Vegetaion pahse I	12,900-12,450
Pleniglacial	Pleniglacial		

Figure 6: Biostratigraphical correlation of the Lateglacial in north-western central Europe (from Litt et al., 2001) in addition the biostratigraphy of Vorpommern in Northeast Germany is given (from De Klerk, 2002).

The following part of this paragraph will be used to give a short overview of the vegetation development in West Germany, from the beginning of the Lateglacial to the beginning of the Holocene. In general 6 zones can be identified in West Germany in this period: 1) the Pleniglacial, 2) Bølling, 3) Earlier Dryas, 4) Allerød, 5) Younger Dryas and 6) Holocene. They were described thoroughly by Walker (1995) for Europe.

Zone 1: Pleniglacial (before 12,450 C^{14} years BP)

The Pleniglacial starts just after the maximum of the Last glacial period, also called the Last Glacial Maximum (LGM). The LGM is characterized by cold steppe conditions in Germany (Merkt & Müller, 1999; Leroy et al., 2000; Scharf et al., 2005). Some parts of Germany where ice-covered during the LGM (De Klerk, 2008). After the ice melted in these region there was an open-vegetation landscape. The Pleniglacial was a little warmer and most ice disappeared from German soils. In all studies about the Pleniglacial it was determined that there was an open landscape with low values of arboreal pollen during this period. Most arboreal pollen that were found are *Pinus* (pine trees) pollen. This is because Pine pollen are very resistant and can travel long distances. Usually there is a combination of reworked pine pollen and long distance pine pollen.

Zone 2: Bølling (12,450 - 12,000 C^{14} years BP)

The transition to the Bølling warm period is marked by a sharp rise in *Betula* pollen and a decrease of non-arboreal pollen (Merkt & Müller, 1999; Leroy et al., 2000; Litt et al., 2001). In spite of the decrease in non-arboreal pollen the percentage of non-arboreal pollen and *Artemisia* are still high and suggest open birch woodland (Litt et al., 2001). These findings indicate an increase in temperature.

Zone 3: Earlier Dryas (12,000 - 11,900 C^{14} years BP)

The Earlier Dryas was marked by a slight decrease of *Betula* pollen, which is associated with an increase of non-arboreal pollen *Gramineae* (grasses) and *Artemisia* (Litt et al., 2001; Merkt & Müller, 1999). This indicates that the temperature dropped slightly or that there were drier conditions.

Zone 4: Allerød (11,900 - 11,000 C^{14} years BP)

After the Earlier Dryas there was a rise in arboreal pollen; especially *Betula* and *Pinus* pollen were abundantly found. At the same time a decrease was recorded of non-arboreal pollen to ±20%. For *Artemisia* pollen a similar decrease was found (Merkt & Müller, 1999; Litt et al., 2001). The landscape changed into boreal birch-pine woodland with poplar and willow. At the beginning of the Allerød there was birch dominated woodland and towards the end it changed to a pine dominated woodland.

Zone 5: Younger Dryas (11,000 - 10,000 C^{14} years BP)

During the Younger Dryas, a distinct increase in non-arboreal pollen was recorded. At the same time *Pinus* and *Betula* pollen decreased. However, there was an increase in *Salix* pollen, the combination of these facts show that there was a subarctic steppe tundra with shrubs including willow, juniper, dwarf-birch and sporadic birch trees (Litt et al., 2001). All these findings indicate a temperature decrease. The Younger Dryas has been correlated to the GS-1 stadial at the end of the Weichselian, which is the last cold period before the Holocene (figure 3).

Zone 8: Holocene (after 10,000 C^{14} years BP)

During the transition from the Younger Dryas to the Holocene birch began to expand again (Merkt & Müller, 1999). The *Betula* and *Pinus* pollen increase at the expense of the non-arboreal pollen. The landscape became boreal birch-pine woodland with poplar and willow.

2.3.2 Vegetation development in Northeast Germany

The vegetation development of Northeast Germany was the subject of many studies, but there are few that have reliable age approximations. There are no studies on varve lakes in Northeast Germany. De Klerk (2008) has combined most of the pollen diagrams that were made in Northeast Germany. The following figure shows all the palynological studies that were recorded by De Klerk (2008). This study shows that in Northeast Germany there were three open vegetation phases and in between these open vegetation phases there is first a Hippophaë phase and then a Lateglacial Betula/Pinus forest phase. The sequence given in figure 6 is the sequence, which was found in Vorpommern but can be used for the whole region (De Klerk, 2008).

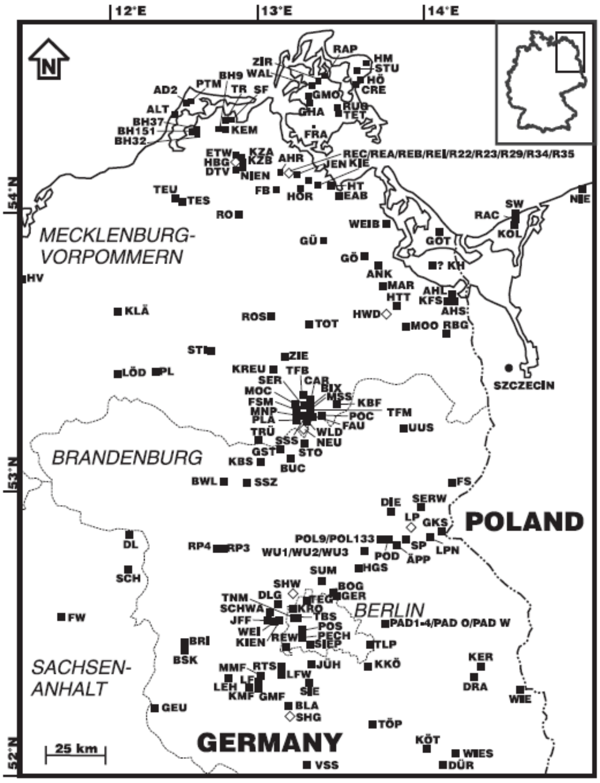


Figure 7: Localities in Northeast Germany and the adjacent fringe of Northwestern Poland that were palynologically studied (from De Klerk, 2008).

The Open Vegetation phase I correlates to zone 1a found in the Netherlands by Van Geel (1989). The Hippophaë phase correlates to the Bølling warm phase. The second Open Vegetation phase correlates to the Earlier Dryas. The Lateglacial Betula/Pinus forest phase correlates to the Allerød. The last Open Vegetation phase correlates to the Younger Dryas (De Klerk, 2008) (figure 6). The Pleniglacial is not found in Northeast Germany for the region was covered with ice and no vegetation could exist in this area.

3 Research area

The research area of this study is the Friedländer Große Wiesen (FGW) in Northeast Germany. It is located in the Southeastern part of Meckelenburg-Vorpommern in Northeast Germany (figure 8). In the figure are given the cross sections that were made to research the Lateglacial deposits. These cross-sections were also used to determine the sampling location. X marks the spot where the core was taken from.

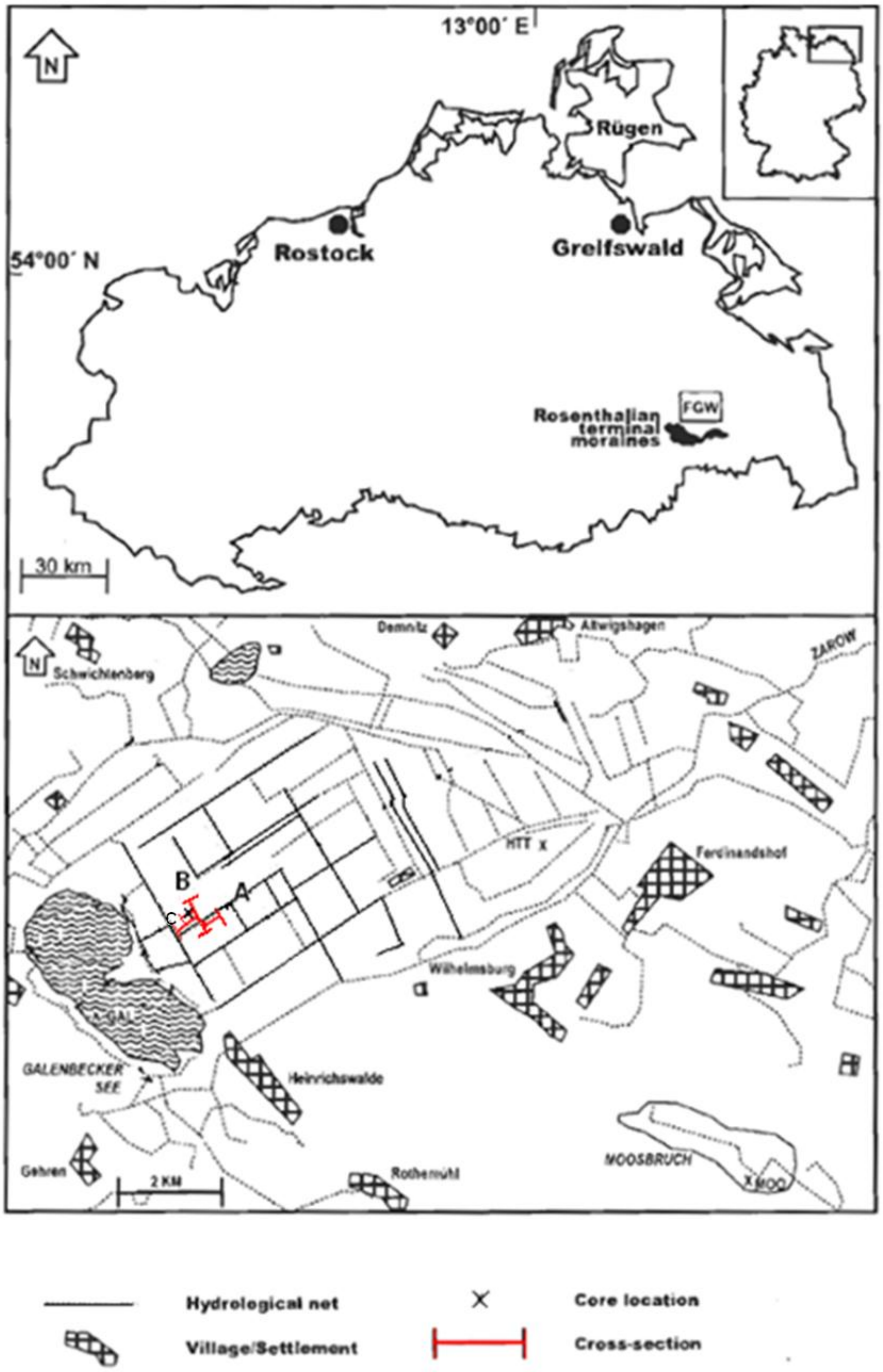


Figure 8: Location of the Friedländer Große Wiese (FGW) in Southeastern Mecklenburg-Vorpommern (Northeast Germany) (from De Klerk, 2004). Indicated are the positions of the cross-sections A, B, and C and the location of the position of the palynologically analyzed core.

This study area was described by De Klerk (2004). He did a palynological investigation of this area, for it has always been an important area for research into genesis, ecology, conservation and restoration of peat lands. The core position (coordinates 5417558 W and 5945989 N) that was used for the present study can be seen in figure 8; this position was chosen after the cross sections were made. Here the depth of the Lateglacial lake was 10 m, this was not too deep to core by hand and the section seemed to contain the entire Lateglacial (from the Pleniglacial until well into the Holocene).

The Friedländer Große Wiese (FGW) peat land is the infilling of an 8 x 12 km long depression that is believed to be a former glacial valley. To the south of the FGW the Rosenthalian terminal moraines can be seen (figure 8). These terminal moraines mark a regional advance of the ice after the melting of the Pomeranian inland ice (de Klerk, 2004). The melting of this inland ice was dated to be 14.8 ± 1.0 thousand years ago (ka) (Rinterknecht et al., 2005). This is thought to be associated with the warming of the Bølling warm stage. The former glacial valley and the other basins are primarily filled with lake marls and calcareous gyttja. On top of this peat formed. The basins which were found ranged in depth from 6 – 11m (de Klerk, 2004).

During the LGM there is an ice-sheet that covers the northeastern part of Germany. This ice-sheet melts at the onset of the Interstadial, 14.8 ± 1.0 ka. After this the depressions that were formed under the ice (glacial valley) become lakes where calcareous gyttja is formed. After the lake becomes shallow enough due to the accumulating sediments hydroseres form, hydroseres are communities in which pioneer plants invade open water and peat is formed.

4 Methods

The methods that were used for this study are: coring of cross-section, Loss on Ignition (LOI), $CaCO_3$ analysis, oxygen isotope analysis, pollen analysis and tephra chronology. These methods will be shortly described in the sections below.

4.1 Lithological cross-sections

The fieldwork in Northeast Germany had two goals. The principle objective was to retrieve a core that was suitable for the study. The core position was required to be deep enough to contain the entire Lateglacial. To determine where the location for the Lateglacial lake core had to be positioned, two cross-sections were cored to obtain an overview of the sediments in the direct subsoil. This was done by two large cross-sections one from southwest to northeast (A) and one from southeast to northwest (B) (figure 8). In addition to the two long cross-sections, a small cross-section was cored perpendicular to the cross-sections. The location of the small cross-section was at the deepest point found in the two cross-sections; this was done to verify if this really was the deepest point of the lake. The deepest point of the lake is the best possible location to position the core. For this point contains the longest staked sediments. However, the depth should not exceed the depth that is able to core manually. The other goal of the fieldwork was to gain a general overview of the geomorphology of the Lateglacial Lake. This was also achieved by studying the cross-sections. The core was retrieved using a 6cm hand-operated piston corer. This piston corer is widely used to sample peat and clay (Lowe & Walker, 1997).

4.2 Loss in Ignition

Loss on ignition (LOI) is a method that determines the organic content of sediment. To establish the organic content in a sample the weight loss is measured when an oven dried sample is put in a furnace. The organic material in the sample is combusted in the furnace and the weight loss is accepted to be the organic content (Lowe & Walker, 1997). This study used a combustion time of one hour at a temperature of 400 ˚C. This was done because then al the organic content was combusted and the carbonates in the sample did not combust. This was found after experimentation on samples with known organic content and carbonate content. The samples for the LOI determination from the core were taken continuously every 2cm up to a depth of 771cm. Between depths 770 and 520 samples of 2cm were taken every 10cm. After this, between depths 520 and 469, the samples were taken again continuously. Knowing the organic content of the sample is relevant because it establishes a small part of the deposition productivity. A lower organic matter content indicates a higher amount of clastic material and could indicate a colder or drier climate, because productivity is lower. However, if organic content is lower because carbonate formation is higher, than it indicates that it is warmer. This is why carbonate content must also be established.

4.3 $CaCO_3$ analysis

With $CaCO_3$ analysis the carbonate content of the samples is measured. This method measures the amount of carbon dioxide that is released when the carbonates react with hydrochloric acid. The chemical formula is given below.

$$\mathrm{CaCO_3 + 2HCl = CO_2 + H_2O + CaCl_3}$$

With this method the amount of $CaCO_3$ is measured and this gives an indication of the climatic conditions of the time that these sediments where formed. In general the more $CaCO_3$ the warmer the climate is. But when the sedimentation rate increases the $CaCO_3$ values may indicate a false cooling. This is only the case if more organic material is present in the record, if clastic material is more deposited than there is a cooling for the landscaped is then more open. The $CaCO_3$ was measured at the same depths as the LOI samples; this was done for a direct correlation between the two proxies. The amount of material was that was taken for this method was ±0,200g of the 2cm at each measured depth.

4.4 Oxygen isotope analysis

Oxygen isotope analysis is the analysis of the ratio of the different stable oxygen isotopes. Oxygen can exist in three isotopic stages. Two of these stages, ^{18}O and ^{16}O, are stable and exist in the atmosphere. The ratio ^{18}O:^{16}O in the oceans and on land varies with the amount of land ice present. The ratio compared to a standard is called $\delta^{18}O$ the formula is given below. The $\delta^{18}O$ value can be measured from the carbonate that is preserved in the sediment.

$$\delta^{18}\mathrm{O} = 1000 \times \frac{{}^{18}\mathrm{O}/{}^{16}\mathrm{O}\ \text{sample} - {}^{18}\mathrm{O}/{}^{16}\mathrm{O}\ \text{standard}}{{}^{18}\mathrm{O}/{}^{16}\mathrm{O}\ \text{standard}}$$

Oxygen isotope ^{16}O in water evaporates easier out of the sea. Land ice extracts the ^{16}O from the atmosphere for a brief time, because it captures the evaporated water. In fact ice functions as a temporary storage of the ^{16}O. More land ice results in a larger $\delta^{18}O$ in the sea and the reverse for ice itself: more land ice results in a lower $\delta^{18}O$ in the ice (Lowe & Walker, 1997). These $\delta^{18}O$ values can be correlated to the amount of land ice and in return the amount of land ice gives an indication of summer temperatures. Summer temperatures regulate the melting or the preservation of ice over the summer. Thus the $\delta^{18}O$ values are a good proxy for summer temperatures. The $\delta^{18}O$ values are directly related to the precipitation temperature.

The relation between $\delta^{18}O$ in ice-cores is very direct and reflects the temperature change. But the $\delta^{18}O$ in biogenically precipitated carbonate, such as in lake marl, is less directly related to temperature (Schwander et al., 2000). Besides the temperature of the precipitation in the catchment area it is mainly affected by the moisture source, the water balance and the lake temperature. Furthermore, the $\delta^{18}O$ of the precipitation in the area is modified by evaporation in the catchment area and from the lake surface, as well as fractionation during carbonate formation (Schwander et al. , 2000). This may lead to very different values in the $\delta^{18}O$ of the lake marl. However, according to Schwander et al. (200)

there is a link to temperature, for all these factors have a link to temperature though, they do not have a direct link like in the ice-cores. The $\delta^{18}O$ was measured every 10cm with samples of 2cm over the total depth of the core. The analysis was done using an accelerator for mass spectrometry.

4.5 Pollen analysis

Pollen analysis is a technique that uses small samples that are taken from equally spaced sections of the core. The samples are prepared by stripping all access material from the sample (using Acidic acid, KOH, Acetolyse and heavy liquid); this is well described by Fægri & Iversen (1989). After preparation the remainders in the samples are the pollen. These samples are placed on a glass slide to be counted.

The pollen slides are used to make pollen counts. The different samples are taken from different depths. The percentages of the different pollen are representative for the percentages of the different plant species, which grew during that period (Lowe & Walker, 1997). Thus the vegetation composition of the samples at different depths can be established.

To make an assessment of the pollen concentration in a sample *Lycopodium* pollen were added to the sample, 20 tables of *Lycopodium* were mixed in 100ml water with acidic acid. One tables contains 10679 *Lycopodium* grains. From this mixture 1ml was added to each sample. This means that each sample contains $\frac{20\times 10679}{100} = 2135.8$ *Lycopodium* pollen.

This method has been used since the 1920s. It has proven to be an accurate means of correlating Quaternary time periods, also called stratigraphic units, reconstructing vegetation history (Huntley & Birks, 1983; Delcourt & Delcourt, 1991) and to investigate the impact of human activity (e.g. Behre, 1986). The pollen slides where taken from the same depth as the $\delta^{18}O$ samples. This was to correlate them directly to one other.

4.6 Tephra chronology

Tephra chronology uses tephra layers to determine the age of a sample. Tephras are ash-layers that have been deposited over a wide spread area (Lowe & Walker, 1997). These ash-layers are formed when a volcano erupts. Each tephra has its own geochemical signature (Einarsson, 1986), so each distinct tephra layer can be recognized. These tephra layers can be dated in various manners: radio carbon dating, Potassium-Argon dating and if found in ice-cores the annual layering of the ice-core give accurate ages as well. One Lateglacial tephra comes from the Eifel area: the Laacher See tephra (Van den Bogaard, 1995). The Laacher See tephra was formed during the last eruption of the East Eifel volcanic field, which was 12,900 years BP. This age is very important for this particular research in Northeast Germany, since the eruption took place at the end of the Allerød warm period and the Laacher See tephra has also been found in Northeast Germany (De Klerk, 2008). The analysis of the tephra found in this core is ongoing and is done by Nelleke van Asch. This paper only uses the results found up to this stage.

5 Results

This section will present the results of the cross-section, Loss on ignition, $CaCO_3$ analysis, oxygen isotope analysis, pollen analysis and tephra ash layers.

5.1 Lithological cross-sections

The three cross-sections cored for this study can be seen in figure 9, 10 and 11. Figure 9 and 10 are the cross-sections and show the lithology and Lateglacial morphology. Profile A (figure 9) shows the subsoil from the southwest to the northeast. Profile B (figure 10) shows the subsoil from the southeast to the northwest. In both A and B can be seen that there is a similar succession of sediments though the depths vary significantly. First there is a calcareous gyttja, till 270cm depth, which is interrupted by a 2cm thick layer of sand at a depth of ± 400cm. The thickness of the layer of sand is relatively constant. On top of this calcareous gyttja there is an organic gyttja, which is overlain by peat.

In the third profile (C) this same succession it seen, but the lake increases in depth very rapidly to the southeast. This indicates that the cross-sections A and B have been cored in the borders of the lake. Since the lake is too deep in the deepest parts the core was taken at the position of core 23 (Profile C). A detailed version of the profiles has been attached in the Appendix.

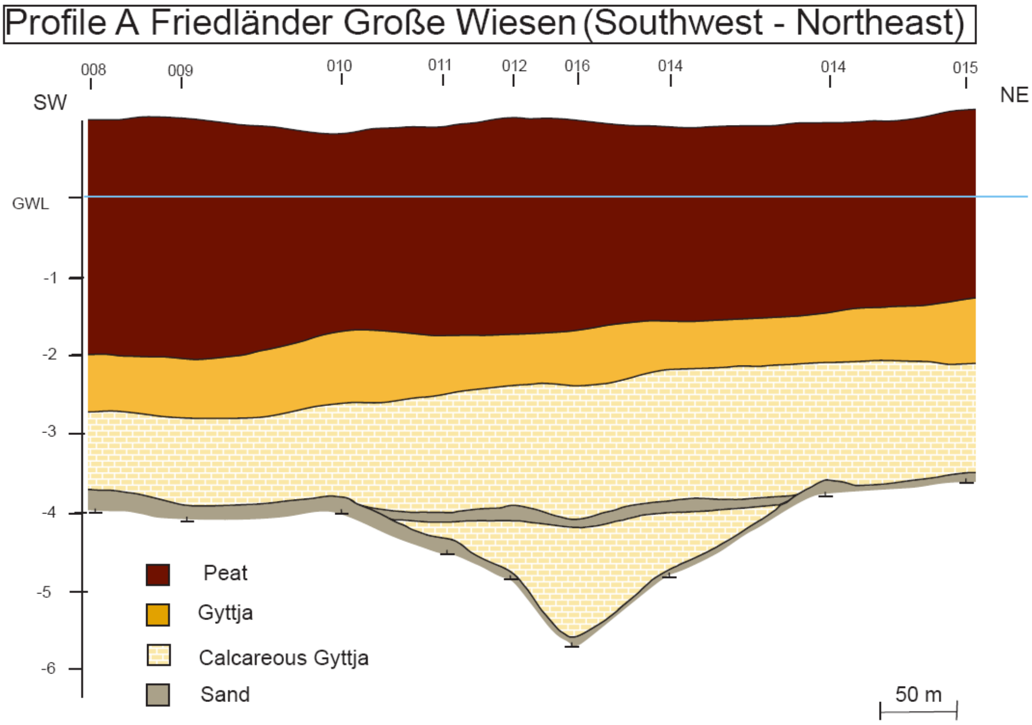


Figure 9: A southwest northeast transect of the subsoil: Profile A.

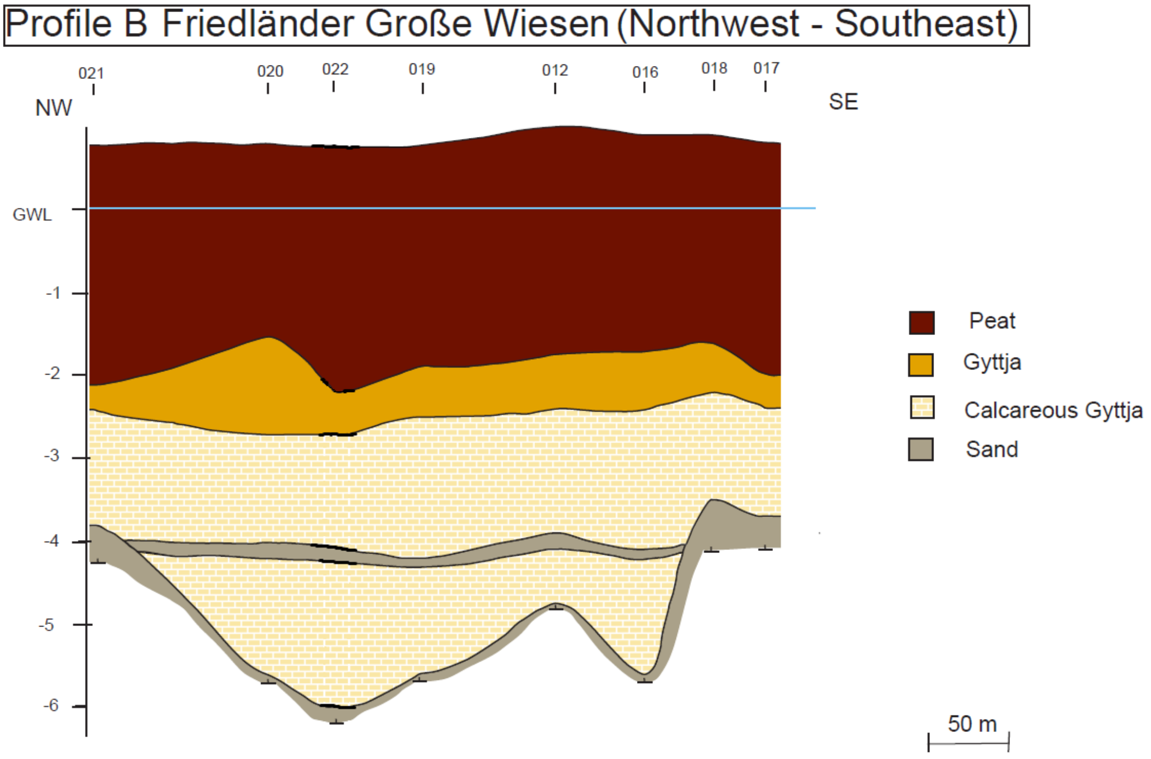


Figure 10: A Southeast northwest transect of the Subsoil: Profile B.

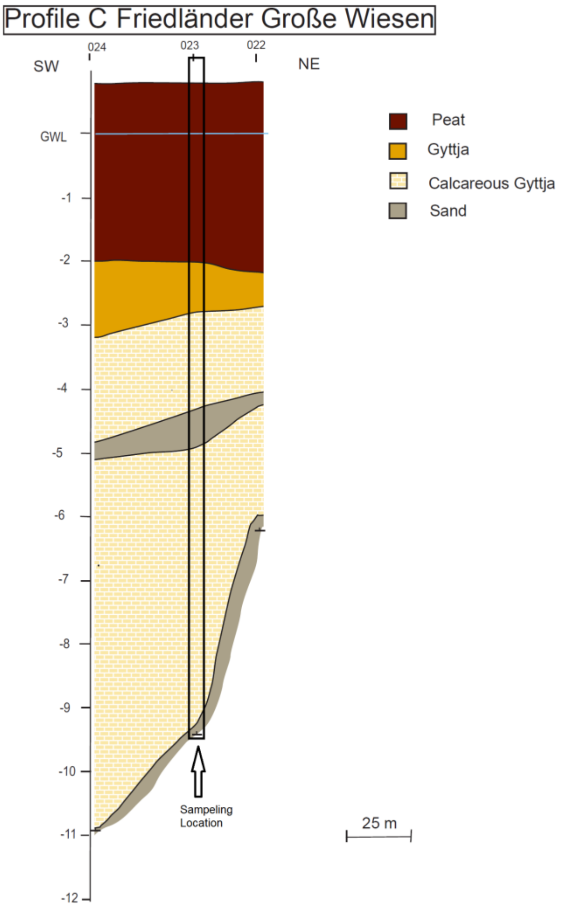


Figure 11: A southwest northeast transect of the deepest point on profile B.

5.2 Organic matter content

The loss on ignition curve that resulted from the analysis is given in figure 12. This curve shows the organic content of the samples. The different sampling intervals show different resolution in the record. The deepest part of the record till ±760cm the resolution in much higher than above ±760cm depth. There is an overall increasing trend in the organic content. At ±995cm there is a sharp increase in organic content till it fluctuates around 10%. Around 750cm depth there is a slow decrease of organic content till a minimum of ±1% at a depth of 515cm. After this minimum there is a sharp increase in organic content.

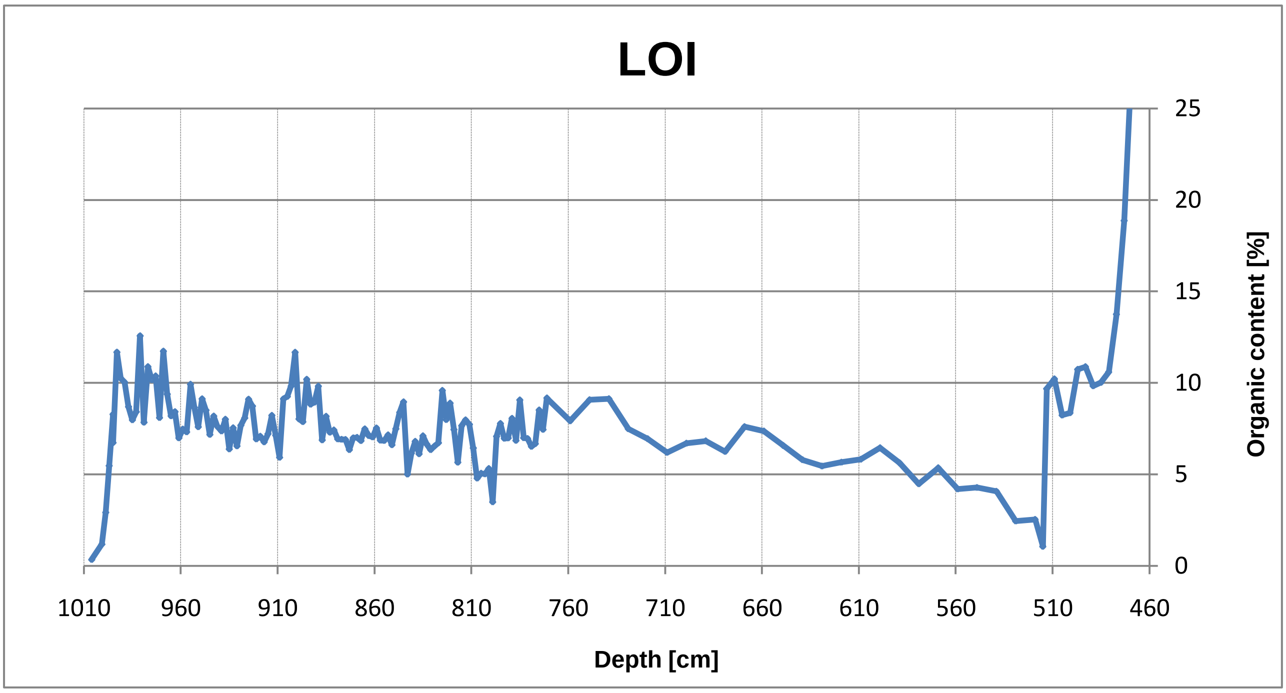


Figure 12: Organic matter content of core FGW. The organic matter content is determined as a loss on ignition.

5.3 $CaCO_3$ analysis

The results of the $CaCoO_3$ analysis is shown in figure 13. This figure shows the amount of carbonates in the samples in percentages. As can be seen in most samples around 80% of the mass are carbonates. There is again a resolution difference in the core which changes around 760cm depth. The deepest parts of the sediment show an increase in carbonates from ±5% to ±80% at a depth of ±995cm. After this the carbonate percentages fluctuate around 80%. There are some smaller oscillations at ±940cm and ±760cm. The carbonate percentages start to decrease exponentially at ±650cm depth. The minimum of 5% carbonate content is reached at a depth of 515cm. After this minimum there is a sharp increase to levels around 70%.

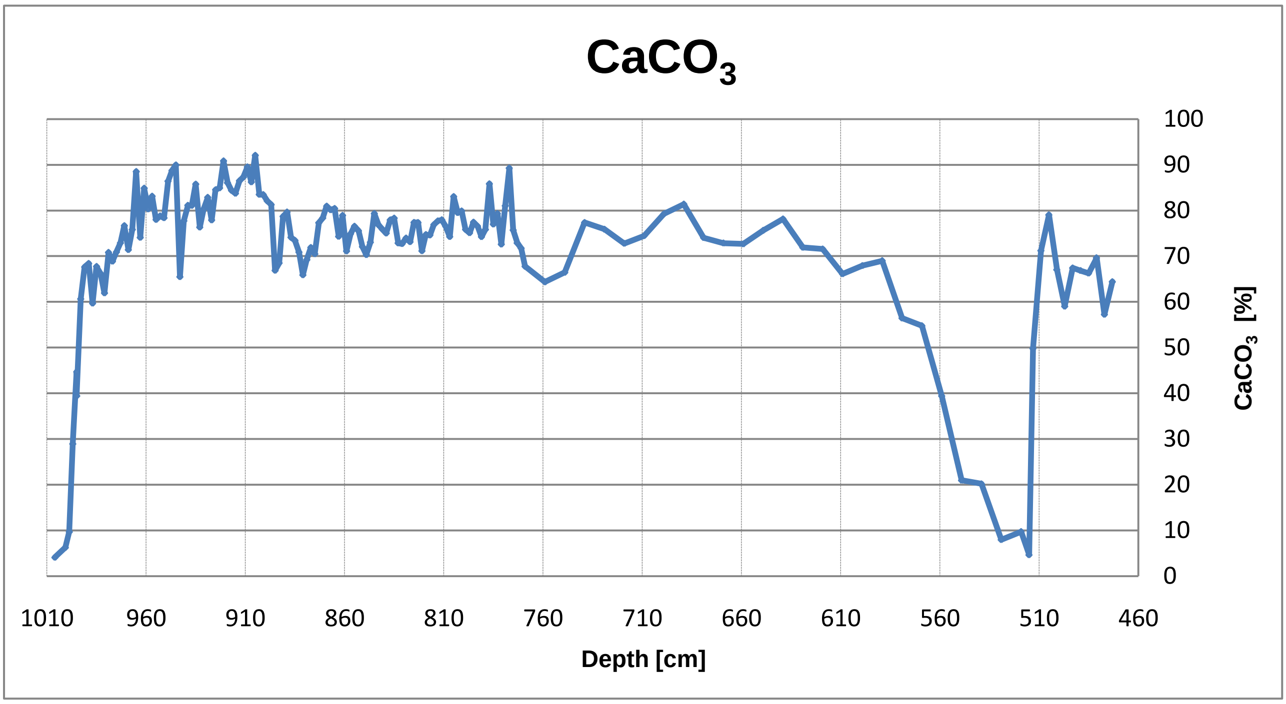


Figure 13: $CaCO_3$ content of core FGW.

In figure 14 the combined results of LOI and $CaCO_3$ are presented. This is an interesting result because this result shows the percentage of clastic material in the sample. It is thought that cold stages have more clastic material than warmer stages. Because, cold stages have open landscapes and no carbonates are formed in cold stages. In this curve the same sequence can be seen as in the $CaCO_3$ curve, this is because the amount of carbonates compared to the organic matter is much more significant. The most interesting feature is that at a depth of 515cm there is a very high percentage of clastic material.

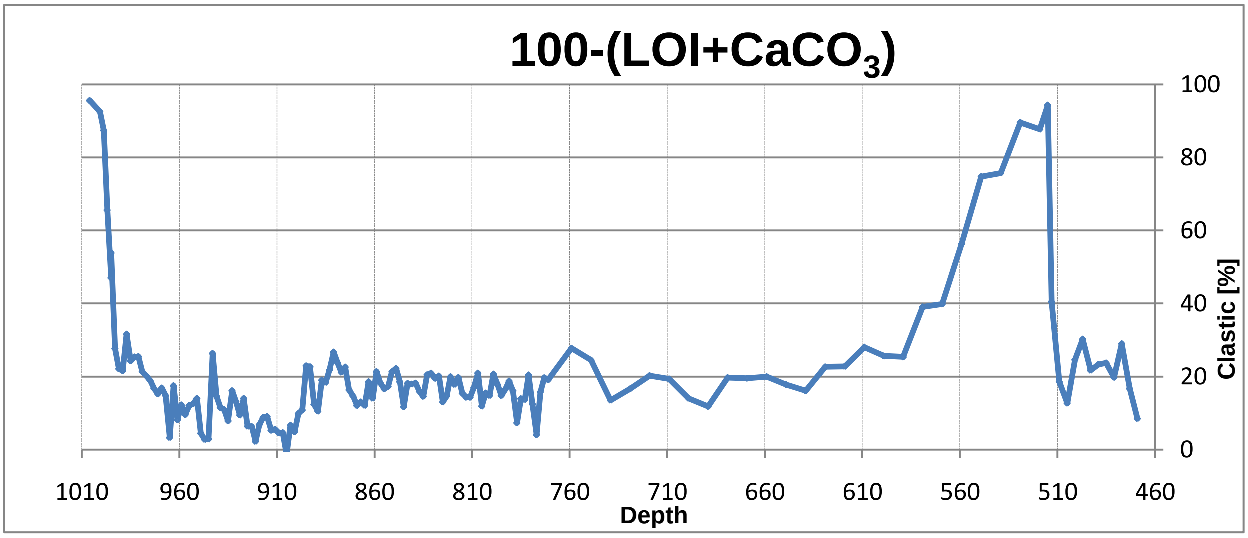


Figure 14: The amount of clastic sediment in the samples resulted from: 100 % (- LOI + $CaCO_3$)

5.4 Oxygen isotope analysis

The curve that was obtained after mass spectrometry is given in figure 15. This figure shows the δ^{18}O in ‰. A δ^{18}O value of -7 ‰ indicates that the samples has 0.7% less ^{18}O than the standard. This curve is significantly different than the curves obtained with LOI and carbonate content analysis. This curve has three major components. There is a sharp decrease from -4.1‰ to -7‰ δ^{18}O at a depth of ±995cm. After this there is the values of δ^{18}O fluctuate between -7‰ and -8‰. In this interval there is an oscillation at a depth ±910 and ±979, here the levels of δ^{18}O first increase and then decrease. At a depth of 515cm there is an increase in δ^{18}O to ±-6‰.

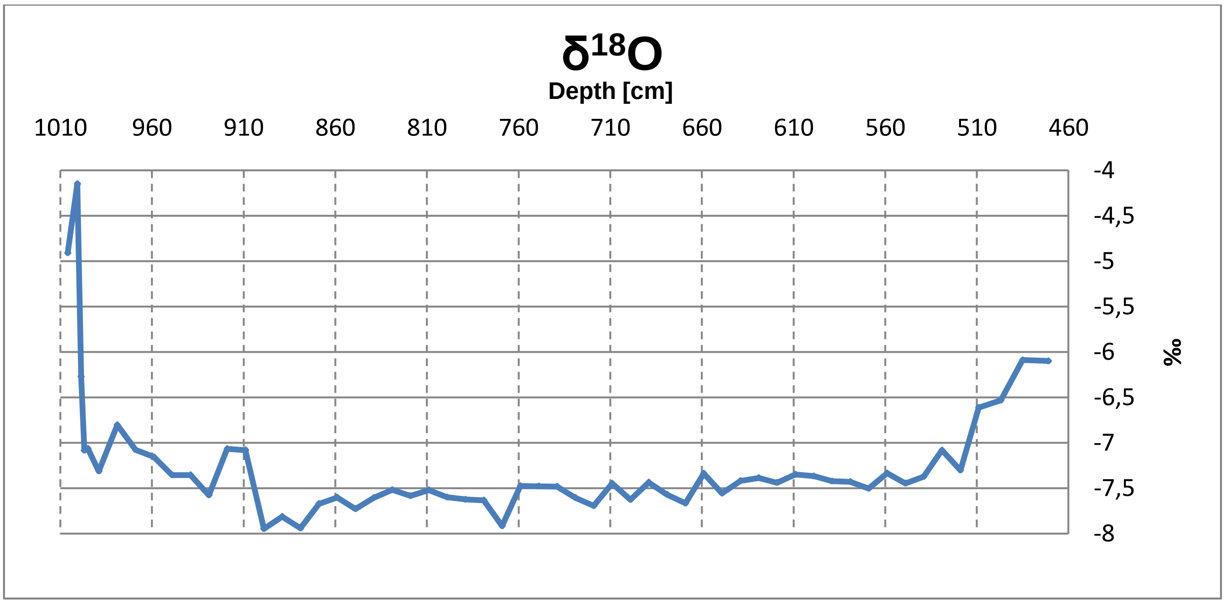


Figure 15: Oxygen isotope record of FGW.

5.5 Pollen analysis

The pollen diagram that was constructed can be seen in figure 16. This pollen diagram shows the fluctuation in Non-arboreal pollen (NAP) and arboreal pollen (AP) as well as the percentages of the different types of pollen. Included in the diagram in the Appendix are also a diatom count and *Lycopodium* count, *Lycopodium* are not represented as percentages but as the actual number in the sample.

The pollen diagram can be divided into 5 different zones (figure 16). These zones range from 1) 1006cm to 998cm, 2) 998cm to 890cm, 3) 890cm to 570cm, 4) 570cm to 515cm and 5) 515cm to 465cm.

The divisions of the zones were mainly done on the basis of the AP and the NAP but other counts were also taken into account. For instance, diatoms were abundant in the second phase. In addition, it can be seen that the *Lycopodium* increased rapidly in the fourth phase indicating that the landscape was more open at that time. For increasing amounts of *Lycopodium* indicate that there are relatively less amounts of pollen in the samples, and thus less vegetation. But most changes occurred in the AP and the grasses (*Gramineae*), which are the most dominant NAP. The transition from phase 1 to phase 2 is defined by a sharp increase in AP. Phase 1 is only indicated as 1 pollen sample and this pollen sample had a relatively low percentage of AP. This increase is mostly shown in Birch and Pine trees. Phase 2 is a phase with fluctuations in Birch and Pine pollen. At the end of phase 2 there is a small oscillation in the AP. There is first a decrease and then an increase. Phase 3 is a very stable phase with high percentages of Pine pollen. This results in the maximum percentages of AP. Phase 4 is characterized by a decrease in AP and with that an increase in NAP. The AP pollen decrease to about 60%, so still have a dominant role, but more herbs are seen in this phase. It can also be seen that *Juniperus* increase in percentages, *Juniperus* is a plant that needs some open space to thrive. This indicates that the woodland have opened enough for it to grow. In phase 5 the AP increase again and *Juniperus* disappears. *Empetrum* is more abundant phase 3. *Artemisia* fluctuates throughout the section but is fairly stable, only in phase 1 and 3 it is more dominant.

From the *Lycopodium* count the pollen concentration can be determined (the *Lycopodium* count can be seen in the Pollen diagram in Appendix 1). The *Lycopodium* count shows that the terrestrial pollen concentration in zone 4 decreases to its minimum, which is: ±24%. The largest part of the pollen diagram, zone 2, 3 and 5 the pollen concentrations fluctuate between the 400 an the 1200%. In zone 1 there is a higher *Lycopodium* count which results in a lower pollen concentration: ±80%.

5.6 Tephra chronology

In the core of FGW 6 ash layers were observed. These ash layers occurred at a depth of 735cm, 745cm, 760cm, 786cm, 855cm, and 860cm. All these ash layers looked similar and seem to be Laacher See tephra (Van Asch & Hoek, pers. comm.). The Laacher See tephra has an age of 12,900 years BP. At larger depths there Van Asch & Hoek found smaller tephra shards which are not visible without a microscope.

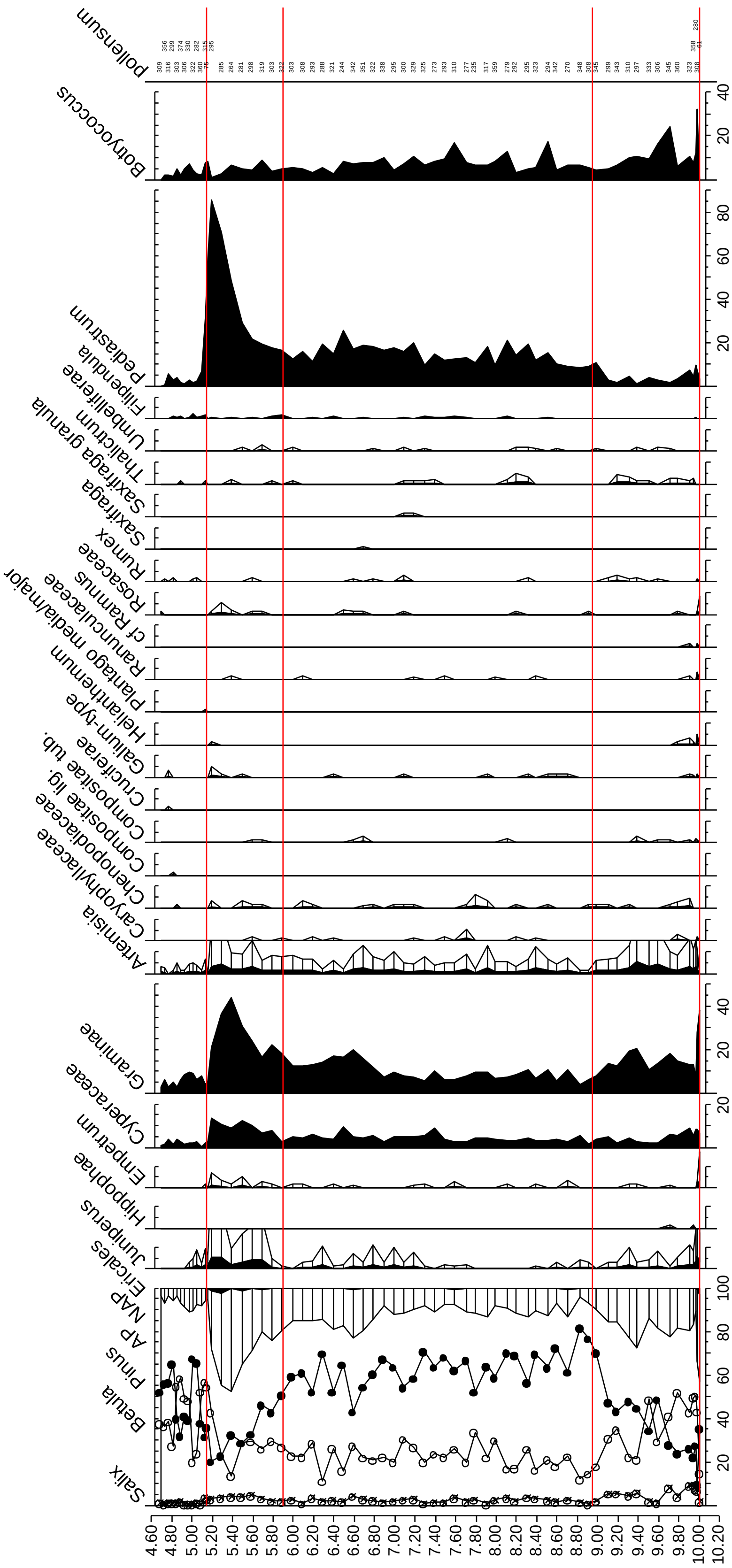


Figure 16: Pollen diagram of FGW.

6 Discussion

This section will discuss the results that have been presented in the previous section. The different zones that are found in the different diagrams will be correlated and conclusions can be made about the climate. These zones will then attempted to be correlated to the Greenland ice-cores (figure 17).

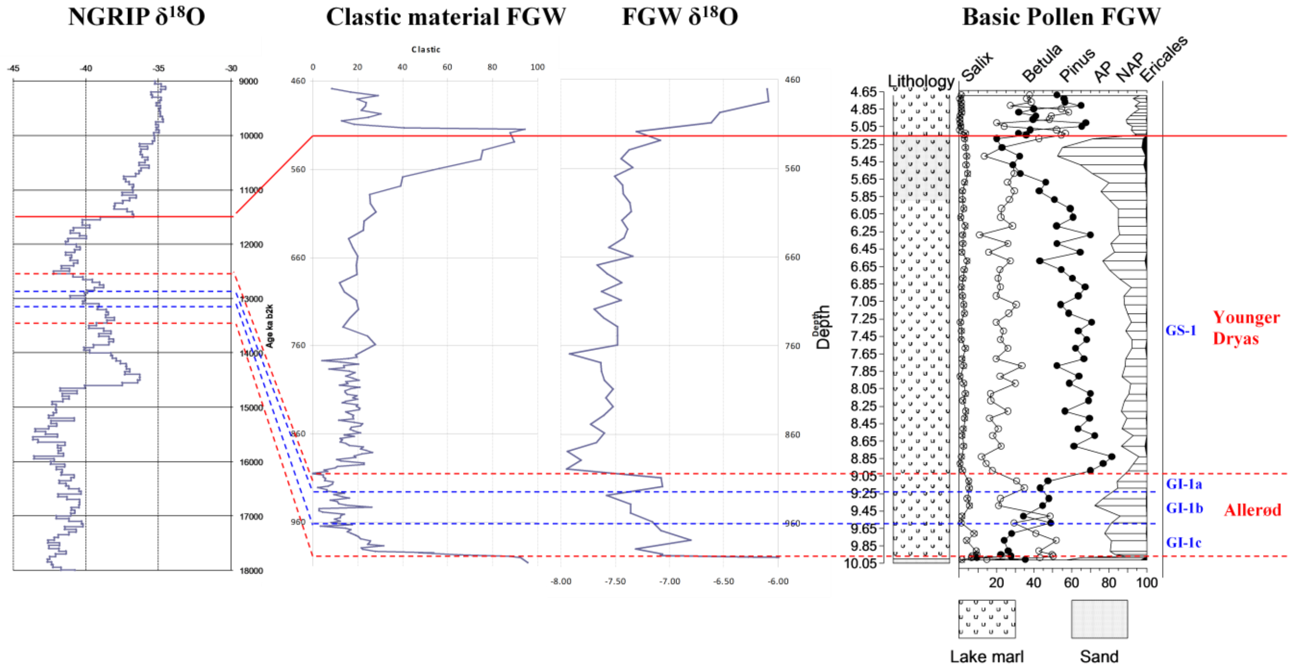


Figure 17: The correlation of the FGW records with the Greenland ice-cores.

Figure 17 shows that the correlation of the records of the FGW is not very straight forward. The only boundary that is shown in all the records is the transition of the Younger Dryas to the Holocene. This is shown in the figure with a hard line. The other boundaries indicated in the figure are an interpretation of the data at hand but more research is needed to definitely correlate them with the boundaries in the Greenland ice-cores. The following section will give a description of the interpretations shown in the figure.

Before the Allerød there is a cold phase in the clastic material and the pollen record of the FGW core. This cold phase is hard to correlate with a interstadial in the Greenland ice-cores. If the record is chronological it could be assumed that this interstadial is the Earlier Dryas. However, there the climate at the time was very high energetic in the region of northeastern Germany. The ice melted and it is probable that there is a hiatus in the record. Because this cold phase is not very large in the record it is inconclusive.

Allerød (GI-1a to c)

This zone starts with a rapid warming. This can be seen in the records for LOI, $CaCO_3$ and the pollen diagram. The isotope record does not show this warming, it shows a cooling. The LOI shows that the organic content increases considerably, this indicates that vegetation thrives with the climate changes that occurred. Also the $CaCO_3$ increases rapidly, this is also an indication that a warm period starts. The decrease in the isotope record is not consistent with these findings. This is also why the correlation cannot be for certain. The pollen diagram shows an increase in AP, the landscape changes from an open landscape to woodland with the dominant trees being Burch and Pine. After this warming there is a phase with different warmer and colder stages. This is shown in the pollen record and in the isotope record. There are also fluctuations in the percentage of clastic material.

Younger Dryas (GS-1)

This is a cold phase which can be seen in the isotope composition. The vegetation composition changes to a very dominated pine forest. This pine forest exists until the very last part of the Younger Dryas when the cold climate gets a grip on it and there is a noticeable decrease of AP. The landscape becomes more open at the expense of the Pine forest. This enables more grasses to grow and the *Juniperus* have more room to grow. This last cold phase can also be seen in the decrease of organic material and the decrease of $CaCO_{3,}$ resulting in a high percentage of clastic material. The coldest part of this zone is at 515cm depth.

Holocene

The boundary between the Younger Dryas and the Holocene is the only boundary that is certain in the records of the FGW. For this boundary is very clearly seen in all the proxies. In the pollen diagram the AP increase very rapidly towards the Holocene. Indicating that this is a warm period. The clastic material in the samples decrease rapidly. This is a result of the fact that $CaCO_3$ and organic material increase. This transition is also clearly visible in the core.

7 Conclusions

The records of the FGW core are difficult to correlate for the different cold and warm phases had different effects on the climate. For instance the transition to the Allerød is noted as a cooling in the isotope record while all other records indicate a warming. This can be caused by the different responses of the hydrological system to the different warming events. The different ash layers found indicate that these depths are younger than 12,900 years BP, the age of the volcanic eruption. The ash layers and shards found in the record have determined the interpretations of the records. As was the case with the interpretation of the pollen diagram. For most of the pollen diagrams in western Europe show an opening of the landscape at the beginning of the Younger Dryas and this pollen diagram shows an increase of AP.

However, the correlation that was made in this paper was based on oscillations in most of the records. The sequence of the cold events as shown in figure 17 is: first a cold phase, which is followed by the Allerød interstadial (GI-1a to c). After the Allerød the Younger Dryas stadial (GS-1) starts. After the Younger Dryas the Holocene is clearly visible in all records of the FGW core. The first cold phase could not be correlated to a certain cold event in the Lateglacial without a absolute dating method, further research is necessary.

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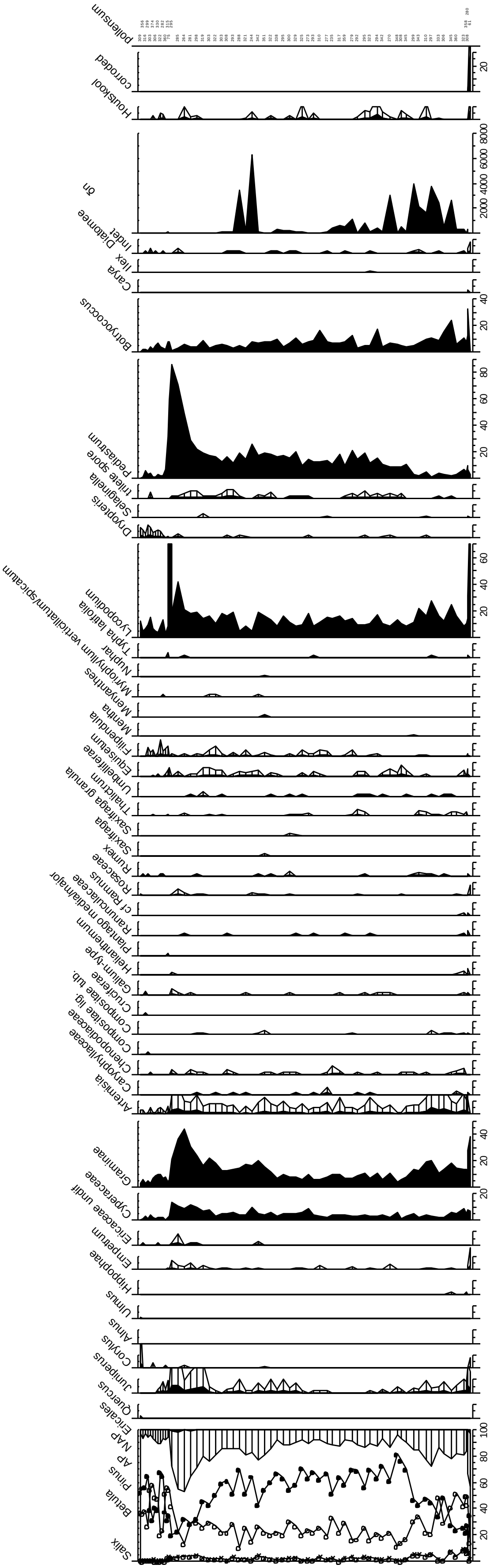
Appendix 1


Salix
Betula
Pinus
AP
NAP
Ericales
Quercus
Juniperus
Corylus
Alnus
Ulmus
Hippophae
Empetrum
Ericaceae undif
Cyperaceae
Gramineae
Artemisia
Caryophyllaceae
Chenopodiaceae
Compositae lig.
Compositae tub.
Cruciferae
Galium-type
Helianthemum
Plantago media/major
Ranunculaceae
cf Ranunculus
Rosaceae
Rumex
Saxifraga
Saxifraga granula
Thalictrum
Umbelliferae
Equisetum
Filipendula
Mentha
Menyanthes
Myriophyllum verticillatum/spicatum
Nuphar
Typha latifolia
Lycopodium
Dryopteris
Selaginella
trilete spore
Pediastrum
Botryococcus
Carya
Ilex
Diatomee
Indet
Bn
Houtskool
corroded
pollensum
20 40 60 80 100
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4.60 4.80 5.00 5.20 5.40 5.60 5.80 6.00 6.20 6.40 6.60 6.80 7.00 7.20 7.40 7.60 7.80 8.00 8.20 8.40 8.60 8.80 9.00 9.20 9.40 9.60 9.80 10.00 10.20